SPECIES STATUS ASSESSMENT
for the
Tennessee Cave Salamander (*Gyrinophilus palleucus*)

Version 1.2

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U.S. Fish and Wildlife Service
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VERSION UPDATES

Version	Date	Author	Rationale
1.1	October 2022	Tennessee Cave Salamander SSA Core Team	Updated analysis to align with Service guidance and recommendations
1.2	January 2023	Division of Conservation and Classification, Southeast Region	Updated current and future condition analyses to reflect knowledge of species, threats, and species response to threats

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EXECUTIVE SUMMARY

Background

This species status assessment (SSA) document reports the results of a comprehensive status review for the Tennessee cave salamander (*Gyrinophilus palleucus*). In this assessment, we describe the species' historical and current distribution and condition and provide estimates of future condition under a range of different scenarios.

The Tennessee cave salamander is a large, neotenic and stygobiotic (obligate subterranean aquatic) salamander found in cave systems in central and southern middle Tennessee, northern Alabama, and extreme northwestern Georgia. Historically, the salamander is known from 90 caves (45 caves in 6 counties in Alabama, 2 caves in 1 county in Georgia, and 43 caves in 11 counties in Tennessee) and 1 spring in Tennessee. Tennessee cave salamanders are primarily associated with karst caves in the Interior Plateau and Southwestern Appalachians ecoregions in the Coosa, Cumberland, and Tennessee River basins.

Distribution of the Tennessee cave salamander has not changed significantly since its discovery in the mid-1940s. Several new sites (species occurrence in a cave system) have been documented in increased survey efforts since 2000. The Tennessee cave salamander is likely extirpated from one site known historically. The species has not been observed in Shelta Cave since 1968, despite 20 surveys between 2018 and 2021. We include Shelta Cave in our analysis to assess habitat condition and provide information for potential recovery efforts.

Also, populations at three of the cave sites have not been documented individually since 1966, 1983, and 1992. However, no Tennessee cave salamanders had been observed at Bobcat Cave and Sauta Cave since the 1970s and 1995, respectively. The species was rediscovered in 2019 and 2022. Based on observation of the species after almost 50 years of surveys (with repeated survey efforts) in some sites and the inherent potential for rediscovery, we included all sites in our analyses and describe only Shelta Cave as an extirpated site based on unsuitable conditions. Survey effort has increased since 2000, with species occurrence at 64 of the 91 Tennessee cave salamander sites since 2000. Ten additional sites with historical (pre-2000) occurrences have been surveyed with no Tennessee cave salamander observations, and 15 sites with historical (pre-2000) occurrences have not been resurveyed (due primarily to access issues).

Little information is available on many aspects of the Tennessee cave salamander life history including egg deposition sites, incubation, larval habitat and diet, and breeding behavior. Tennessee cave salamanders are estimated to reach sexual maturity at 2 to 6 years with a lifespan of 9 to 14 years. The Tennessee cave salamander requires suitable habitat in a cave ecosystem to include sufficient water quality and availability, low sediment load, suitable habitat (substrate and cover), and adequate food sources. Suitable habitat occurs in cave systems with extensive areas that cannot be accessed and surveyed by humans. The extent of suitable habitat that occurs within these areas in unknown, but the three-dimensional nature of the habitat is an important feature of the species environment.

Historical and ongoing factors influence the viability of the Tennessee cave salamander. The most significant stressor is groundwater pollution from residential, commercial, industrial, and agricultural sources, depending on land use changes within recharge areas of cave systems. Contaminants include septic system leachate, sewage, urban and storm water runoff, livestock waste, heavy metals, pesticides, and other chemicals used in agriculture and residential areas. Sedimentation associated with urbanization, agriculture, and silviculture can degrade important habitats for eggs, young larvae, and the species' invertebrate forage base. Mining and quarrying can result in direct habitat loss or alteration of hydrology and energy input to cave systems. Groundwater extraction for agricultural or domestic water supply can reduce available habitat. At some caves, high human visitation and over-collection for amateur or scientific purposes may reduce abundance. Emergent amphibian diseases, such as chytridiomycosis and Ranavirus may impact populations in the future. Climate change may alter environmental conditions, hydrology, and habitat availability; and it may work synergistically with other stressors to negatively affect populations. Conservation measures and regulatory mechanisms are also in place across the species range with approximately 30 percent of cave sites occurring on protected lands.

Methodology
To evaluate the current and future viability of the Tennessee cave salamander, we assessed a range of influences to determine the species' resiliency, representation, and redundancy. For the purposes of this assessment, we delineated analysis units (AUs) based on surveys conducted during the period of 2000-2022 and relevant geology, hydrology, morphological, and genetic information.

We delineated analysis units (AUs) for Tennessee cave salamander using available spatial occurrence data (2000–2022) from surveys by Federal and State agencies, non-governmental organizations, and universities. Based on Tennessee cave salamander individual and population needs, we developed an approach using key habitat and demographic parameters to assess population resiliency. These included two habitat factors: water quality assessed using agricultural land use and detrital input assessed using forest cover; and two demographic factors: abundance and evidence of reproduction/recruitment. We assessed habitat factors within a 4-km buffer because conditions in that area have a stronger determinative effect on cave condition where the species occurs. If we assessed these parameters over the entire AU, land cover or land use distant to the site could affect resiliency score without actual corresponding effects on the species condition. We developed a scoring framework for current resiliency that categorized each AU as high, moderate, low, or very low. We also describe site-specific threats (including urbanization, recreational caving disturbance, agriculture, sewage/septic systems, impoundments, quarry/mining, chemical manufacture) in a qualitative approach.

Then, we developed three plausible future scenarios with varying levels of the primary threats to the species to determine the effect on the resiliency, representation, and redundancy of Tennessee cave salamander. We projected the species' future condition under three scenarios at two future timesteps in the years 2040 and 2060. We chose the timesteps based on the average lifespan of the species, confidence in models and projections of factors influencing the species' viability, and certainty in predictions of the species' response to those factors.

To project the future viability of Tennessee cave salamander, we analyzed forest cover change expected to affect the species in the future. We qualitatively assessed expected levels of urbanization and land use change (Forest Retention Index) and described future resiliency of AUs as no change, slightly decreased, or decreased from current resiliency. Although we expect the effects of climate change and site-specific threats may act on the species, we do not have information available to project the magnitude, imminence, timing or species response to these threats. Consequently, we do not include these potential threats in our future condition analyses. Three scenarios that bound our expectations for plausible threat levels were assessed when predicting future condition: (1) status quo minimum; (2) status quo maximum; and (3) increased impacts.

Conclusion

Current Condition – Sites with greater observed salamander abundance occur in the Crow-Battle Creek, Sauty Creek, and Paint Rock River analysis units. These units occur in the escarpment of the Cumberland Plateau near the tri-state area (Tennessee, Alabama, and Georgia). The results of our analysis indicate 2 of the 12 Tennessee cave salamander AUs exhibit high resiliency, 8 exhibit moderate resiliency, and 2 AUs exhibit low resiliency. No AUs currently exhibit very low resiliency. The two high resiliency units include the Paint Rock and Crow-Battle Creek AUs. The two low resiliency units occur on the western edge of the species' range and include the Lower Elk and Lower Tennessee AUs. Tennessee cave salamander occurs in a variety of habitats within caves across ecoregions, exhibits morphological variation, and has genetic diversity indicative of moderate species-level representation. The species' current high level of redundancy is characterized by multiple sites with high or moderate resiliency distributed across the historical and current range of the species.

Future Condition – Our future condition analysis indicated the Tennessee cave salamander resiliency is projected to decline to varying extents in the future, with greater decline in higher impact scenarios and longer timesteps. Under the status quo minimum scenario (Scenario 1), 1 and 3 AUs are projected to have slight decreases (10–25% loss of forest cover) in 2040 and 2060. All other AUs are projected to experience forest cover loss less than 10% and, therefore, no change in resiliency. Under the status quo maximum scenario (Scenario 2) in 2040, 1 AU is projected to exhibit a decrease in resiliency (forest cover loss of over 25%), and 2 AUs experience a slight decrease in resiliency. Under Scenario 2 in 2060, 2 AUs exhibit decreased resiliency, and 1 exhibits a slight decrease. Under the increased impacts scenario (Scenario 3) in 2040, 5 AUs are projected to decrease in resiliency, and 1 AU is expected to slightly decrease in resiliency. In 2060, compared to 2040, an additional AU is expected to experience a slight decrease in resiliency (5 decreased, 2 slightly decreased). Our analysis does not project extirpations in Tennessee cave salamander AUs. The most severe projection of AU resiliency decline occurs under Scenario 3 in both timesteps, when the Lower Tennessee is projected to experience a decrease in resiliency from its current low resiliency condition.

Under the 2040 and 2060 projections, redundancy is projected to decline slightly as resiliency declines, but will remain at a moderate level. In 2040 and 2060, representation may be reduced to some extent but is expected to be largely maintained at a moderate level as AUs exhibiting potential adaptive capacity evidenced in morphological differences or occurrences in cave habitats with environmental variability remain on the landscape.

CHAPTER 1 – INTRODUCTION AND ANALYTICAL FRAMEWORK

1.1 Background and Previous Federal Actions

This report summarizes the results of a Species Status Assessment (SSA) conducted for the Tennessee cave salamander (*Gyrinophilus palleucus*). In this chapter, we discuss the previous Federal actions (including the petition history for the Tennessee cave salamander) and the analytical framework used to evaluate the status of the species.

The Tennessee cave salamander is a large, neotenic, plethodontid salamander endemic to subterranean waters in limestone caves in central Tennessee, northern Alabama, and northwestern Georgia. On April 20, 2010, the U.S. Fish and Wildlife Service (Service) was petitioned to list 404 riparian and wetland species, including the Tennessee cave salamander, in the southeastern United States as endangered or threatened under the Endangered Species Act (Act) and designate critical habitat for those species (CBD 2010, entire). On September 27, 2011, the Service published a 90-day finding, which concluded that the petition contained substantial information indicating the Tennessee cave salamander may warrant listing (76 FR 59836). The Service is required to make a 12-month finding on whether the species is warranted for listing, and therefore, a review of the status of the species was initiated to determine if the petitioned action is warranted. Based on the status review, the Service will issue a 12-month finding for the Tennessee cave salamander.

We conducted an SSA to compile the best available data regarding the species' biology and factors that influence the species' viability. The SSA report for the Tennessee cave salamander is a summary of the information assembled and reviewed by the Service, and it incorporates the best scientific and commercial data available. This SSA report documents the results of the comprehensive status review for the Tennessee cave salamander and will be the biological underpinning of the Service's forthcoming decision on whether the species warrants protection under the Act.

1.2 Analytical Framework

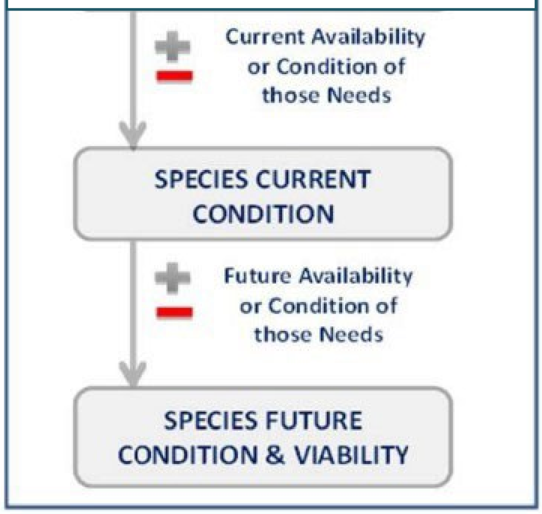
Using the SSA Framework (figure 1.1; Service 2016, entire), this SSA report provides an in-depth review and evaluation of the species' biology and threats and an assessment of the resources and conditions needed to maintain long-term viability. The intent isfor the SSA report to be easily updated as new information becomes available and to support all functions of the Endangered Species Program, from Candidate Assessment to Listing to Consultations to Recovery. As such, the SSA report will be a dynamic document that may be used to inform Endangered Species Act decision-making, such as listing, recovery, Section 7, Section 10, and reclassification (the latter four decision types are only relevant should the species warrant listing under the Act).

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

For the purpose of this assessment, we define viability as the ability of the Tennessee cave salamander to sustain populations in cave systems over time. To assess viability, we use the conservation biology principles of resiliency, redundancy, and representation (Shaffer and Stein 2000, pp. 308–311). To sustain populations over time, a species must have the capacity to withstand:
(1) environmental and demographic stochasticity and disturbances (Resiliency),
(2) catastrophes (Redundancy), and
(3) novel changes in its biological and physical environment (Representation).

Species Status Assessment Framework

Figure 1.1. Species Status Assessment framework.



A species with a high degree of resiliency, representation, and redundancy (the three Rs) is better able to adapt to novel changes and to tolerate environmental stochasticity and catastrophes. In general, species viability will increase with increases in resiliency, redundancy, and representation (Smith et al. 2018, p. 306). Using the SSA framework (figure 1.1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, representation, and redundancy (Service 2016, entire; Wolf et al. 2015, entire). To evaluate the viability of the Tennessee cave salamander, we estimated and predicted the current and future condition of the species in terms of the three Rs.

Resiliency is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature and rainfall), periodic disturbances within the normal range of variation, and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity) (Redford et al. 2011, p. 40).
Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions.

We can best gauge resiliency by evaluating population-level characteristics such as: demography (abundance and the components of population growth rate, survival, reproduction, and migration), genetic health (effective population size and heterozygosity), connectivity (gene flow and population rescue), and habitat quantity, quality, configuration, and heterogeneity. Also, for species prone to spatial synchrony (regionally correlated fluctuations among populations), distance between populations and degree of spatial heterogeneity (diversity of habitat types or microclimates) are also important considerations. For the Tennessee cave salamander, resiliency may be characterized by demographic and habitat condition parameters.

Representation is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments (referred to as adaptive capacity) is essential for viability, as species need to continually adapt to their continuously changing environments (Nicotra et al. 2015, p. 1269). Species adapt to novel changes in their environment by either (1) moving to new, suitable environments or (2) by altering their physical or behavioral traits (phenotypes) to match the new environmental conditions through either plasticity or genetic change (Beever et al. 2016, p. 132; Nicotra et al. 2015, p. 1270). The latter (evolution) occurs via the evolutionary processes of natural selection, gene flow, mutations, and genetic drift (Crandall et al. 2000, pp. 290–291; Sgro et al. 2011, p. 327; Zackay 2007, p. 1).

We can best gauge representation by examining the breadth of genetic, phenotypic, and ecological diversity found within a species and its ability to disperse and colonize new areas. In assessing the breadth of variation, it is important to consider both larger-scale variation (such as morphological, behavioral, or life history differences which might exist across the range and environmental or ecological variation across the range), and smaller-scale variation (which might include measures of interpopulation genetic diversity). In assessing the dispersal ability, it is important to evaluate the ability and likelihood of the species to track suitable habitat and climate over time. Lastly, to evaluate the evolutionary processes that contribute to and maintain adaptive capacity, it is important to assess (1) natural levels and patterns of gene flow, (2) degree of ecological diversity occupied, and (3) effective population size. In our species status assessments, we assess all three facets to the best of our ability based on available data. For the Tennessee cave salamander, we assess representation based on the species' environmental variability.

Redundancy is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population health and for which adaptation is unlikely (Mangal and Tier 1993, p. 1083). We can best gauge redundancy by analyzing the number and distribution of populations relative to the scale of anticipated species-relevant catastrophic events. The analysis entails assessing the cumulative risk of catastrophes occurring over time. Redundancy can be analyzed at a population or regional scale or, for narrow-ranged species, at the species level. For Tennessee cave salamander, we determined the number of moderate and highly resilient analysis units and assessed the distribution of these units across the range to measure redundancy.

This SSA report provides a thorough assessment of the biology and natural history of the Tennessee cave salamander and assesses demographic risks, stressors, and conservation factors in the context of determining the viability and risk of extinction for the species. Importantly, the SSA report does not result in, nor predetermine, any decision by the Service under the Act. In the case of the Tennessee cave salamander, this SSA report does not determine whether the species warrants the protections of the Act, or whether it should be proposed for listing as an endangered or threated species under the Act. That decision will be made by the Service after reviewing this report, along with the supporting analysis, any other relevant scientific information, and all applicable laws, regulations, and policies. The results of a decision will be announced in the *Federal Register*.

CHAPTER 2 – BIOLOGY AND LIFE HISTORY

In this chapter, we provide biological information about the Tennessee cave salamander, including its taxonomy, morphological description, habitat, historical and current distribution, and known life history. We then describe the resource needs of individuals, populations, and the species.

2.1 Taxonomy and Phylogenetic Relationships

The Tennessee cave salamander was first described from specimens collected from Sinking Cove Cave in Franklin County, Tennessee in 1944 (McCrady 1954, entire). Two subspecies of the Tennessee cave salamander have been recognized: the pale salamander (*G. p. palleucus*) and Big Mouth Cave salamander (*G. p. necturoides*) (Lazell and Brandon 1962, entire; Moriarty 2017, p. 32). The two subspecies are diagnosed based on differences in morphology and coloration; however, intergrades between the two subspecies are common in northern Alabama (Lazell and Brandon 1962, p. 302; Brandon 1966, p. 68; Cooper and Cooper 1968, pp. 19–21; Mount 1975, p. 125). As described above, two subspecies of Tennessee cave salamander have been recognized (Big Mouth Cave salamander and pale salamander), but not all studies support this distinction (Niemiller 2006, pp. 45–48; Niemiller et al. 2008, p. 2265; Niemiller et al. 2009, p. 245). Although recent genetic evidence suggests that recognition of the two subspecies may not be warranted, there is no taxonomy uncertainty around the Tennessee cave salamander recognized as *G. palleucus* (Niemiller et al. 2008, pp. 2–15; Kuchta et al. 2016, p. 641).

The Tennessee cave salamander is a member of the Tennessee cave salamander species complex that also includes the Berry Cave salamander (*G. gulolineatus*). The congeneric cave-dwelling Berry Cave salamander was described as a third subspecies in 1965, then recognized as a separate species from the Tennessee cave salamander based on allopatric distributions, dissimilarity in bone structures of transformed adults, and morphology of neotenic adults (Brandon 1965, pp. 1–6; Brandon et al. 1986, p. 1–2; Collins 1991, pp. 42–43; Miller and Niemiller 2008, pp. 1–20; Niemiller et al. 2008, pp. 2–15; Niemiller and Miller 2010, pp. 862.1–862.4; Moriarty 2017, p. 32). Allozyme data support recognition of two taxa in the Tennessee cave salamander complex (Tennessee cave salamander and Berry Cave salamander) (Niemiller et al. 2022, in review). Phylogenetic studies have suggested that populations of the Tennessee cave salamander and the Berry Cave salamander are phylogenetically nested within the spring salamander (*G. porphyriticus*) with evidence of past and possibly contemporary gene flow between the cave salamanders and the spring salamander (Niemiller et al. 2008, pp. 2–15; Niemiller et al. 2009, pp. 242–248; Wray 2013, p. 28–30; Bonett et al. 2014, p. 474; Kuchta et al. 2016, p. 641, 646). Divergence of cave-dwelling *Gyrinophilus* from an ancestor similar to present-day spring salamanders was recent and likely occurred during the Pleistocene (also hypothesized by Brandon 1971) (Niemiller et al. 2008, entire). Divergence was not facilitated by strict geographic isolation (i.e., allopatric speciation) but occurred with periodic bouts of secondary contact and limited gene flow with spring salamanders (Niemiller et al. 2008, 2009). Populations of Tennessee cave salamanders likely have been isolated from Spring Salamanders the longest based on the parapatric distributions of the two species, compared to Berry Cave salamanders (overlapping distribution but limited syntopy with spring salamanders) and West Virginia spring salamanders (overlapping distribution and extensive syntopy with Spring Salamanders).

Past morphological and genetic studies of *Gyrinophilus* suggest a complex evolutionary history with several alternative phylogenetic reconstructions proposed. However, phylogenetic studies have predominantly employed few mitochondrial loci. A comprehensive phylogenomic study employing a nuclear genomic dataset has not been published to date but is in review and but expected to inform our understanding of the potential subspecies and intra-specific variation to a greater extent. The Tennessee cave salamander exhibited low levels of genetic variation overall (Niemiller et al. 2008, p. 2265). Genetic information may also elucidate connections within a drainage basin. Visual observations during surveys are limited by human access into the three-dimensional matrix of cave ecosystems. If caves with Tennessee cave salamander occurrences have connections through deeper aquifers, we may be able to infer those connections from genetics.

Figure 2.1. An adult Tennessee cave salamander from Cave Cove Cave, Franklin County, Tennessee. Photo by Matthew L. Niemiller.

2.3 Species Description

The Tennessee cave salamander is a relatively large neotenic salamander (retaining larval characteristics into reproductive maturity) with an adult size range of 70 to 120 millimeters (mm) (2.7 to 4.7 inches (in)) snout-vent length and 135 to 240 mm (5.3 to 9.4 in) total length. The head is broad, with a truncated and spatulate snout. Lidless eyes are variable in size but generally small compared to above-ground spring salamanders and may be completely covered with skin tissue in some older adults (figure 2.2). Although eyes are reduced, they still respond to light (Beharse and Brandon 1973, p. 464). Larviform individuals possess long, pinkish gills that may become bright red when a salamander is handled or stressed. The trunk has 16–19 costal grooves, and limbs are relatively slender and moderately long. There are four toes on the front feet and five toes on the hind feet. Toes lack webbing. The tail is laterally compressed and oar-like in appearance with a distinct caudal fin. The lateral line system is well-developed on both the head and body. Unpigmented sensory pores often can be observed on larger individuals.

Smaller larvae are paler and usually a uniformly colored pink compared to larger larvae and adults. Larger larvae and adults have more pronounced coloration and pigmentation with varying levels of conspicuous dark flecks, spots, or blotches on the dorsum and sides of the body, depending on the subspecies and population. Populations along the eastern escarpment of the Cumberland Plateau in Franklin and Marion Counties, Tennessee, and Jackson County, Alabama, typically lack flecks, spots, or blotches (figure 2.1). In other populations, markings typically increase in size and intensity with body size and age and are largest on the dorsum, becoming progressively smaller on the sides of the body (figure 2.2). Ground coloration in adults can range from flesh and pink tones to red, purple, beige, and brown depending on the subspecies and population. The venter and undersurfaces of the limbs and ventral third of the tail are typically flesh-colored and lack pronounced markings.

Tennessee cave salamanders occasionally metamorphose and lose their larval characteristics in nature (Yeatman and Miller 1985, pp. 304–306; Brandon et al. 1986, p. 1; Miller and Niemiller 2008, p. 14). In addition, metamorphosis has been induced in the laboratory with exposure to hormones (Dent and Kirby-Smith 1963, entire). Metamorphosed individuals have well-formed eyelids and nasolabial grooves, but the eyes are not as large and developed as in the related spring salamander. The gills are completely reabsorbed, but gill scars remain. The labials and tail fin are reduced compared to larviform individuals. The tail remains laterally compressed.

Figure 2.2. An adult Tennessee cave salamander from Shell Caverns, Wilson County, Tennessee. Note that skin tissue almost completely covers the eyes. Photos by Daniel Istvanko.

2.4 Resource Needs and Habitat

The Tennessee cave salamander occurs in lentic and lotic groundwater habitats in limestone caves throughout its range. Tennessee cave salamanders are most often found in low velocity, shallow (less than 1 meter (m) (3.3 feet (ft)) pools in subterranean streams (figure 2.3) but also have been found in riffles, runs, rimstone pools, underground lakes, and at spring outflows (Simmons 1975, pp. 4–18; Caldwell and Copeland 1992, p. 2; Godwin 2000, p. 1). The species has been observed in water as shallow as a few centimeters to as deep as 5.5 m (18 ft). Many of the cave systems inhabited by Tennessee cave salamanders have dynamic stream flow, such that water depth and velocity can vary daily and seasonally depending on local precipitation and hydrogeology.

Water availability is fundamental to survival of the Tennessee cave salamander. All life stages rely on sufficient flow as their source of oxygenatedwater and for habitat availability, especially during low flow periods. Low streamflow (especially during summer and fall) reduces availability of escape cover for juveniles and adults in some sections of cave systems, resulting in migration to more suitable habitat. Although the Tennessee cave salamander can survive out of water for a limited period of time, dispersal across un-submerged damp or muddy substrate exposes individuals to conditions of physiological stress that may reduce fitness if prolonged stress occurs (Niemiller 2022, pers. comm.).

Substrates in Tennessee cave salamander habitats vary among caves with respect to size and composition, but predominantly consist of cobble, gravel, and sand with larger boulders and limestone bedrock present. Some sites with Tennessee cave salamander occurrences have higher proportion of sand or silt substrate. These differences in substrate generally correlate with cave morphology and vary among ecoregions. The ability of Tennessee cave salamanders to escape potential predators increases at sites with greater heterogeneity and quantity of cobble, boulder, and bedrock habitat, which are likely used as substrate for egg deposition. Salamanders also have been found in pools of clay, silt, and/or mud substrate, but are most often found under rocks and other cover (Niemiller et al. 2016, pp. 36–37).

Salamanders also are reported from within deposits of leaves and wood in pools. Tennessee cave salamanders also require the inflow of organic detritus to support the invertebrate community that, in turn, serves as the prey base for salamanders. The amount of natural detritus that can enter a cave system and act as the energy source for the food web is influenced by the local hydrogeology contributing to the cave system and amount and location of vegetation present in the watersheds. The degree of karstification or natural entry points into the cave system (sinkholes) also influences the amount of detritus that moves into the cave system. The presence of a complex system of sinkholes, springs, and underground streams throughout karst systems results in very little filtering of surface input (detritus) when surface water enters the subterranean system (White 2002, pp. 85–105; Butscher and Huggenberger 2009, p. 1666). Increases in detritus can improve conditions for the Tennessee cave salamander by increasing potential cover and, more importantly, increasing the otherwise limited prey base. Increased detrital input is associated with increased abundance at Tennessee cave salamander sites. Observed salamander densities are greater in caves with higher organic matter input (Huntsman et al. 2011, pp. 1750–1757). Detrital input and food sources do not appear to be a significant limiting factor for Tennessee cave salamander currently (Niemiller 2022, pers. comm). Tennessee cave salamanders may partition habitat based on bodysize, as smaller juveniles are most frequently observed in shallower pools and within intersticesof cobble in riffles and runs compared to larger adults that reside in deeper pools (Niemiller and Miller 2020, unpublished data).

Figure 2.2. An isolated pool in a cave stream during season low water conditions at Blowing Spring Cave, Coffee County, Tennessee. Photo by Matthew L. Niemiller.

Limited information is available on abiotic requirements of the Tennessee cave salamander. Groundwater where the species occurs exhibits a pH range from 7.2 to 7.7 and a temperature range from 11.5 to 15.0 degrees Celsius (°C) (52.7 to 59 degrees Fahrenheit (°F)), but water quality parameters can be variable at individual sites (Simmons 1975 p. 58; Caldwell and Copeland 1992, p. 14; Huntsman et al. 2011, p. 1751). Water quality requirements have not been comprehensively evaluated for the species, but these pH values and temperatures may represent typical ranges for each life stage. Tennessee cave salamanders can acclimate to higher temperatures in the captivity (25°C) (Simmons 1975, p. 64). Tennessee cave salamander also presumably rely on the availability of habitat with appropriate water quality, although specific water quality parameter tolerance and preference of the species are currently unknown.

Table 2.1**.** Life stage needs of the Tennessee cave salamander.

Life stage	**Resources needed**
Eggs	• Suitable cobble/boulder substrate for egg deposition • Low amounts of silt and fine sediment • Suitable water quality and quantity
Juveniles	• Sufficient gravel/cobble/boulder substrate or other suitable cover • Aquatic invertebrate food source • Suitable water quality and quantity
Adults	• Sufficient cobble/boulder/bedrock substrate • Sufficient cover material (rock, woody debris) • Aquatic invertebrate/vertebrate food source • Sufficient water quality and quantity

2.5 Population and Species Needs

At the population level, resilient Tennessee cave salamander populations need the same key habitat-based resources as individuals (table 2.1), as well as a sustainable population size and connectivity within and among populations. To be resilient to stochastic events, populations of Tennessee cave salamanders need to be of sufficiently robust density (i.e., abundance) to support population resiliency and species viability; the species also needs redundancy of multiple populations in multiple sub-watersheds (i.e., spatial extent). Additionally, populations require environmental conditions that provide suitable habitat and water quality such that adequate numbers of individuals are supported. Without these factors, a population has an increased likelihood for localized extirpation.

In general, larger connected populations will have increased opportunities for reproduction via emigration and immigration in order to maintain genetic diversity. To maintain gene flow, there needs to be some population connectivity to facilitate reproduction between different populations. The extent and connectivity of cave ecosystems is often difficult to ascertain; and the three-dimensional matrix of caves allows for multiple connections between caves, other karst features, and aquifers. These connections may contain suitable habitat that meets Tennessee cave salamander individual needs or may seasonally contain conditions that allow dispersal or movement of Tennessee cave salamander. Maintaining gene flow within and among populations will be facilitated by maintaining suitable corridors for movement of individuals throughout the cave network.

For species viability, there must be adequate representation (suitable genetic and environmental diversity to allow the species to adapt to changing environmental conditions) and redundancy (suitable number and distribution of populations with sufficient resiliency to withstand catastrophic events). Redundancy improves with increasing numbers of populations at moderate and high resiliency conditions and connectivity among those populations to allow populations to "rescue" each other after catastrophic events. Representation improves with increased genetic diversity and environmental conditions within and among populations.

2.6 Life History and Demography

Limited information is available regarding the life history and ecology of the Tennessee cave salamander (figure 2.4), like most stygobiotic fauna. In this section, we summarize the best available information on Tennessee cave salamander reproduction, growth and development, demography, diet, and predation.

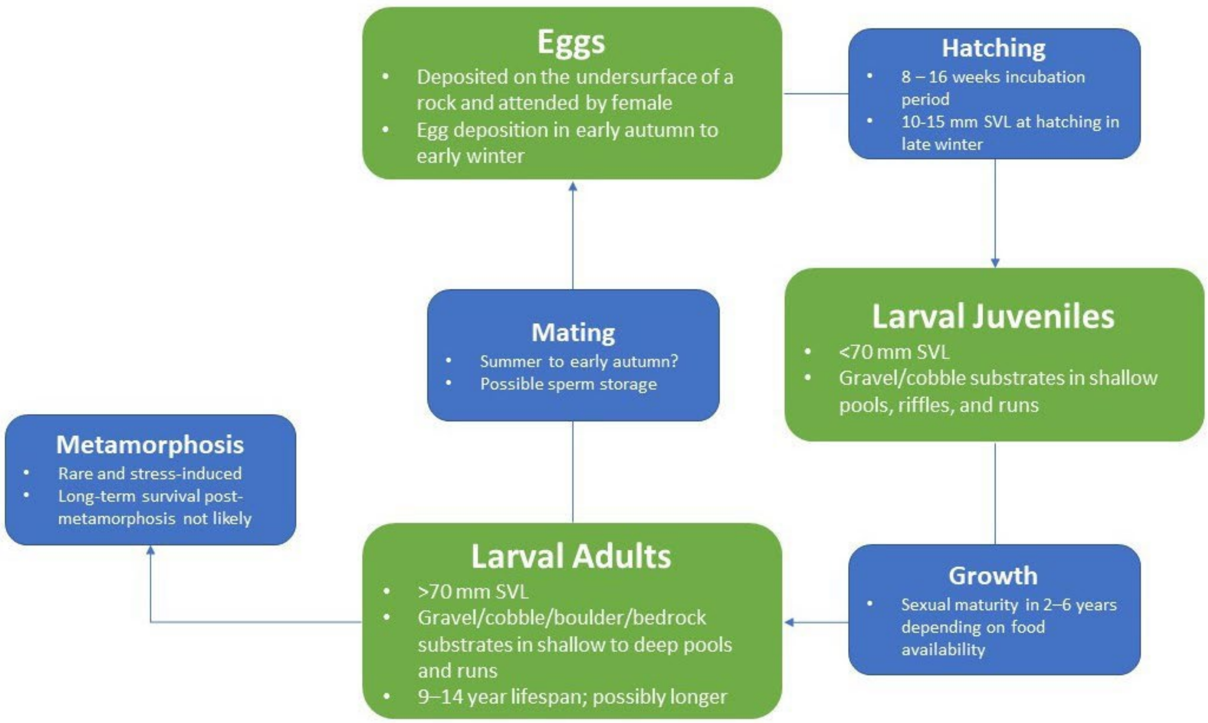


Figure 2.3. Life cycle of the Tennessee cave salamander based on available information, observations, congeners and other cave-dwelling salamanders.

2.6.1 Reproduction

Very little is known regarding reproduction in Tennessee cave salamanders, as nests have never been discovered. Moreover, no aspects of courtship or mating have been observed. Female Tennessee cave salamanders may possibly store sperm, similar to the spring salamander (Collazo and Marks 1994, p. 240). Both mating and egg deposition are thought to occur in water in early autumn into early winter (Simmons 1975, p. 28). Gravid females have been observed in July and August, and small larvae have been observed in January and February (Petranka 1998; p. 281; Miller and Niemiller , unpublished data; Niemiller, unpublished data). Nests have not been found in surveyed habitat or observed anecdotally but are presumed to be attached to the undersurfaces of rocks and other cover. Clutch size is unknown but probably is similar to spring salamanders with approximately 24–106 eggs/clutch (Bruce 1969, pp. 50–52; Bruce 1972, p. 242; Bruce 1978, p. 60). The developmental time of eggs from deposition to hatching is unknown but thought to be similar to spring salamanders at 8–16 weeks (Organ 1961, entire; Girard et al. 2014, p. 14).

2.6.2 Growth and Development

Comprehensive studies in 2011 and 2016 inform much of our knowledge on the growth, longevity, and demography of the species. Sexual maturity for the Tennessee cave salamander was estimated at 2–6 years assuming maturity as attained at 66–70 mm (2.6–2.7 in) snout-to-vent length, with males possible reaching sexual maturity at a smaller size and younger age (Dent and Kirby-Smith 1963, p. 129; Simmons 1975, pp. 23–28; Huntsman et al. 2011, p. 1749; Niemiller et al. 2016, p. 37–38). The Tennessee cave salamander life span is estimated at 6–14 years (Huntsman et al. 2011, p. 1757; Niemiller et al. 2016, p. 38). The oldest Tennessee cave salamander on record was collected in the wild at an unknown age and lived 18.5 years in captivity (Snider and Bowler 1992, p. 7).

Tennessee cave salamanders occasionally metamorphose and lose their larval characteristics in nature as described in **2.2 Species Description** (Yeatman and Miller 1985, pp. 304–306; Brandon et al. 1986, pp. 1-2; Miller 1995, p. 103; Miller and Niemiller 2008, pp. 8, 14). Natural metamorphs have been reported from the following caves: Jess Elliot Cave and Tony Sinks Cave (Jackson County, Alabama); Custard Hollow Cave and Sinking Cove Cave (Franklin County, Tennessee); Smith Hollow Cave No. 1 (Grundy County, Tennessee); and an unnamed spring along the Collins River (Warren County, Tennessee). Natural metamorphosis appears to be extremely rare and related to a significant stressor, for example, individuals that have been washed out of a spring or in an isolated rimstone pool during a period of prolonged drought (Miller 1995, p. 103; Niemiller 2006, pp. 46–47).

2.7 Demography

Based on visual censuses, most populations of Tennessee cave salamanders are reportedly small. Fewer than 20 individuals have been observed during most cave surveys with 1 or 2 salamanders observed in 60 percent of sites surveyed since 2000 (Simmons 1975, p. 99;Caldwell and Copeland 1992, p. 4; Petranka 1998, p. 281; Samoray and Garland 2002, entire; Beachy 2005, p. 775; Miller and Niemiller 2008, p. 1; Niemiller and Miller 2010, p. 862.3; Niemiller 2022, pers. comm.). There have been few attempts to estimate population sizes and densities. Population and density estimates vary among sites and habitat quality (table 2.2) with available population estimates that range from 73 to 215 individuals and density estimates ranging from 0.03 to 0.15 individuals per m^2 (Simmons 1975, p. 37; Huntsman et al. 2011, p. 1751; Niemiller et al. 2016, p. 37). Adult survival probabilities generally greater than 0.75 were estimated in a 26-month study at Big Mouth Cave (Niemiller et al. 2016, pp. 35–37). No estimates of juvenile survival are available.

Table 2.2**.** Historical (pre-2000) and current (2000–2022) Tennessee cave salamander population and density estimates for caves with current Tennessee cave salamander occurrences.

Site	Population Estimate	Density Estimate	Study
Jess Elliot Cave, Jackson Co, AL	88	0.15 individuals per m^2	Simmons 1975, p. 37

Big Mouth Cave, Grundy Co, TN	76 ± 23	0.11 ± 0.03 individuals per m^2	Niemiller et al. 2016, p. 37
Tony Sinks Cave; Jackson Co, AL	215 (95 percent CI: 128–302)	0.10 individuals per m^2	Huntsman 2011, p. 1751
Bluff River Cave, Jackson Co, AL	109 (CI: 77–141)	0.03 individuals per m^2	Huntsman 2011, p. 1751

2.8 Diet

Tennessee cave salamanders are top predators in the groundwater ecosystems they inhabit. Evidence suggests that they are generalists that feed on a variety of aquatic prey. A comprehensive study on the diet of the species found the most frequent prey included oligochaetes, fly larvae, isopods, mayfly larvae, and copepods (Huntsman et al. 2011, pp. 1751–1752). Other prey included leeches, bivalves, mites, stonefly larvae, beetle larvae, ostracods, and amphipods. Prey biomass was highest in late winter and early spring (January–April), which is likely attributed to seasonal variation in precipitation and invertebrate life cycles. The isopod *Lirceus* sp. was the major prey item by biomass consumed at Tony Sinks Cave, whereas the two-toothed cave isopod (*Caecidotea bicrenata*) and oligochaetes were the dominant prey items by biomass at Bluff River Cave. Additional prey items reported include terrestrial earthworms, salamander larvae, and crayfishes (Lazell and Brandon 1962, p. 305; Miller and Niemiller 2008, p. 12). Cannibalism among Tennessee cave salamanders has also been documented (Lazell and Brandon 1962, p. 305; Niemiller, unpublished).

2.9 Activity and Home Range

Home range size has not been estimated for Tennessee cave salamanders but is presumed to be small based on measures of activity for congeneric species. However, we note the three-dimensional aspect of subterranean species home ranges that is not expressed in terrestrial faunal home range estimates. Most Tennessee cave salamanders recaptured in mark/recapture studies were found in the same general location, including under the same cover object in some instances (Simmons 1975, p. 48). For the congeneric Berry Cave salamanders, the mean distance between recaptures was 17 ± 5.0 m at Meads Quarry Cave in Knox County, Tennessee (Niemiller et al. 2018, p. 21). Larger Berry Cave salamander individuals exhibited the lowest amount of spatial overlap with conspecifics, which may be related to territoriality and/or reproduction. At Big Mouth Cave, several adult Tennessee cave salamanders were recaptured in the same isolated pools, but movement has not been quantified (Niemiller and Miller, unpublished data). Tennessee cave salamanders have been observed moving over land between isolated pools, presumably in response to decreasing water levels during periods of drought (Niemiller and Miller, unpublished data). Tennessee cave salamander may exhibit site fidelity to some extent, as the same salamanders have been observed in a site for two and three years (Niemiller and Miller, unpublished data). We expect Tennessee cave salamander individuals may move among areas inaccessible to surveyors, but we have no evidence individuals move between caves (i.e., no captures of the same animal in two sites or caves).

2.10 Range and Distribution

The Tennessee cave salamander occurs in subterranean waters associated with karst landscapes in central and southern middle Tennessee, northern Alabama, and extreme northwestern Georgia (figure 2.5) (Godwin 2004, pp. 33–34; Godwin 2008, pp. 202–204; Miller and Niemiller 2008, pp. 1, 10–11; Miller and Niemiller 2012, p. 884.3). We are aware of Tennessee cave salamander occurrence records in 91 cave systems (Appendix A) – 45 caves in six counties in Alabama, 2 caves in one county in Georgia, and 43 caves in 11 counties in Tennessee (figure 2.5) – plus one spring in Tennessee. The species also has been reported from an unnamed spring in Warren County, Tennessee (Miller 1995, p. 103). Of the other 91 sites, 75 have been confirmed by biologists through direct observations, genetics, voucher specimens, or photo vouchers. The remaining 17 sites are reports from credible sources; we determined these records to be valid and include them in our analyses.

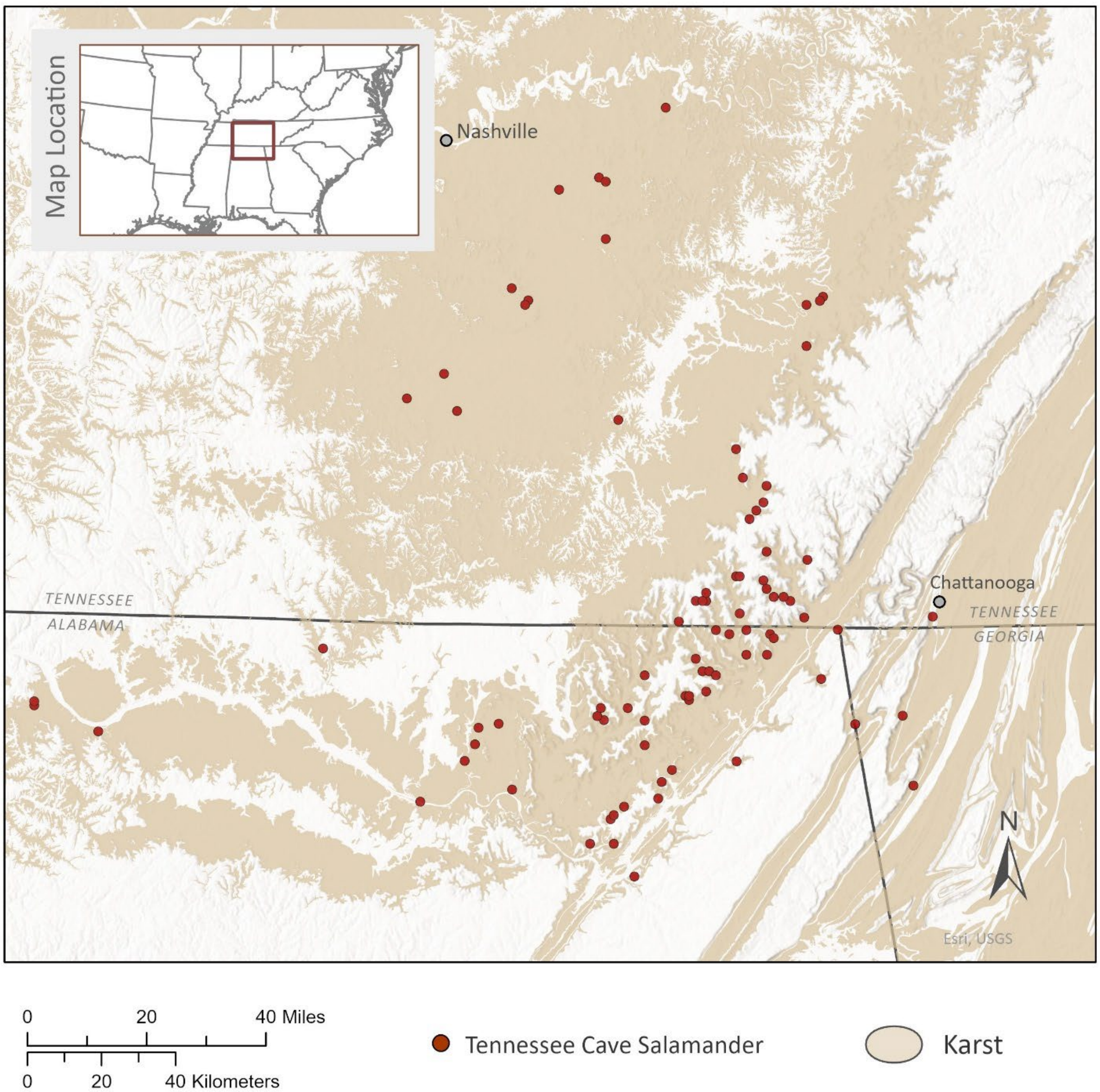


Figure 2.4. Range and distribution of 91 historical and current Tennessee cave salamander occurrences in karst geology in Tennessee, Alabama, and Georgia. Tan areas on the map indicate karst and potential karst areas in carbonate rocks at or near the land surface (Weary and Doctor 2014, p. 5).

Tennessee cave salamanders are primarily associated with caves (sites) in the Interior Plateau and Southwestern Appalachians EPA level III ecoregions, with some sites on the borders with the Ridge and Valley and Southeastern Plains ecoregions (figure 2.6; Omernik and Griffith 2014, p. 1260). In the Interior Plateau, most sites are known from the Cumberland Plateau (level IV EPA ecoregion, figure 2.7) in the following counties: Franklin, Grundy, Coffee, Marion, and Hamilton counties, Tennessee; Jackson, Marshall, and DeKalb counties, Alabama; and Walker County, Georgia. In the Interior Plateau, additional clusters of sites are known from the Eastern Highland Rim (level IV EPA ecoregion) in the following counties: Warren County, Tennessee, and Madison, Limestone, and Colbert counties, Alabama. Sites with Tennessee cave salamander occurrences also are scattered through the Inner Nashville Basin (level IV EPA ecoregion) in Marshall, Maury, Rutherford, and Wilson counties in central Tennessee. Two isolated sites are known from the Outer Nashville Basin (level IV EPA ecoregion) in Bedford County, Tennessee, and Limestone County, Alabama.

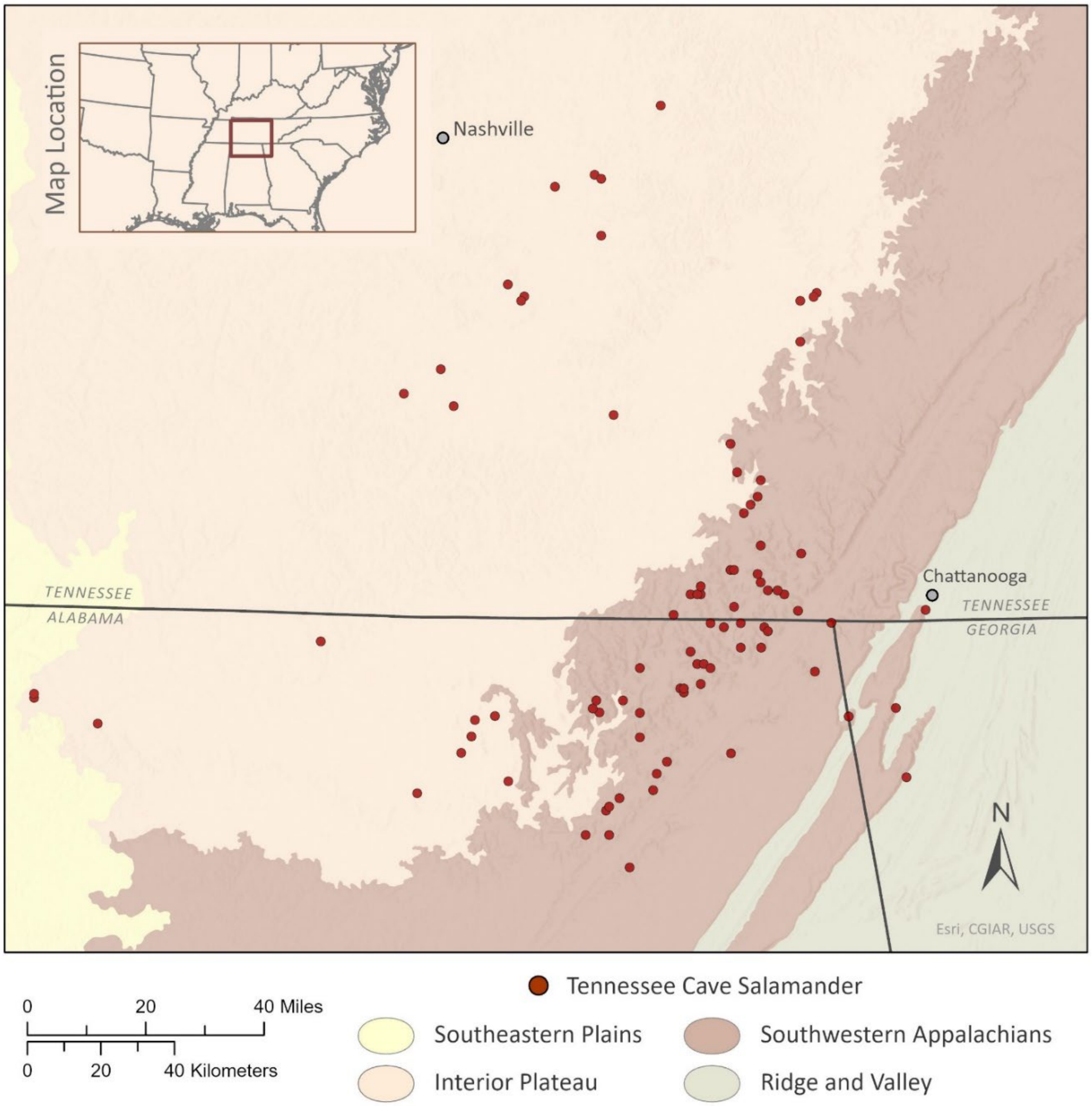


Figure 2.6. Range and distribution of 91 historical and current Tennessee cave salamander occurrences in the Southwestern Appalachians and Interior Plateau EPA level III ecoregions in Tennessee, Alabama, and Georgia.

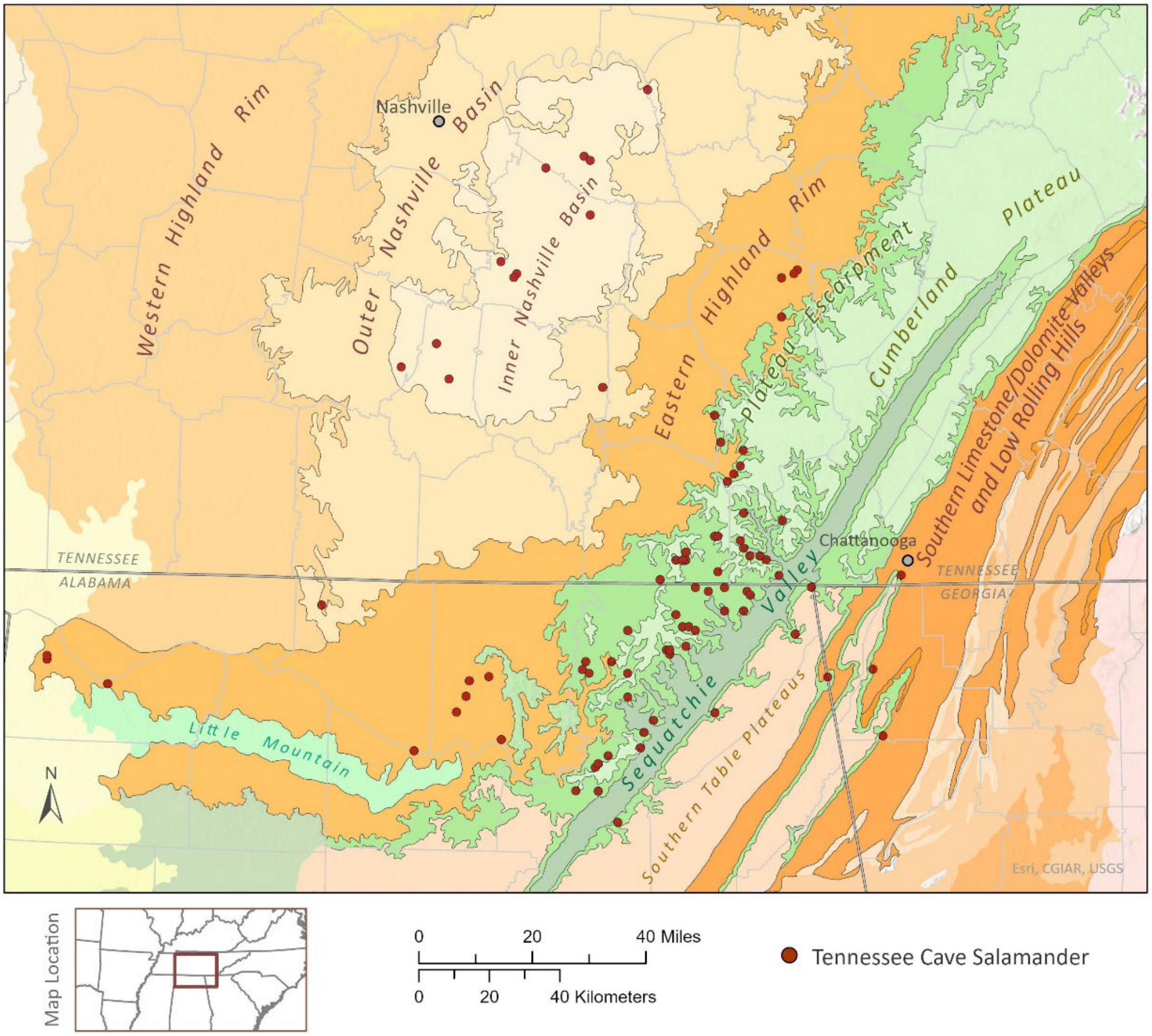


Figure 2.5. Range and distribution of 91 historical and current Tennessee cave salamander occurrences in 6 EPA level IV ecoregions in Tennessee, Alabama, and Georgia.

Tennessee cave salamanders occur in 12 Hydrologic Unit Code (HUC) 8 watersheds in the Coosa, Ohio, and Tennessee River basins (figure 2.8). The majority of occurrences are in the Guntersville Lake and Wheeler Lake HUC 8 watersheds. Watersheds with Tennessee cave salamander occurrences include the Upper Coosa watershed in the Coosa River basin; the Collins, Harpeth, Stones, and Lower Cumberland-Old Hickory Lake watersheds in the Cumberland River drainage; and the Upper Duck, Upper Elk, Lower Elk, Middle Tennessee-Chickamauga, Guntersville Lake, Wheeler Lake, and Pickwick Lake watersheds in the Tennessee River basin. In Georgia, Tennessee cave salamanders have been reported from only two caves in Walker County – one located on Lookout Mountain in the Tennessee River basin and the other on Pigeon Mountain in the Coosa River basin (Godwin et al. 2007, p. 2; Godwin 2008, p. 202–204).

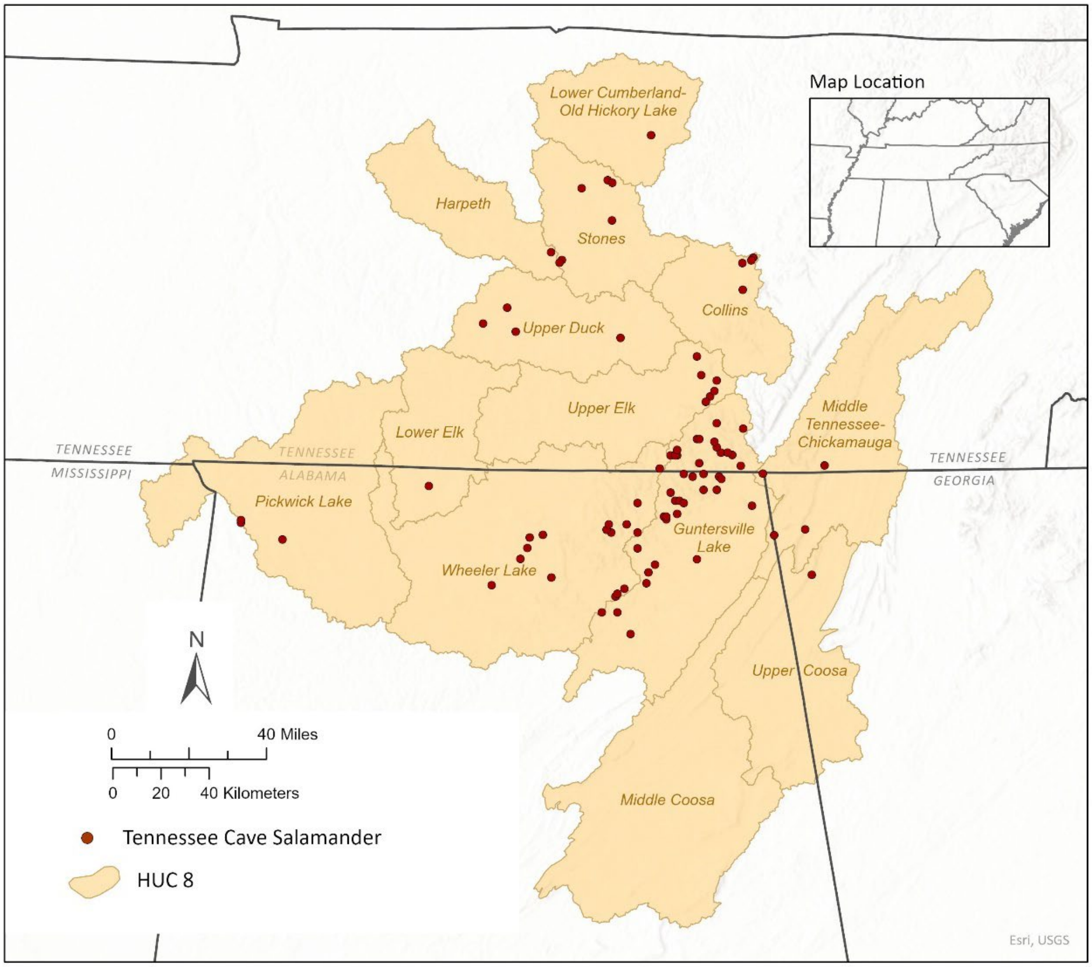


Figure 2.6. Range and distribution of 90 historical and current Tennessee cave salamander occurrences in HUC 8 watersheds in Tennessee, Alabama, and Georgia.

2.11 Population Trends

Cave surveys involve visual area observation of aquatic habitat for adults and larvae, including searches for salamanders beneath rocks and other cover and between small cobble. Detection probabilities of Tennessee cave salamanders among caves is likely quite variable because of variation in aquatic habitat available to survey as well as variation in substrate composition among caves. For example, detection probability (reported as capture probability) was estimated at 0.28 ±0.03 at Big Mouth Cave over the duration of a 26-month study (Niemiller et al. 2016, p. 37). Given the extent of suitable habitat in cave ecosystems is unknown and may not be accessible to surveyors, we do not have a thorough understanding of species presence or abundance. Additional habitat that meets Tennessee cave salamander life history needs may be present in sites with Tennessee cave salamander occurrence (Miller and Niemiller 2008, p. 13).

From 2020 to 2022, there has been a substantial survey effort to update information about size of the extant populations (or abundance) of Tennessee cave salamander at sites with historical occurrences. Moreover, cave surveys have been conducted throughout much of central Tennessee and northern Alabama to locate additional undiscovered populations in the Interior Plateau. Of the

90 Tennessee cave salamander sites, 35 sites have observations prior to 2000 (discovery between 1967 and 1999) and are historical sites that have not been resurveyed since 2000. Of these 35 sites, 24 sites have been resurveyed after the initial species discovery. Tennessee cave salamander has been confirmed at 16 of the 24 resurveyed historical sites. Most Tennessee cave salamander sites have been resurveyed more than once, with 5 caves resurveyed 10 or more times (including Big Mouth, Shelta, Jackson, Limrock Blowing, and Tumbling Rock caves). Two sites in the Tennessee cave salamander range have historical occurrences and have been resurveyed recently with current observations. One Tennessee cave salamander was last observed in McFarland Cave in 1999; three Tennessee cave salamander were observed at the site in 2022 after repeated negative surveys in the intervening years. Sauta Cave has been a site with high historical abundance (17 Tennessee cave salamander observed in 1995), but the species was not observed for several decades before its rediscovery in 2022 with the observation of 2 Tennessee cave salamanders. Based on available survey information, Matthews Cave has a historical occurrence (1992), but no Tennessee cave salamander observations despite repeated surveys with the most recent survey in 2019. For the purposes of our SSA, we do not categorize Matthews Cave site as extirpated, since Tennessee cave salamander has been rediscovered at sites with no observations in over 30 years and may still occur (unobserved) at Matthews Cave.

Abundance based on visual censuses at sites with the largest known populations have exhibited varying trends. Recent surveys at Cave Cove, Sinking Cove, and Custard Hollow caves in Franklin County, Tennessee, demonstrated that populations are robust and stable. In contrast, recent surveys at Big Mouth Cave in Grundy County, Tennessee in 2017 and 2019 only yielded 1–2 salamanders compared to 24 salamanders on average during the 2000s. Available information does not indicate that the rangewide distribution of the Tennessee cave salamander has expanded or contracted significantly since the discovery of the species in the mid-1940s. Several additional populations have been documented in the past 20 years, increasing the known distribution of the species; but this reflects existing gaps in our knowledge of Tennessee cave salamanders rather than range expansion (Miller and Niemiller 2008, pp. 9–10, 13–14).

CHAPTER 3 – FACTORS INFLUENCING VIABILITY

This chapter provides a summary of the past, current, and future factors that are affecting or could affect the current and future condition of the Tennessee cave salamander throughout all or a portion of its range. The broad categories of threats to cave and karst biota are documented and include high sensitivity to groundwater contamination by sediments and toxic compounds, disruption of food supply due to deforestation, and direct modification of habitats due to cave visitation and urban development of karst areas (Culver et al. 2000, pp. 387, 392–396; Pipan et al. 2010, entire). Factors we have identified as those that are influencing or may influence the viability of the Tennessee cave salamander include habitat destruction and modification from a variety of sources, disease and predation, climate change, and conservation efforts.

3.1 Habitat Quality

3.1.1 Water Quality

The most significant threat to the Tennessee cave salamander rangewide is groundwater pollution, but the sources, scope, and severity varies among sites and analysis units in relation to predominant land use, overburden (the rock and soil above the cave system), and local hydrology. Impacts from groundwater pollution can be chronic, occurring over years to decades, or acute, occurring on the order of hours or days. Subterranean species in karst environments are particularly vulnerable to groundwater pollution, as karst aquifers often have low potential for auto-depuration and have a high probability of retention of contaminants (Kačaroğlu 1999, p. 338; Ford and Williams 2007, p. 471–472; De Waele et al. 2011, p. 5). Sources of groundwater pollution in the Tennessee cave salamander's range include land cover change, urbanization and development, chemical manufacture (historical), mining and quarrying activities, and impoundments. Additional sources of groundwater pollution in the range of Tennessee cave salamander include septic system leachate, sewage, urban and storm water runoff, livestock waste, heavy metals, pesticides, herbicides, and other chemicals used in agriculture and residential areas (lawns and landscaping).

Land Cover Change

Land cover versus land use is an important distinction in addressing potential impacts to the species. Changes in land use in cave recharge basins can lead to habitat loss and degradation (Booth and Jackson 1997, p. 1077; Caldwell and Copeland 1992, pp. 2–3). Forested habitats tend to provide the greatest benefits because of its ability to afford minimal transport of sediment and toxicants, to maximize detrital input to karst systems with in-flowing streams, and to buffer hydrologic and temperature fluctuations. Shifts to other habitats such as grassland, residential lawns, or commercial developments with paved areas tend to result in impairment of caves – whether acute or chronic. Land use often tends to dictate the degree and type of impairment. For example, a shift from silviculture to pastureland for harvest of hay may result in decreased detrital input to caves. Conversion to livestock grazing could result in increased sediment transport, and conversion that results in anthropogenic influence (e.g., row-cropping, residential areas, commercial development, and mining) could introduce toxicants, increase sediment transport, and alter the physical condition of water such as flow regime and temperature. Conversion of land for development, agriculture, and silviculture can lead to increased sedimentation and changes in local hydrology, which may degrade the quality of habitat, reduce the amount of habitat available, or alter the amount of allochthonous organic input (Caldwell and Copeland 1992, p. 3). The groundwater pollution effects of land use change, including sedimentation and other pollutants from silvicultural activities that do not implement best management practices (BMPs) or improperly implement BMPs and agricultural practices, have been noted in 18 caves with Tennessee cave salamander occurrences. We expect that these habitat changes may affect the individuals in those caves.

Urbanization and Development
In urban areas, conversion of land to impervious surfaces such as roads, parking lots, and sidewalks can increase the velocity and amount of storm water runoff leading to degradation ofaquatic habitat through more rapid transport of contaminants and increased sediment load (Booth and Jackson 1997, pp. 1078–1079; Hart 2006, pp. 35–36). The initial stages of residential and commercial development projects often can result in a pulse of sediment to downstream areas, including into cave systems in karst regions. Increased sediment load can degrade and reduce habitat available, including filling the interstitial space between cobble and gravel used for Tennessee cave salamander egg deposition (assumed based on congeneric species) and larvae occupancy. Sediment input to caves can smother salamander eggs and the salamander forage base (i.e., invertebrates). Likewise, sedimentation can negatively impact the invertebrate prey base (McNie and Death 2017, pp. 1999, 2003) that Tennessee cave salamanders depend upon. Depending on the spatial and temporal extent of development (and effectiveness of sediment containment practices), any activity could chronically impact salamander habitat.

Increases in impervious surfaces associated with urbanization tend to result in greater hydrologic “flashiness” (i.e., a tendency toward more rapid increases and decreases in flow) with subsequent increases in sediment transport (Booth and Jackson 1997, p. 1078). In addition to increases in sediment deposition as a result of flashiness of hydrologic input, high input flows may directly affect Tennessee cave salamander by displacing individuals from preferred habitat sites and causing injury or mortality. The effect of sedimentation and siltation on species reproduction is unknown but assumed to be detrimental. The Tennessee cave salamander occurs at sites with increased sedimentation (e.g., Muddy Cave, Bobcat Cave, and Shelta Cave), and evidence of reproduction in the form of gravid females and juveniles is present at these sites. However, the degree to which sedimentation and siltation in the cave habitat substrate drives Tennessee cave salamander recruitment varies, and information is not available to determine the tolerance or threshold of effects to the species. It is feasible that Tennessee cave salamanders may relocate breeding activities in portions of caves with lower sediment loads that may not be accessible during visits by salamander survey crews. Groundwater within karst systems can move relatively fast compared to surface streams, sediments can be re-entrained, and sediment is reincorporated into water flow (Pähtz et al. 2020, p. 1). Effects to habitat resulting from urbanization have been noted in 5 caves with Tennessee cave salamander occurrences, particularly in the Huntsville area.

Chemical Manufacture
Toxicant issues are recognized as an area of concern in the vicinity of Redstone Arsenal (near Huntsville, Alabama) and some urban areas. DDT was manufactured at the site from 1947 to 1971, and widespread contamination was discovered at the plant site in the late 1970s (USEPA 1983).

The Tennessee cave salamander population of Matthews Cave, for example, may be extirpated as a result of pollutants. One observation of a large, gilled salamander in 1992 is categorized as a Tennessee cave salamander occurrence. However, no Tennessee cave salamander (or other salamanders) have been observed despite repeated surveys (the most recent in 2019). This cave is located near Bobcat Cave, where the observed Tennessee cave salamander abundance is low and habitat conditions may not be suitable for Tennessee cave salamander due to the threat of groundwater pollution. A Tennessee cave salamander was observed at Bobcat Cave in 2019. Although the hydrologic or karst connection between these two caves is not known, a hydrologic connection may exist other during flood conditions, allowing the transport of pollutants or contaminants. The best available information indicates that this threat is limited to the Greater Huntsville area, including Bobcat Cave and Matthews Cave. Although the chemical manufacture is no longer occurring, the residual effects from this threat are ongoing and expected to continue in the future.

Other Activities
Mining and quarrying can result in the direct destruction of caves, while noise and vibration from blasting may disturb or alter behavior of subterranean organisms including Tennessee cave salamanders (Niemiller and Taylor 2019, p. 823). Likewise, impoundments, such as those along the Tennessee, Elk, Duck, and Stones rivers may flood cave systems, resulting in alteration to hydrology, sediment load, and organic input while also potentially introducing predators, such as catfishes, into some systems. Effects to habitat related to nearby mining and quarrying have been noted at 3 caves with Tennessee cave salamander occurrences. Impoundments have negatively impacted cave habitat in 5 sites with species' records.

3.1.2. Water Quantity
Groundwater withdrawal for agriculture or other human needs may reduce available habitat for Tennessee cave salamanders in parts of its range. Populations of the Tennessee cave salamander in the Eastern Highland Rim may be impacted from significant groundwater withdrawal for irrigation associated with nurseries, sod farms, and row crop agriculture thatare most prevalent in this region. Some towns and cities in the range of the Tennessee cave salamander derive drinking water in part from groundwater sources (e.g., the city of Huntsville, Alabama). In rural areas, groundwater withdrawal from wells is thought to haveminimal impact on groundwater levels, particularly as many households transition to public water utilities. Groundwater withdrawal may potentially exacerbate the impacts of drought when water demand is greatest. The best available information indicates that this threat has not impacted the species or its habitat, but it may do so in the future if water withdrawals increase and water levels in the caves with species' occurrences are affected.

3.2 Cave Visitation and Collection
Human visitation levels among caves occupied by Tennessee cave salamanders are generally not well documented but are thought to be highly variable among caves. Potential impacts resulting from human visitation associated with recreational caving include injury or death toindividual salamanders or eggs from trampling, introduction of pathogens such as *Batrachochytrium dendrobatidis* (*Bd* or chytrid fungus) or the iridovirus *Ranavirus*, and disturbance that leads to stress, altered behaviors, and decreased fitness. Impacts from recreational caving are likely minimal at most sites, as cavers typically avoid direct wading in streams and other aquatic habitats when possible. However, amateurspelunkers may pose a greater risk at some sites (often near urban

areas) due to increased levels of littering and vandalism (Niemiller and Taylor 2019, p. 824). Effects to habitat or indications of visitation have been noted at 17 caves with Tennessee cave salamander occurrences, although we do not have direct evidence that this visitation has affected salamander individuals or populations.

Although Tennessee cave salamanders are elusive and quick to seek shelter if disturbed, it can be relatively easy for an experienced collector to capture salamanders at some caves (Miller and Niemiller, unpublished data). Consequently, there is potential for significant overcollection for bait, the pet trade, or scientific studies at some sites. Removal of significant numbers of salamanders from any particular site could greatly diminish a breeding population.For a species with a potentially low reproductive rate, this may jeopardize populations at somesites. The species is not known to be targeted for significant amateur or scientific collection at this time. We have determined that overcollection is not a key driver of species condition at this time. The difficulty associated with accessing aquatic habitats at many caves may deter collection.

3.3 Predation and Disease

Tennessee cave salamanders are top predators in groundwater ecosystems throughout their distributional area. Natural predators have not been well documented, but may include crayfishes, fishes (facultative cave-dwelling catfishes and sculpin), and conspecifics. Few predators of the Tennessee cave salamander have been reported but include American bullfrogs (*Rana catesbeiana*) and conspecifics (Simmons 1975, p. 49; Niemiller unpublished data). Some fishes, such as catfishes (family Ictaluridae) and sculpin (*Cottus* sp.) may potentially prey on Tennessee cave salamanders, but this has yet to be documented. Over 30 percent of salamanders observed at Big Mouth Cave in Grundy County, Tennessee, over a 26-month period had damage to or were regenerating tails or limbs (Niemiller et al. 2016, p. 38–39). Antagonistic interactions among conspecifics may be a leading cause of this pattern; however, possible predation attempts by co-occurring crayfishes might also be responsible (Niemiller et al. 2016, p. 39). For example, the cavespring crayfish (*Cambarus tenebrosus*) has been reported to capture and feed on other amphibian species in caves (Miller and Niemiller 2005, p. 23; Niemiller and Reeves 2014, p. 8). However, the best available information indicates that predation is not a significant threat to the Tennessee cave salamander at this time.

Emergent amphibian diseases, including chytridiomycosis caused by the fungal pathogens *Bd* and recently discovered *Batrachodhytrium salamandrivorans* (*Bsal*), and the iridovirus Ranavirus, have the potential to impact populations of the Tennessee cave salamander. No studies to date have assessed the prevalence of these pathogens in populations of Tennessee cave salamander. Across the southeast, Ranavirus may act as a greater emerging threat than *Bd* (Niemiller 2022, pers. comm.) However, *Bd* has been detected in cave populations of the grotto salamander (*Eurycea spelaea*) as well as other amphibian cave community associates in the Ozarks (Rimer and Briggler 2010, entire). Few internal parasites of Tennessee cave salamander have been reported. Acanthocephalan parasites (spiny-headed worms) were reported from stomach contents of Tennessee cave salamanders from Big Mouth Cave, Grundy County, Tennessee (Brandon 1967, p. 53; Simmons 1975, p. 49). Cestodes (tapeworms) and nematodes (roundworms) occurred in Tennessee cave salamanders at Sinking Cove, Jess Elliot, and Bluff River caves (Simmons 1975, p. 49; Huntsman et al. 2011, p. 1753). Although disease may affect individuals or populations of

Tennessee cave salamander, the best available information indicates that the threat does not affect the species as a whole.

3.4 Competition and Hybridization

Tennessee cave salamanders could compete with southern cavefish and cave crayfishes for food, shelter, and other resources, although competition between these species has not been studied. The typically epigean (above ground) spring salamanders have been documented from several cave systems in Tennessee, Georgia, and Alabama may potentially compete or hybridize with Tennessee cave salamanders in the limited areas where the species occur in the same cave system (Zigler et al. 2020, p. 148). However, the distributions of Tennessee cave salamanders and spring salamanders are largely separate but contiguous and abut along common boundaries (parapatry). There is no evidence of contemporary hybridization between the two taxa. Hybridization between Berry Cave salamanders and spring salamanders has been documented in eastern Tennessee (Niemiller et al. 2008, p. 2271, Niemiller et al. 2010, p. 4). The best available information indicates that competition and hybridization are not substantial threats to the species as a whole, but they may affect individuals or populations.

3.5 Climate Change

Climate change is predicted to have significant impacts on the levels, quality, and sustainability of groundwater through direct influence on groundwater organisms, environmental conditions, and ecosystem processes (Taylor et al. 2012, entire; Klove et al. 2014, entire). In particular, changes in water temperature, dissolved oxygen, recharge rates, altered hydrological regime, groundwater levels, and groundwater quality are expected effects of climate change in the future (Earman and Dettinger 2011, entire; Treidel et al. 2012, entire). Many groundwater species, including Tennessee cave salamander, may be particularly vulnerable to impacts of climate change because of their unique habitat requirements, endemicity, adaptations, and often limited dispersal abilities (Taylor and Niemiller 2016, p. 22). The Tennessee cave salamander was assessed as “moderately vulnerable” to the impacts of climate change (Glick et al. 2015, pp. 18, 30, 98).

Most climate change models predict an increase in extreme weather events, such as droughts and heavy precipitation (IPCC 2021, p. 15). Since the 1970s, moderate to severe droughts in the Southeast have increased by 12 percent during spring months and by 14 percent during summer months (Jones et al. 2015, p. 126). Droughts reduce stream discharge, which can lead to a reduction of available habitat with required water quality and water quantity in cave streams. Increased groundwater withdrawal for agriculture or other human needs during droughts may potentially exacerbate the impacts of reduced quantity or frequency of precipitation. During periods of prolonged drought, previously connected pools can become isolated and strand salamanders in habitat that does not support the species. However, adult Tennessee cave salamanders have been observed traveling on land between pools and may seek out more permanent aquatic habitats during such periods of low flow or drought. Dispersal, migration, or limits on movement potential of the Tennessee cave salamander has not been documented. The effects of droughts may be more pronounced for smaller size classes that are more common in riffle and run habitats, which are affected by less severe low flow events as compared to pool habitats. Tennessee cave salamanders of this size may be vulnerable to desiccation due to higher surface area to body mass ratio and increased energy expenditure to seek out suitable pool, riffle, or run habitat within the cave system. Small individuals may face increased risk of predation in pools, particularly if the majority of potential predators (including conspecifics) are concentrated in pools during periods of drought. Likewise, reduced water levels in caves may reduce the amount of habitat available for egg deposition.

Extreme weather events such as flash flooding associated with heavy precipitation events can impact Tennessee cave salamander through habitat degradation and modification and displacement, injury,or death of salamanders. Heavy rainfall can directly modify cave stream habitat through effects to surface features including streambed erosion and downcutting that increase mobilization and transport of silt and sediment into cave systems. Increased sedimentation and siltation fill in interstitial spaces and degrades habitat or reduces the amount of habitat by removing cover areas and feeding areas for juvenile and adult Tennessee cave salamander. Increased loads of sedimentation and siltation in a cobble and boulder cave environment impacts the invertebrate food source and affects Tennessee cave salamander life history requirement, particularly in a cave ecosystem with limited prey base options. However, the impact to sedimentation and siltation is uncertain as Tennessee cave salamanders occur in caves with a high degree of sedimentation. Flash flood or extreme high flow events may also transport salamanders downstream into suboptimal habitats or even onto the surface (Miller 1995, p. 103). Flooding is a critical and dynamic component of these cave ecosystems and renews needed detrital input resources, but the impacts to Tennessee cave salamander individuals and populations are uncertain and likely vary by site characteristics including hydrology, surface land use, and cave morphology.

Increases in mean annual temperature are projected for the Tennessee cave salamander range in Tennessee, Alabama, and Georgia (Alder and Hostetler 2013, unpaginated). Under RCP4.5, in 2040 an overage annual temperature increase of 1.4°C (2.6°F) is expected with a 2°C (3.6°F) increase expected in 2060. Under RCP8.5, increases in annual average temperature of 1.6°C (2.8°F) in 2040 and 3°C (5.4°F) in 2060 are projected. However, the effects of increased surface temperature may not directly or immediately produce effects in subterranean systems. Cave systems are semi-closed systems characterized by thermal stability (Mammola et al. 2019, p. 99). This thermal stability confers a lag time between the air temperature change and cave temperature change that may be years or decades long (Mammola et al. 2019, p. 102). This lag time may act to slow the effects to the species or the species' response to changes in climate characteristics including temperature, precipitation, and extreme weather events. However, caves may vary in morphology and thermal stability and a site-by-site characterization of temperature variation and thermal stability caves with Tennessee cave salamander occurrence has not been conducted. The thermal tolerances and effect on Tennessee cave salamander reproduction is unknown, but reproduction in amphibians is often tightly linked to temperature (E. Carter 2022, pers. comm.). However, little is known about Tennessee cave salamander or close congener reproduction in relation to temperature.

Although increases in temperature are predicted, the cave environment where Tennessee cave salamander occurs is buffered from these changes to some extent. While the precise thermal tolerances of Tennessee cave salamander are unknown, currently occupied caves experience a range of temperatures based on the water temperature of stream flow into caves over different seasons. In addition, Tennessee cave salamander habitat extends in a three-dimensional matrix within the cave system, providing opportunities to seek deeper, cooler, or wetter areas as habitat conditions shift. The best available information indicates that the effects of climate change have not affected Tennessee cave salamander populations or the species as a whole at this time, although we expect that changes in hydrology of climate change will impact the Tennessee cave salamander through the effects of drought and other extreme weather events, including floods, in the future.

3.6 Synergistic and Cumulative Effects

Due to the complexity of cave ecosystems, any single factor influencing Tennessee cave salamander viability often impacts the species in a variety of ways. The interconnectedness of influences and their ecological impacts create complex cumulative effects on Tennessee cave salamander viability. For example, urbanization and development results in increased impervious surface area and increased runoff that exacerbates the effects of flashiness of stream discharge due to extreme weather events (Booth and Jackson 1997, entire). Flooding and transport of pollutants affect Tennessee cave salamander resiliency by degrading the water quality required by Tennessee cave salamander in occupied cave systems. Additionally, urbanization can also exacerbate drought conditions by channeling stormwater runoff from impervious surfaces into ditches and drains that directly flow into sewer lines and/or larger order streams, thereby decreasing the amount of water available for groundwater recharge. Without adequate groundwater recharge, cave hydrology may be affected with decreased water quantity in sites with Tennessee cave salamander occurrence.

Projected warmer temperatures and more frequent and/or severe drought associated with climate change could lead to decreased water availability. As a result of limited water availability, water withdrawal from nearby streams or groundwater sources would likely increase in order to support agricultural and/or municipal water supply demands. Increased withdrawal as a result of climate change will affect Tennessee cave salamander by reducing the required water quantity in caves.

Reductions in water quantity or water flow may concentrate aquatic-dependent organisms, including Tennessee cave salamander, in smaller areas. This increased density may allow for increased disease transmission (e.g., *Ranavirus* and *Bd*). The concentration of aquatic cave dwellers into smaller areas also increases the risk of predation and the competition for available food resources in these refugia.

3.7 Conservation Efforts and Regulatory Mechanisms

3.7.1 State Protections

The Tennessee cave salamander is listed by the State of Tennessee as threatened. Under the Tennessee Nongame and Endangered or Threatened Wildlife Species Conservation Act of 1974 (Tennessee Code Annotated §§ 70-8-101-112): "[I]t is unlawful for any person to take, attempt to take, possess, transport, export, process, sell or offer for sale or ship nongame wildlife, or for any common or contract carrier knowingly to transport or receive for shipment nongame wildlife." Further, regulations included in the Tennessee Wildlife Resources Commission Proclamation 00-14 (Wildlife in Need of Management) (1) prohibits the knowing destruction of habitat of designated species without authorization and (2) provides circumstances for which permits can be given to take, posses, transport, export, ship, remove, capture, or destroy a designated species. The Tennessee cave salamander is listed as threatened in Georgia under the Georgia Endangered Wildlife Act of 1973 (O.C.G.A. 27-3-130 et seq.). This law limits protection of listed species to individuals found on State public lands (excluding Georgia Department of Transportation lands). Tennessee cave salamanders on private lands are not protected under Georgia law. The Tennessee cave salamander is designated as a Priority 2 species in Alabama. Although it does not have an endangered species law, the State of Alabama protects the Tennessee cave salamander as a nongame species with no allowable take except by special permit (ADCNR, Nongame Species Regulation 220-2-.92).

Tennessee cave salamanders also are afforded some protection through the Tennessee Cave Protection Act (Tennessee Code § 11-5-108), Alabama Cave Protection Act, Georgia Cave Protection Act, Georgia Erosion and Sedimentation Act, Tennessee Water Quality Control Act of 1977, other State laws and regulations regarding natural resources, the Federal Cave Resources Protection Act of 1988, U.S. National Park Service Act of 1916, and Clean Water Act. These regulations provide for protection of cave habitats where Tennessee cave salamander occurs through requirements to reduce direct impacts to caves from human use, to reduce impacts from incompatible land use of the area surrounding the caves on Federal lands, and to reduce impacts to surface waters that flow into Tennessee cave salamander sites

In Tennessee, streams supporting federally threatened or endangered species receive additional protection under Tennessee's water quality standards. State-level regulation of water quality occurs through the Tennessee Department of Environment and Conservation (TDEC), whereby laws such as Tennessee's Water Quality Control Act 0f 1977 (T.C.A. 69–3–101) are enforced. Pursuant to Chapter 0400-40-03-.06 (General Water Quality Criteria-Antidegradation Statement), Exceptional Tennessee Waters include those with State or Federally listed species or designated critical habitat. Exception Tennessee Waters receive additional protection from new or increased discharges or withdrawals, with some exceptions. For caves with surface hydrology connections or input, these regulations offer some water quality protections. TDEC personnel also monitor water quality in surface waters throughout the state, including watersheds within the Tennessee cave salamander's range.

The Tennessee cave salamander was identified as a Species of Greatest Conservation Need (SGCN) in the Tennessee (Tennessee Wildlife Resources Agency 2015), Alabama (Alabama Department of Conservation and Natural Resources 2015, p. 14), and Georgia (Georgia Department ofNatural Resources 2015, p. 73) State Wildlife Action Plans (SWAPs). Caves and cave organisms were apriority in the revised 2015 Tennessee SWAP. The Tennessee cave salamander was identified as a Tier 1 species, which are those defined as "wildlife" under Tennessee Code Annotated 70– 8–101 (i.e., amphibians, birds, fish, mammals, reptiles, crustaceans, and mollusks). Subterranean habitats were classified and mapped in support of the 2015 Tennessee SWAP (Wisby and Palmer 2015, pp. 12–13). Caves were included as key habitats in the 2015 Alabama SWAP. As a conservation action, it was recommended that populations of the Tennessee cave salamander be monitored every three to five years. Caves were included as priority habitats in the 2015 Georgia SWAP.

3.7.2 Federal Protections

The Tennessee cave salamander receives incidental protection under the Endangered Species Act of 1973 (Act), as amended (16 U.S.C. 1531 et seq.) where the species co-occurs with the federally listed gray bat (*Myotis grisescens*) or the Alabama cave shrimp (*Palaemonias alabamae*). The range of the Tennessee cave salamander overlaps with the ranges of 66 listed species and portions of 6 designated critical habitats, although the Tennessee cave salamander co-occurs with one other listed species, the Alabama cave shrimp. Within the Tennessee cave salamander range, only three sites in the Lower Tennessee watershed are shared with the Alabama cave shrimp. Section 7 of the Act requires Federal agencies to consult with the Service on any action that may affect a listed species or any action that may destroy or adversely modify critical habitat. Section 9 of the Act also provides protection against "take" of the species ("take" means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or attempt to engage in any such conduct).

The Clean Water Act of 1972 (33 U.S.C. §1251) provides some protections to the habitat where Tennessee cave salamander occurs through contributions of surface waters to cave hydrology. Section 404 of the Clean Water Act requires a Department of the Army permit to discharge dredge or fill material in "waters of the United States" including jurisdictional wetlands and areas below the ordinary high-water mark in streams and rivers. Applicants for a section 404 permit must show that steps have been taken to avoid and minimize impacts to wetlands, streams, and other aquatic resources, and that compensation will be provided for all remaining unavoidable impacts.

3.7.3 Protected Lands

Approximately 33 percent of caves with Tennessee cave salamander occurrences are owned and/or managed by State or Federal agencies or cave conservancies (figure 3.1, table 3.1). Four of the seven sites with the greatest current abundance occur on protected lands (Cave Cove Cave, Custard Hollow Cave, Sinking Cove Cave, and Tony Sinks Cave). Some sites, including Cave Cove, Custard Hollow, and Sinking Cove caves are privately owned but managed by the Southeastern Cave Conservancy, Inc. On these sites, land management actions on lands surrounding the cave are not restricted, although access to caves is controlled. Rangewide, access to many of the sites on protected lands is limited to authorized individuals. Other sites have been gated to protect sensitive biological, archaeological, or cultural resources. Gating and fencing to prohibit unauthorized access can reduce possible impacts associated with high levels of human visitation, including trampling, vandalism, and other disturbance. However, inappropriate gate/fence design can negatively impact behavior and cave use by important trogloxene species (species that sporadically live in underground habitats, such as bats) that transfer important energy and nutrients from the surface into subterranean habitats. In general, we assume occurrences on State, Federal, or conservation agency lands are somewhat buffered from the effects of urbanization and development and that those lands experience management that is not detrimental to the Tennessee cave salamander.

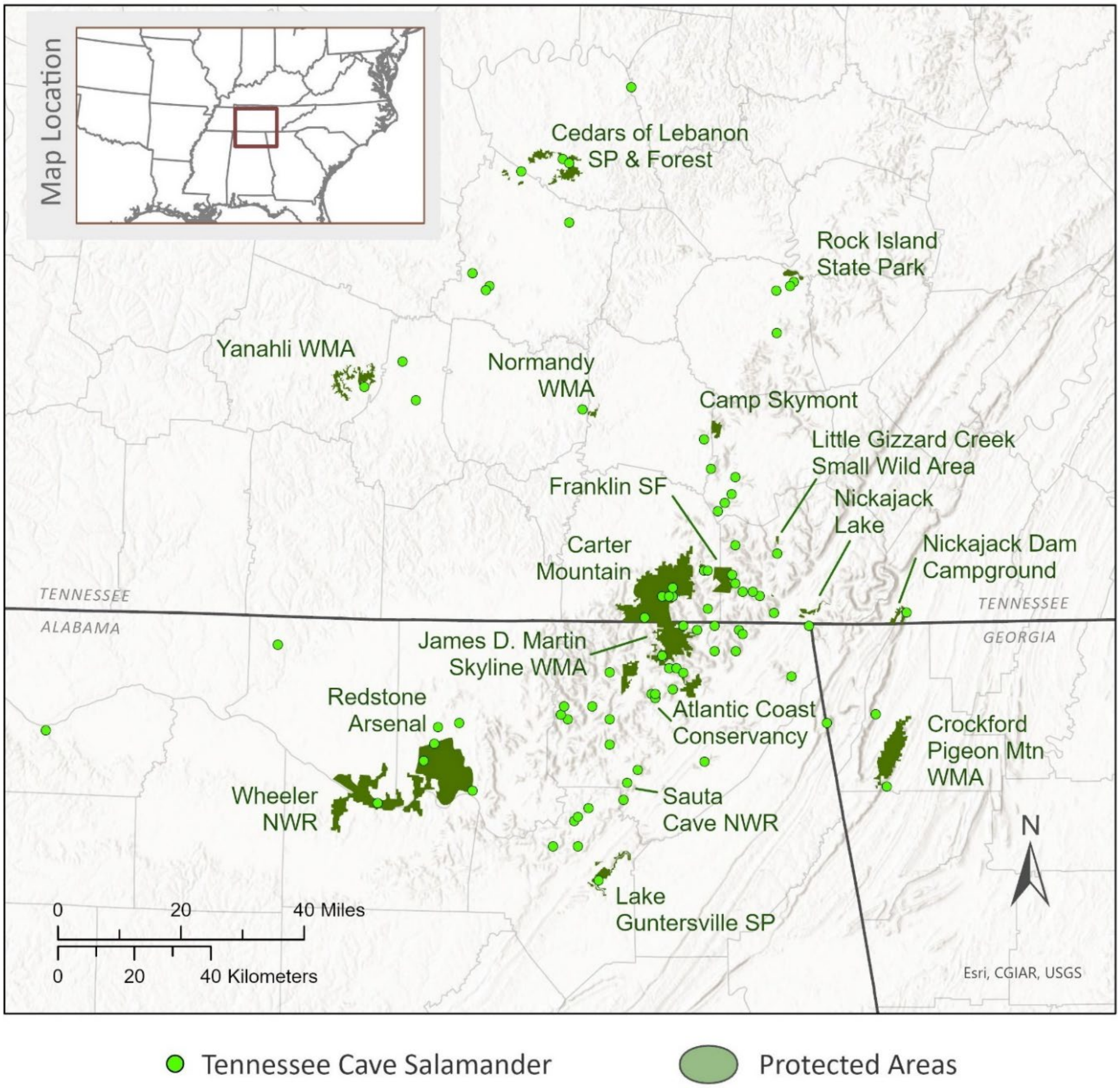


Figure 3.1. Tennessee cave salamander known occurrences and protected areas in the range of the species including Federally-owned and State-owned lands. Sites protected by non-governmental organizations including cave conservancies are not shown but are listed in table 3.1.

Table 3.1. Tennessee cave salamander sites within protected lands.

Analysis Unit	Ownership/ Management	Site Name	Protected Lands
Crow-Battle Creek	National Park Service	Russell Cave	Russell Cave National Monument
Crow-Battle Creek	Southeastern Cave Conservancy, Inc.	Tumbling Rock Cave	John T Dolberry Tumbling Rock Cave Preserve
Crow-Battle Creek	Southeastern Cave Conservancy, Inc.	Valhalla Cave	Valhalla Cave Preserve
Crow-Battle Creek	State of Alabama	Tate Cave	James D. Martin - Skyline Wildlife Management Area
Crow-Battle Creek	State of Tennessee	Buggytop Cave	Mr. & Mrs. Harry Lee Carter State Natural Area
Crow-Battle Creek	State of Tennessee	Tom Pack Cave	Mr. & Mrs. Harry Lee Carter State Natural Area
Crow-Battle Creek	Southeastern Cave Conservancy, Inc.	Cave Cove Cave	Sinking Cove Cave Preserve
Crow-Battle Creek	Southeastern Cave Conservancy, Inc.	Custard Hollow Cave	Sinking Cove Cave Preserve
Crow-Battle Creek	Southeastern Cave Conservancy, Inc.	Sinking Cove Cave	Sinking Cove Cave Preserve
Crow-Battle Creek	Southeastern Cave Conservancy, Inc.	Waterfall Cave	Sinking Cove Cave Preserve
Crow-Battle Creek	Southeastern Cave Conservancy, Inc.	Wolf Cove Cave	Sinking Cove Cave Preserve
Crow-Battle Creek	Southeastern Cave Conservancy, Inc.	Gourdneck Cave	Gourdneck Cave Preserve
Crow-Battle Creek	Southeastern Cave Conservancy, Inc.	South Pittsburg Pit	South Pittsburg Pit Preserve
Upper Duck River	State of Tennessee	Pompie Cave	Yanahli Wildlife Management Area
Nashville Basin	Southeastern Cave Conservancy, Inc.	Snail Shell Cave	Snail Shell Cave Preserve
Nashville Basin	State of Tennessee	Jackson Cave	Cedars of Lebanon State Park

Nashville Basin	State of Tennessee	Hurricane Cave	Cedars of Lebanon State Park
Nashville Basin	Corps of Engineers	Pattons Cave	Percy Priest Reservoir Rutherford Co TN
Lookout-Sand Mountain	Southeastern Cave Conservancy	Fricks Cave	Fricks Cave Preserve
Lookout-Sand Mountain	National Park Service	Lookout Mountain Cave	Chickamauga and Chattanooga National Military Park
Sauty Creek	Service	Sauta Cave	Sauta Cave National Wildlife Refuge
Sauty Creek	Southeastern Cave Conservancy	Limrock Blowing Cave	Limrock Blowing Cave Preserve
Paint Rock River	The Nature Conservancy	Tony Sinks Cave	Sharp-Bingham Mountain Preserve
Paint Rock River	The Nature Conservancy	McFarland Cave	Sharp-Bingham Mountain Preserve
Lower Tennessee River	National Speleological Society	Shelta Cave	Shelta Cave Preserve
Greater Huntsville	Department of Defense	Bobcat Cave	U.S. Army Redstone Arsenal
Greater Huntsville	Department of Defense	Matthews Cave	U.S. Army Redstone Arsenal
Greater Huntsville	Service	Rockhouse Cave	Wheeler National Wildlife Refuge
Greater Huntsville	North Alabama Land Trust	Muddy Cave	Muddy Cave Preserve

3.8 Summary of Influences on Viability

Effects to groundwater quality and quantity due to land use (including urbanization and agriculture) are key drivers of the viability of the Tennessee cave salamander. Sediment and other pollutants act as significant stressors locally at some sites and may affect individuals or populations. Human visitation of caves affects the species at some sites, although this threat is not rangewide. Disease, predation, hybridization, and competition may affect individuals at some sites, but do not influence viability at a rangewide scale. The best available information does not indicate that the influence of climate change alone on the current species condition is significant; but the effects of climate change may act synergistically with other threats and exacerbate the effects of urbanization, drought, and water withdrawal, particularly in the future. Conservation tools, including regulatory mechanisms, have been implemented to benefit the species, and additional opportunities to implement habitat management efforts that may result in improved species' viability are present rangewide.

CHAPTER 4 –CURRENT CONDITIONS

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

4.1 Population Delineation

Historically, individual caves with Tennessee cave salamander occurrences have been treated as distinct populations. While many sites may effectively operate as distinct populations, others may represent subpopulations within a larger metapopulation through interconnected caves or subterranean hydrological systems. The full spatial extent and connectivity of most Tennessee cave salamander sites is unknown. The analysis units (AUs) as described may not be an accurate reflection of all populations on the landscape or their boundaries; however, we use the best available information regarding hydrological, geological, and biotic characteristics as a measure of connectivity in delineation of AUs.

For the purposes of the SSA analyses, we determined analysis units within the Tennessee cave salamander range at a scale useful for assessing the species' condition. We recognize the units may not represent distinct biological populations; however, we have determined unit boundaries using the best available information. We began by masking the sensitive cave locations within a random, scattered distribution up to 0.5 mile (mi). We then examined abiotic and biotic criteria to determine AUs for the Tennessee cave salamander. The abiotic criteria of the sites and surrounding area that we examined to determine the AUs include proximity of sites to each other, karst geology (Weary and Doctor 2014, p. 5), HUC 8 watersheds, site-specific hydrology (surface versus subterranean input), barriers to dispersal (e.g., large rivers), etc. The biotic criteria we considered in determining AUs included morphological and genetic information for Tennessee cave salamanders, where available. The majority of Tennessee cave salamander sites do not have genetic information to characterize populations or metapopulations. Several caves with Tennessee cave salamander occurrences have relevant dye trace studies to delineate surrounding watersheds. Where this information was available, we included it in the AU delineation. Based on these criteria, we delineated 12 AUs in the current Tennessee cave salamander range. The AUs range in size from 4,797 acres (ac) (1941 hectares (ha)) to 216,626 ac (87,665 ha) and encompass 1 to 35 sites with occurrence records (figure 4.1).

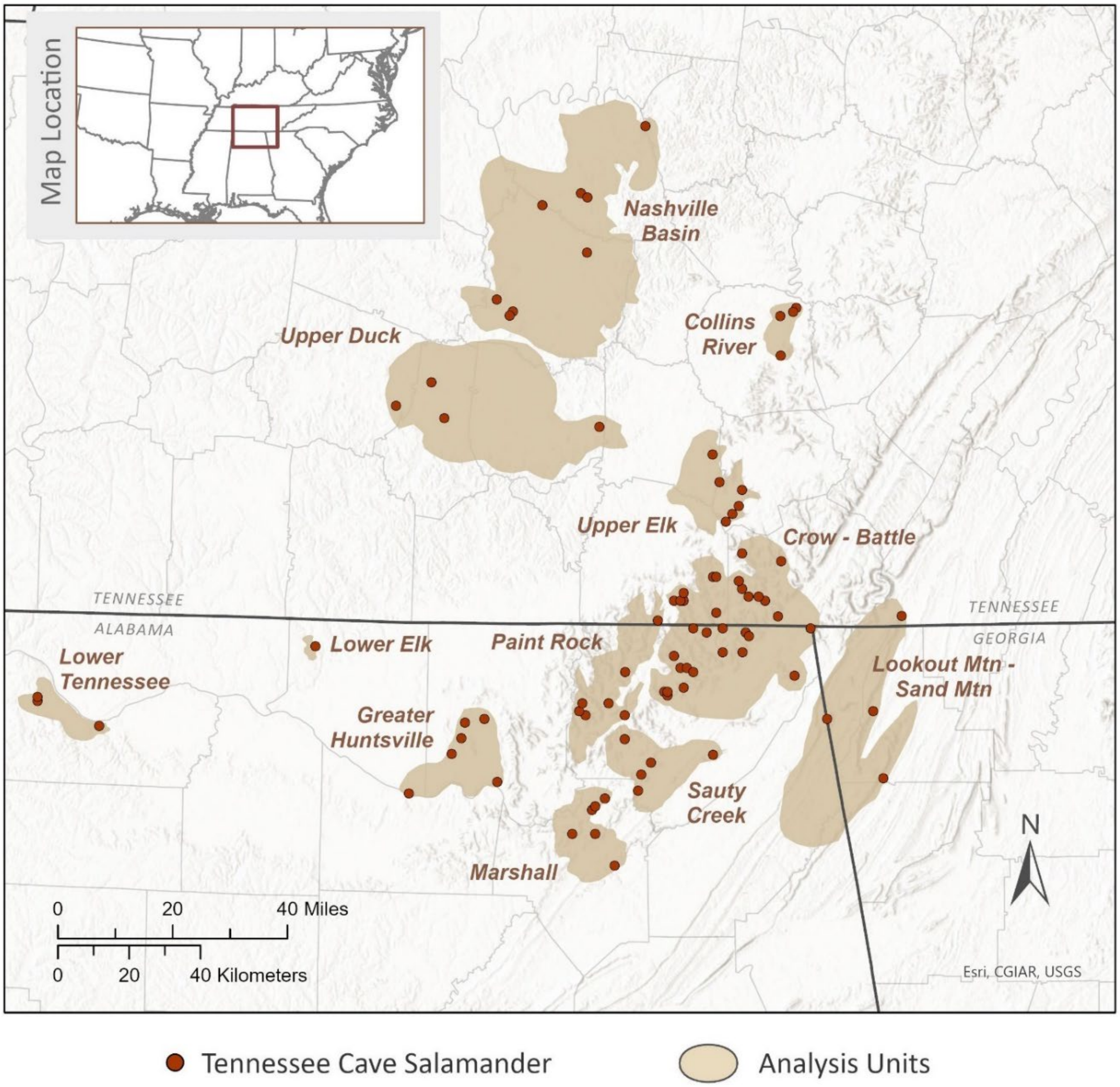


Figure 4.1. Tennessee cave salamander analysis units as determined for Species Status Assessment. analyses.

Table 4.1. Tennessee cave salamander analysis units and the EPA level IV and level III ecoregions where they occur (figures 2.6, 2.7). Analysis units may span more than one level IV ecoregion. In those cases, the ecoregion with the majority of sites is in **bold** text.

Analysis Unit	Level IV Ecoregion	Level III Ecoregion
Crow-Battle Creek	Cumberland Plateau	Southwestern Appalachians
Upper Elk River	Cumberland Plateau	Southwestern Appalachians
Upper Duck River	**Inner Nashville Basin**, Outer Nashville Basin	Interior Plateau
Nashville Basin	Inner Nashville Basin	Interior Plateau
Collins River	**Eastern Highland Rim**, Cumberland Plateau	Interior Plateau
Lookout-Sand Mountain	Cumberland Plateau	Southwestern Appalachians
Sauty Creek	Cumberland Plateau	Southwestern Appalachians
Marshall County	Cumberland Plateau	Southwestern Appalachians
Paint Rock River	Cumberland Plateau	Southwestern Appalachians
Lower Elk River	Outer Nashville Basin	Interior Plateau
Lower Tennessee River	Eastern Highland Rim	Interior Plateau
Greater Huntsville	Eastern Highland Rim	Interior Plateau

4.2 Methods for Estimating Current Condition

Using the SSA framework, we used resiliency, representation, and redundancy (the 3Rs) to qualitatively assess the viability of the Tennessee cave salamander. We described species-specific viability as the ability of the species to sustain populations in occupied caves relative to habitat needs such as good water quality in underground pools or streams, detrital input to support invertebrate prey base, and species' demographics. For this assessment, we described the current condition of the species and predicted a range of plausible future scenarios and conditions (Chapter 5) using the 3Rs.

4.2.1 Population Resiliency

Resilient populations of Tennessee cave salamander should be robust in order to withstand normal stochastic events or disturbances. However, influences contributing to habitat degradation described in *Chapter 3 Factors Influencing Viability* have the potential to exacerbate the impacts of stochastic events and affect population resiliency. Based on these influences, we assessed the resilience of each Tennessee cave salamander AU by synthesizing the best available information about habitat condition and population demographics from survey data as well as studies pertaining to Tennessee cave salamander population density, site occupancy, and population genetics (Niemiller 2006, entire; Niemiller et al. 2008, entire, Niemiller et al. 2009, entire, Niemiller et al. 2016, p. 37; Miller and Niemiller 2008, entire ; Huntsman et al. 2011, entire; Miller and Niemiller 2012, p. 884.3).

Based on Tennessee cave salamander individual and population needs (e.g., availability of cobble/boulder substrate, suitable water quality and quantity, adequate food sources, and appropriate population size and connectivity to support reproduction and recruitment within an analysis unit), we developed an approach using key habitat and demographic factors to assess population resiliency. We assessed two habitat condition parameters (water quality and detrital input), and two demographic condition parameters (relative abundance and reproduction/recruitment) (table 4.3). We also assessed site-specific threats to the Tennessee cave salamander qualitatively as described in the analysis unit assessments. The individual factors that were assessed, the spatial scale at which the factors were assessed, and the scoring process for each are described below. Based on the Tennessee cave salamander lifespan and stable habitat condition of most caves, we determined that the time period from 2000 to the present represents the current condition of the species. Parameters with a temporal component (survey observations of abundance and reproduction or recruitment) were assessed using information from 2000 to 2022.

We categorized the current resiliency for each AU from High to Very Low, based on the total number of points scored out of 16 possible points (table 4.2). We calculated the total number of points possible by summing the scores of two habitat parameters (8 points) and two demographic parameters (8 points). For each parameter, we assigned a score from 1 to 4 (4 = High, 3 = Moderate, 2 = Low, 1 = Very Low) - based on parameter condition categories that we developed in coordination with species experts (table 4.3). The following sections describe our reasoning for each parameter, the parameter condition categories, and the methodology we used to derive an overall score for each parameter.

Table 4.2**.** Scale used to determine overall future resiliency condition class for Tennessee cave salamander analysis units (AUs). Overall scores were calculated by summing the four parameter scores for each AU.

Overall Resiliency Condition Class	Very Low	Low	Moderate	High
Overall Resiliency Score	1–3.99	4–7.99	8–11.99	12–16

Resiliency: Demographic Factors

To evaluate population elements, we use data from ongoing survey efforts for the Tennessee cave salamander and other occurrence records from the past 70+ years (e.g., Caldwell and Copeland 1992, pp. 15–16; Hollingsworth et al. 1997, entire; Godwin 2000, p. 4–7; Miller and Niemiller 2008, pp. 17–20). Cave surveys continue to be conducted at sites where Niemiller and colleagues observed the species previously. Also, surveys are being conducted at other sites of potential occupation. Survey efforts are standardized and employ methods that specifically target salamanders across all size classes.

Species Abundance

We categorize relative salamander abundance at each site based on quantitative visual survey data from 2000 to 2022. We note the uncertainty of these observations based on accessibility of the site to humans and the extent of unknown and inaccessible habitat within the cave ecosystem. The extent of habitat for the Tennessee cave salamander and the occupation of these areas is uncertain.

Given that the extent of habitat is unknown and may not be accessible to surveyors, we do not have a thorough understanding of the species' presence or abundance. Additional uncertainties about Tennessee cave salamander life history and the limited survey data available also affect our certainty in abundance estimates. Nevertheless, without better or more accurate information available, we rely on observed numbers of Tennessee cave salamander to represent presence of the species at the site.

Each site was scored based on the maximum number of individuals observed in surveys since 2000: 12 or more salamanders (score of 4), 5 to 11 salamanders (score of 3), and 1 to 4 salamanders (score of 2). The category of very low (score of 1) was not used, effectively weighting this measure slightly. We then averaged this score over the analysis unit. In addition, we added a point if more than 10 percent of sites in an AU had more than 12 salamanders in surveys since 2000 (current). Abundance of a cave-dwelling species is dependent on observation, and access to the cave habitat varies among sites. Larger caves often have larger passageways and greater opportunities for observation, while smaller caves or those with narrower openings may have limited potential for observation of Tennessee cave salamanders. Additionally, the habitat may extend in a more three-dimensional manner than for non-subterranean species. Cave surveys occur at various frequencies, depending on the cave – some not having been visited since the species was first observed at a site, some being surveyed annually, and many being surveyed on a frequency between these extremes.

Census data have been used in the past to estimate relative abundance and potential population trends (Caldwell and Copeland 1992, entire; Miller and Niemiller 2008, entire). Because of the difficulty in capturing salamanders to conduct mark-recapture studies at most sites, visual census data represent the only measure available to estimate population trends over time. However, we recognize that there is inherent uncertainty in correlating salamander abundance based on visual census surveys and actual population size (i.e., Miller and Niemiller 2008, pp. 10–11). In our assessment of species abundance, we relied on the maximum number of individuals observed during a survey since 2000. However, the Tennessee cave salamander has been observed in 2020 and 2022, respectively, at two sites with historical observations (e.g., Nickajack Cave (1967) and Shelta Cave (1968). Therefore, we determined that populations at sites with historical occurrences are not extirpated if suitable habitat is present at the site.

Most sites have low numbers of individuals; 61 percent of sites have observations of 1 or 2 individuals during a survey. Four AUs have more than 10 percent of sites with greater than 12 salamanders observed during a single survey. These include the Crow-Battle Creek, Upper Elk River, Sauty Creek, and Paint Rock River AUs. These sites of higher abundance constitute the stronghold area of the species.

Reproduction & Recruitment

We categorize reproduction and recruitment by positive observations of small juveniles or gravid females at each site. No eggs have been found on surveys but would also provide evidence of a reproducing population. We scored this parameter as the percentage of sites within an AU that show evidence of reproduction in surveys from 2000 to 2022. Uncertainty around the values for reproduction and recruitment stem from the lack of available information. Consequently, reproduction and recruitment may be occurring at a greater rate in an AU than we have estimated (i.e., it is possible that reproduction or recruitment occurred but was not documented).

Table 4.3**.** Condition categories for demographic and habitat parameters used to assess Tennessee cave salamander current resiliency. All parameters are assessed at the site level and then averaged at the analysis unit level.

Condition Category				
Factor	High (4)	Moderate (3)	Low (2)	Very Low (1)
Species Abundance	12 or more salamanders at the site (2000–2022 surveys)	5 to 11 salamanders at the site (2000–2022 surveys)	1 to 4 salamanders at the site (2000–2022 surveys)	not used
Reproduction & Recruitment	Clear evidence of reproduction (presence juveniles, gravid female) at many sites (≥75 percent) 2000–2022	Evidence of reproduction at some sites (≥50 percent) 2000–2022	Evidence of reproduction at few sites (≥25 percent) 2000–2022	Little to no evidence of reproduction at any sites 2000–2022
Water Quality (within 4-km buffer)	Minimal or no known water quality or related surface land cover issues at sites. Less than or equal to 15 percent ag	Some water quality or related surface land cover issues in AU (15 to 30 percent ag)	Moderate water quality or related surface land cover issues in AU (30 to 40 percent ag)	Severe water quality or related surface land cover issues in AU (greater than 40 percent ag)
Detrital Input (within 4-km buffer)	High organic/detrital input supporting cave ecosystem greater than or equal to 75 percent vegetated	Moderate organic/detrital input supporting cave ecosystem; 50 to 75 percent vegetated	Low organic/detrital input supporting cave ecosystem; 25 to 50 percent vegetated	Minimal organic/detrital input supporting cave ecosystem less than 25 percent vegetated

<u>Resiliency: Habitat Parameters</u>

The appropriate spatial extent in which to assess threats to population resiliency represents another source of uncertainty. Based on hydrology, geology, and overburden (as described in **Analysis Unit Delineation**), we determined that habitat conditions in caves with Tennessee cave salamander occurrences are primarily influenced by factors within an area smaller than that of the analysis unit. For each of the two habitat parameters, we assessed the condition of that parameter within a 2.4 mi-radius (4-kilometer (km)) buffer. Where buffers in close proximity overlap, we used the values obtained within each discrete buffer but recognize that some small areas of habitat in the overlap will be assessed more than once.

Water Quality

Impacts to surface waters in karst areas also impact groundwater quality. For example, cave streams in an Appalachian karst landscape show elevated nitrate, pesticide, and fecal bacteria levels in agricultural areas, including dairy and cow-calf operations (Boyer and Pasquarell 1995, p. 729; Boyer and Pasquarell 1999, p. 292). We assessed water quality within the buffer areas around

Tennessee cave salamander occurrences as a qualitative estimate of water quality within each AU. Suitable water quality is more likely to occur in AUs that have natural or semi-natural landscapes and minimal land use modifications (Coxon 2011, p. 104). AUs in watersheds that are heavily degraded (e.g., urban areas or areas with strong agricultural influences) are more likely to have current or future water quality impairments that would negatively affect groundwater ecosystems and Tennessee cave salamanders. Within AUs, urbanization and development make up a lower percentage of the land use area compared to the percentage in agriculture. Although threats associated with urbanization and development described above in *Urbanization and Development* (e.g., pollutants, sedimentation, and increased flashiness of streams) may affect the species, we determined that the effects of agriculture and associated practices drive the species' condition to a greater extent than those associated with urbanization within the range of the species. Within the Tennessee cave salamander range in Tennessee, Alabama, and Georgia, the threats related to agriculture (including groundwater pollution, runoff of sediment and other pollutants, and groundwater withdrawal) affect the species to a greater extent than urbanization. The Greater Huntsville AU may be an exception with the influence of urbanization outweighing that of agriculture, and we note that in our analysis and results.

To assess potential stressors due to land use modification, we examined land cover classes from the 2019 National Land Cover Database (DeWitz and USGS 2021, unpaginated). We categorized the percentage of agriculture land use in the 4-km buffer around occurrences in each analysis unit and summed these buffer percentages to arrive at the percentage of land area in agriculture for each AU (figure 4.2). We then assigned a score to each resulting percentage (table 4.2). Although the land use outside the 4-km site buffer but within the analysis unit may have some effect on the Tennessee cave salamander, we do not expect it to differ substantially in composition from the areas within the buffers.

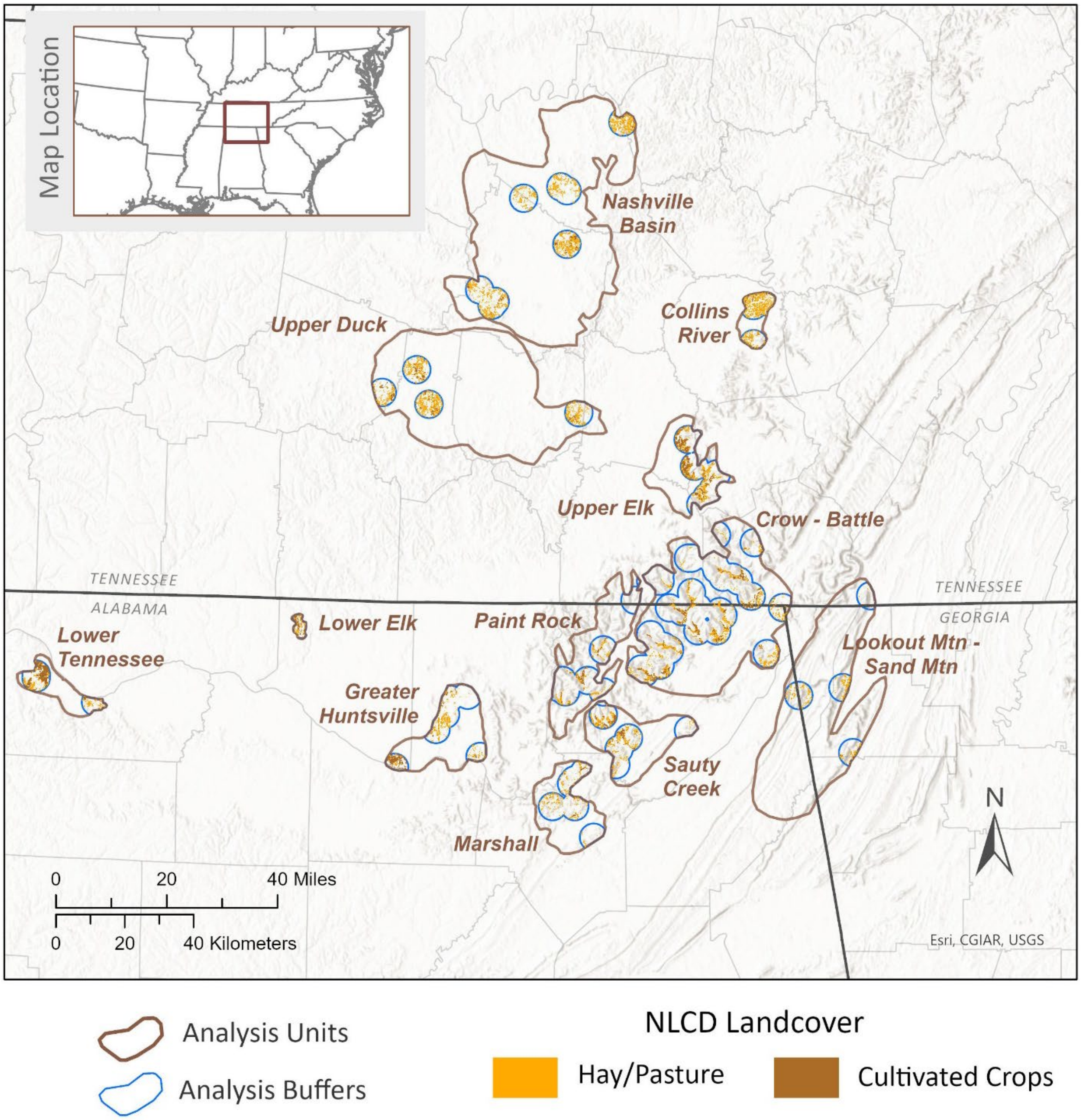


Figure 4.2. Tennessee cave salamander sites with a 4-km buffer within analysis units and 2019 National Land Cover Database hay/pasture and cultivated crops landcover classes representing the portion of the buffered area in agriculture.

Detrital Input

Detrital input forms the basis of the food chain in cave ecosystems where the Tennessee cave salamander occurs. Higher abundance of Tennessee cave salamander is correlated with greater levels of detrital input (Miller and Niemiller 2008, p. 12; Huntsman et al. 2011, entire). The organic detrital load from allochthonous sources (input from outside the cave ecosystem) within each AU is a driver of Tennessee cave salamander resiliency through the support of the invertebrate prey base. To evaluate the condition of this species' need, we assess the detrital load in cave sites by evaluating the percentage of forest cover within a 4-km buffer around sites with Tennessee cave salamander occurrence (figure 4.3). A suitable detrital load is more likely to occur within AUs where the surface land cover within the recharge basins of cave systems contains diverse natural forested communities. Areas with lower percentages of native forest vegetation are expected to experience lower levels of detrital input and support lower abundance or density of Tennessee cave salamander due to limited food supply. The best available information indicates that the quantity of invertebrates as a food source is not a limiting factor for Tennessee cave salamander populations at this time. However, we determined that increased detrital input benefits Tennessee cave salamanders through increased food sources (invertebrates) (Huntsman et al. 2011, entire).

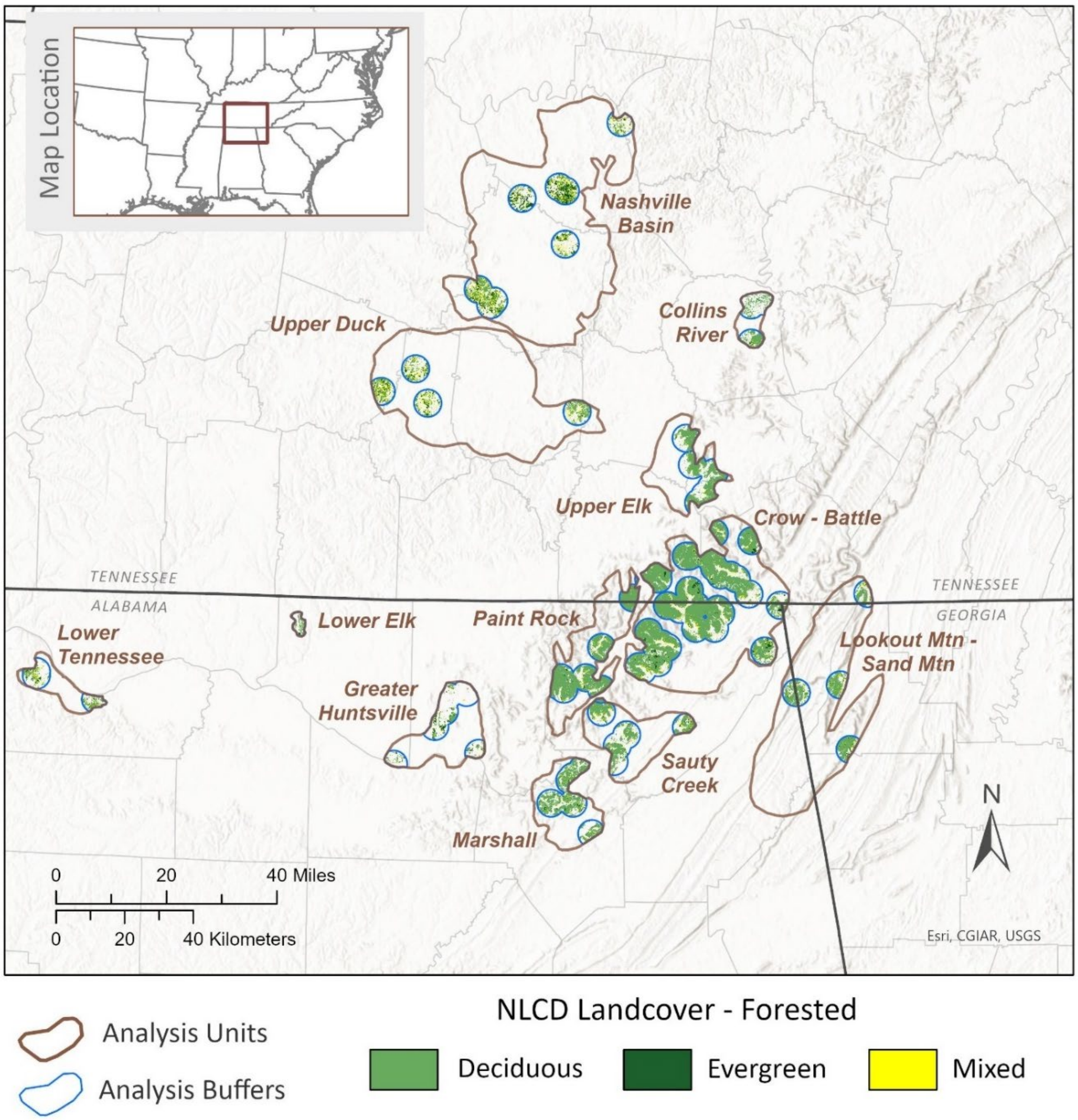


Figure 4.3. Tennessee cave salamander sites with a 4-km buffer within analysis units and 2019 National Land Cover Database deciduous forest, evergreen forest, and mixed forest landcover classes representing the forested portion of the buffered area.

4.3 Current Resiliency

The majority of Tennessee cave salamander analysis units currently exhibit moderate resiliency, with 2 units exhibiting high resiliency, 8 exhibiting moderate resiliency, and 2 units exhibiting low resiliency (figure 4.4, table 4.4). The AUs in low resiliency are the Lower Elk and Lower Tennessee AUs in the westernmost portion of the species' range. Conditions and threats driving the low resiliency levels in these two units include low observed abundance, no or low reproduction, low levels of forest cover, and urbanization (Greater Huntsville).

Within AUs, some sites have high observed abundance and evidence of reproduction in surveys from 2000 to 2022. These high quality or high condition sites may not be reflected in the overall AU resiliency, but they are important to species' viability. This parameter is intended to give additional specificity to the species condition that may be obscured when averaging demographic and habitat parameters over an AU. The proportion and number of sites with high observed abundance and evidence of reproduction/recruitment follows: eight AUs have no sites with 12 or more salamanders observed since 2000 and evidence of reproduction or recruitment since 2000. Four AUs have "high quality" sites including the Crow-Battle Creek AU (5 sites, 14%), Upper Elk River AU (3 sites, 42%), Sauty Creek AU (1 site, 20%), and Paint Rock River AU (1 site, 16%). The Crow-Battle, Upper Elk, and Paint Rock AUs reflect the stronghold and core of the species range.

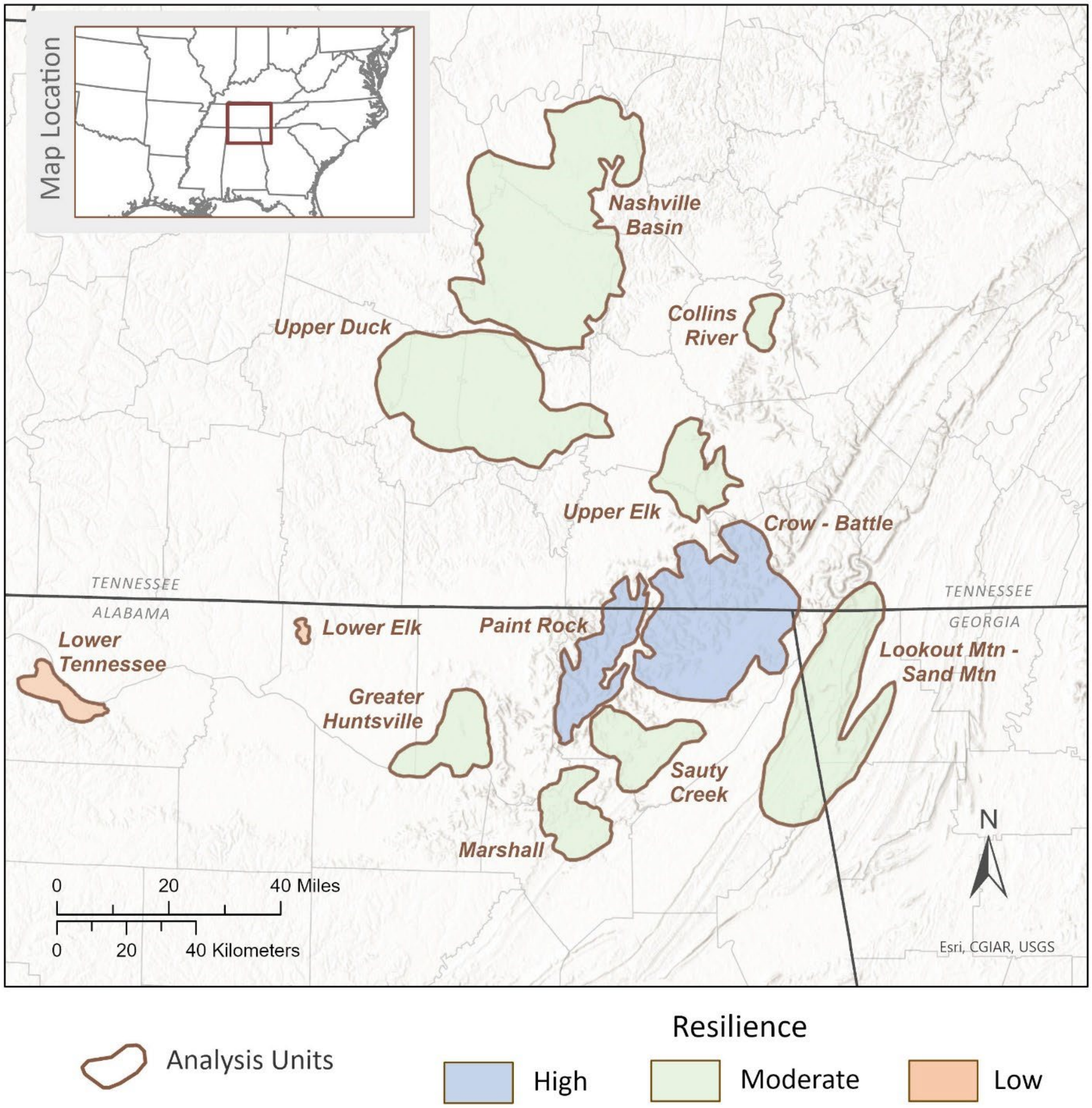


Figure 4.4. Current resiliency of the 12 Tennessee cave salamander analysis units (AUs). Two AUs exhibit high resiliency, eight exhibit moderate resiliency, and two exhibit low resiliency. Site-specific threats are described in section 4.3.1 Site-Specific Threats in Analysis Units.

Table 4.4. Current resiliency levels for Tennessee cave salamander analysis units as determined through analysis of population and habitat parameters.

Analysis Unit	Species Abundance Category	Reproduction Score	Water Quality Score	Detrital Input Score	Resiliency Category
Crow-Battle Creek	Moderate	Low	High	High	High
Upper Elk River	Moderate	Moderate	Low	Moderate	Moderate
Upper Duck River	Low	Moderate	Low	Low	Moderate
Nashville Basin	Low	Low	Low	Moderate	Moderate
Collins River	Low	High	Very Low	Low	Moderate
Lookout-Sand Mountain	Low	Very Low	Moderate	Moderate	Moderate
Sauty Creek	Moderate	Moderate	Moderate	Moderate	Moderate
Marshall County	Low	Low	High	Moderate	Moderate
Paint Rock River	High	Low	High	High	High
Lower Elk River	Low	Very Low	Low	Low	Low
Lower Tennessee River	Low	Very Low	Very Low	Low	Low
Greater Huntsville	Low	Low	Moderate	Very Low	Moderate

4.3.1 Site-Specific Threats in Analysis Units

In order to adequately characterize current resiliency of the Tennessee cave salamander, we also assessed site-specific threats that impact the species. These influences vary in intensity, severity, and timing among sites. We describe the presence of site-specific threats noted on Tennessee cave salamander surveys and, when information is available, describe the trends or observed impacts to the species. There is uncertainty around the extent of impacts to Tennessee cave salamander from these site-specific threats; the presence of a site-specific threat may not have had an impact on the species' current resiliency cases, and the species' long-term response to some threats is unclear. We report resiliency at the analysis unit level. However, we recognize differences between sites within the AU, with some sites supporting greater species' abundance or excellent habitat conditions and others with low or declining numbers of Tennessee cave salamander or lower quality habitat. We note sites with greater abundance and evidence of reproduction/recruitment and those with site-specific threats expected to affect the species in the AU descriptions below. We address the temporal nature and the lack of data regarding site-specific threats in figure 4.5. Sites with current threats information (surveys from 2000 to 2022) are categorized with threats present or absent, while sites with no information are categorized as unknown. We have current information on site-specific threats for 50 percent of sites with Tennessee cave salamander occurrence.

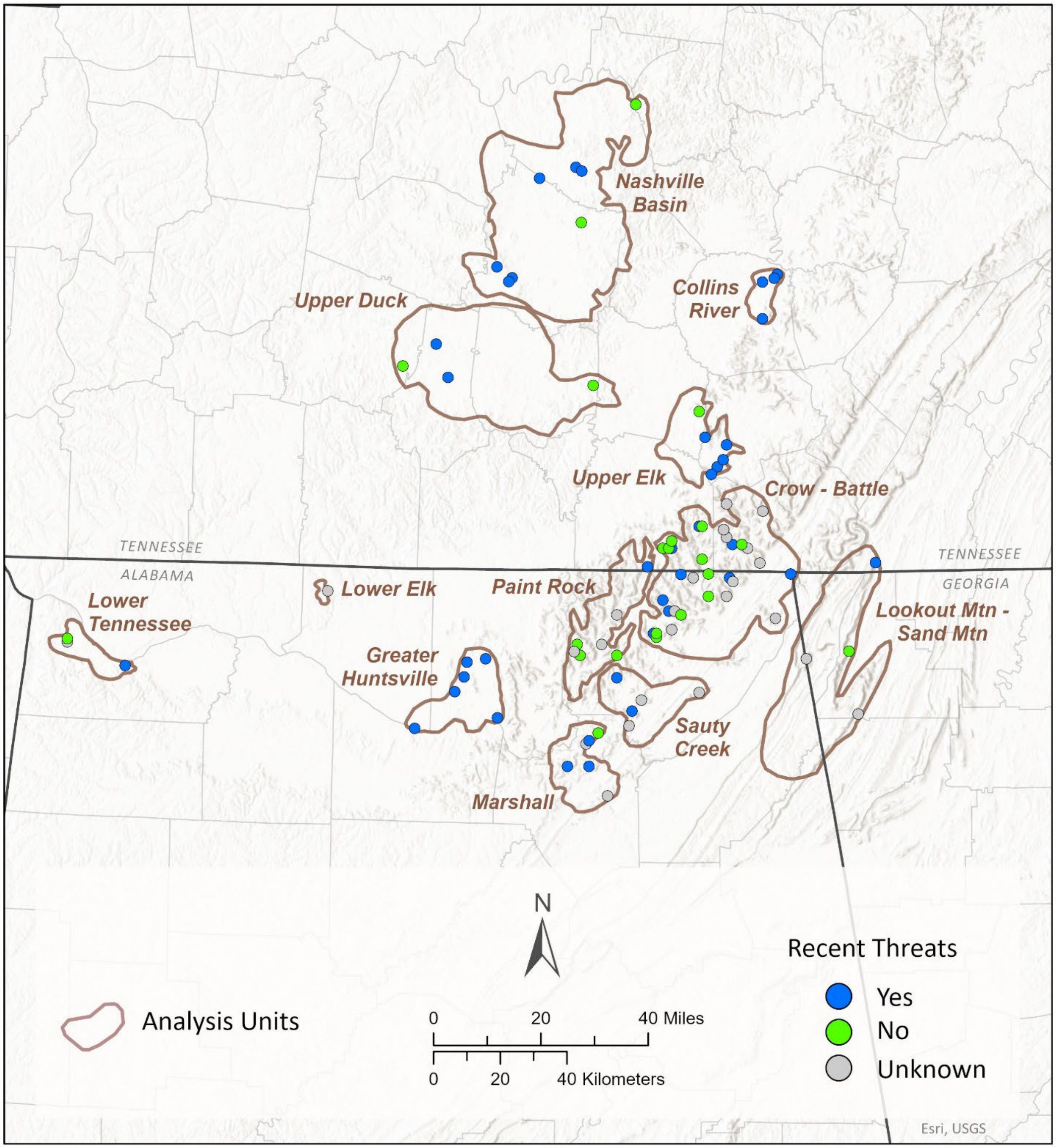


Figure 4.5. Site-specific threats noted on surveys from 2000 to 2022 are shown in Tennessee cave salamander analysis units as “Yes” when a specific threat is observed, “No” when no observed threats are present, and “Unknown” when the status of threats is not indicated on survey reports.

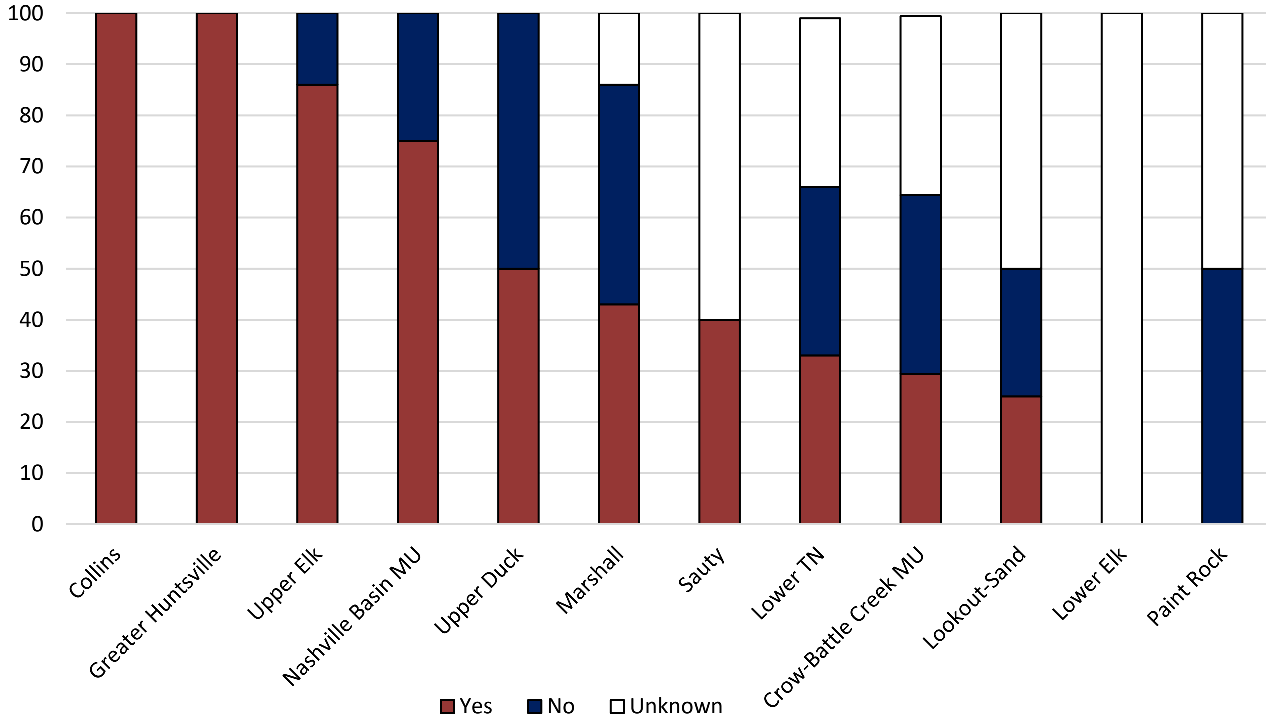


Figure 4.6. Percentage of sites in each AU with site-specific threats as noted on surveys from 2000 to 2022. Sites with at least one site-specific threat identified are represented by red bars, no site-specific threats are represented by dark blue bars, and sites with no site-specific information are identified by white (open) bars.

Crow–Battle Creek

The Crow-Battle Creek AU is the most significant Tennessee cave salamander AU with respect to number of sites and number of sites with larger abundance. This AU comprises 35 sites along the Western Escarpment of the Cumberland Plateau in southern Franklin and southern Marion counties in Tennessee and northeastern Jackson County in Alabama. Many sites in this AU occur in the Crow and Battle Creek drainages. The largest Tennessee cave salamander populations in the Crow-Battle Creek AU occur at Cave Cove, Sinking Cove, and Custard Hollow caves in Franklin County, Tennessee, and Jess Elliot and Bluff River caves in Jackson County, Alabama. Thirteen sites (37 percent of sites in the AU), including the four largest populations, occur on protected public lands or lands owned or managed by cave conservancies.

Site-specific threats occur in this AU but are not thought to impact the species substantially. A few rock quarry operations exist, but impacts are thought to be minimal at this time. Because seven caves in this AU are very popular for recreational caving, impacts to the species related to human visitation may occur. However, impacts to the species related to caving have not been documented in this AU.

Upper Elk River
The Upper Elk River AU consists of seven sites along the Western Escarpment of the Cumberland Plateau in southeastern Coffee and southwestern Grundy counties in Tennessee in the Upper Elk River watershed. Sites with high abundance include Big Mouth, Blowing Springs, and Lusk caves. However, abundance appears to be declining at Big Mouth Cave. During surveys in the 2000s, 12–34 salamanders were typically observed, while recent surveys in 2017, 2019, and 2020 yielded just five salamanders in total (Miller and Niemiller 2008, p. 18; Niemiller 2022, pers. comm.). Water levels were low during the three most recent surveys, and the substrate composition and location of pools had changed in response to significant flood events since 2010. Significant amounts of coarse woody debris (such as tree branches and logs) in substantial state of decay were noted; and the presence of methane was detected in the air, indicating that conditions may be anoxic in some pools.

Site-specific threats are present in six of the seven sites in the Upper Elk AU. Big Mouth Cave and Big Room Cave are affected by commercialization and recreational use of the caves, as well as associated groundwater pollution. The entrance of Big Mouth Cave has a developed music venue that opened in 2018. The Caverns venue hosts live music concerts and other events throughout the year and also offers guided tours into nearby Big Room Cave. Impacts on the Tennessee cave salamander in Big Mouth Cave from commercialization alone have not been quantified, as hydrological changes have affected conditions in the cave in the same time frame. The tour routes in Big Room Cave do not go into the part of the cave where Tennessee cave salamander occurs and likely have minimal impacts. Three other sites in the AU are affected by nearby quarry/mining operations.

Upper Duck River
The Upper Duck River AU is comprised of four sites in Marshall and Maury counties, Tennessee within the Inner Nashville Basin and one site in Bedford County, Tennessee in the Outer Nashville Basin in the Duck River watershed. All sites have been discovered in the past 20 years. This area has many karst features that have not yet been explored, and additional habitat suitable for the Tennessee cave salamander is likely to be present. Abundance at all sites is low, with a maximum of six salamanders observed at Pompie Cave in 2005.

Pompie Cave in Maury County is located on the Yanahli Wildlife Management Area, and all other sites within the AU occur on private lands. Entrances to cave systemsgenerally have substantial forest buffer, and human visitation is very low at these sites. The site-specific threat of groundwater pollution resulting from agricultural activities in the surrounding area has been reported as a primary concern from three sites in the Upper Duck River AU.

Nashville Basin
The Nashville Basin AU consists of eight sites within the Inner Nashville Basin of Rutherford and Wilson counties in central Tennessee. Abundance at sites is low (1–4 salamanders/site). Snail Shell Cave is the largest known cave system in the Inner Nashville Basin at over 21 kilometers (13 miles) of passage, including several miles of submerged passage in which the Tennessee cave salamander has been observed. Nanna Cave is hydrologically connected to Snail Shell Cave. Shell Caverns is a new site recently discovered in northeastern Wilson County that extends the known distribution of

the Tennessee cave salamander almost to the Cumberland River in the Nashville Basin. Other populations may exist throughout the Inner Nashville Basin.

The cities of Murfreesboro, Smyrna, Walterhill, and Lebanon occur within this AU. Documented sites occur outside their city limits, but development continues. Human population growth rate has averaged 2.62 percent and 2.64 percent since 2010 for Rutherford and Wilson counties, respectively. Four sites in the Nashville Basin AU occur on protected lands. The main entrance of Snail Shell Cave is owned by the Southeastern Cave Conservancy, Inc. Jackson and Hurricane Creek caves occur at Cedars of Lebanon State Park, and Pattons Cave occurs on U.S. Army Corps of Engineers land near Percy Priest Lake. All other caves are privately owned. Significant site-specific threats to Tennessee cave salamander in this AU include urbanization (affecting two sites) and groundwater pollution associated with agriculture (two sites). In addition, recreational caving affects Snail Shell Cave and potentially Jackson Cave, although direct impacts to the Tennessee cave salamander are unknown. Septic tank effluent has been detected at Pattons Cave. Groundwater pollution associated with agriculture and urbanization is the mostsignificant threat to the Tennessee cave salamander in this AU.

Collins River

The Collins River AU consists of five sites along the Collins River in Warren County, Tennessee. All but one of the sites have been discovered in the past 20 years. Abundance at these sites is generally low, with amaximum of five individuals observed at Jaco Spring Cave in 2005. All sites occur on private lands. Several plant nurseries are present within the AU; and groundwater pollution associated with horticultural fertilizer, herbicides, fungicides, and pesticides is a substantial site-specific threat to all 5 sites in the AU. In addition, surface water use and groundwater withdrawal occur in this AU to support the horticulture industry.

Lookout–Sand Mountain

The Lookout-Sand Mountain AU is comprised of four disjunct sites at the base on Lookout, Sand, and Pigeon mountains in northeastern Jackson County in Alabama, Walker County in Georgia, and southern Hamilton County in Tennessee. Additional habitat suitable for Tennessee cave salamanders likely occurs at other sites within this AU, although surveys have not been conducted in all suitable habitat to determine Tennessee cave salamander occurrence. Abundance is low at all sites, with a maximum of five salamanders observed at Fricks Cave in 2000. Connectivity among sites likely is minimal, as this AU spans the divide between the Coosa and Tennessee river basins.

Two sites in the Lookout-Sand Mountain AU occur on protected lands. Fricks Cave is ownedand managed by the Southeastern Cave Conservancy, Inc. (SCCi). This site contains a significantgray bat colony, and access is restricted. Lookout Mountain Cave is located at Chickamauga and Chattanooga National Military Park and is owned by the National Park Service.

Sauty Creek

The Sauty Creek AU consists of five sites in the Sauty Creek area of Jackson County, Alabama along the southern margin of the Cumberland Plateau. All sites except Coon Track Cave are located north of the Tennessee River. Coon Track Cave is included in this AU based on geographic proximity; however, this site may belong to another AU pending comprehensive genetic analyses. Sauta Cave is the most significant site in the AU, with an historical maximum of 17 salamanders observed in 1995. Recent observation records are lower, with 2 Tennessee cave salamanders observed in 2022. Abundance at other sites is generally low (1–4 salamanders). Most sites occur on private land. Sauta Cave is owned and managed by the Service as part of the Wheeler National Wildlife Refuge to protect a significant gray bat colony. Limrock Blowing Cave is owned by the Southeastern Cave Conservancy, Inc. Site-specific threats in the Sauty Creek AU include recreational caving (Limrock Blowing Cave) and the past commercialization of Sauta Cave.

Marshall County

The Marshall County AU is comprised of seven sites located both north and south of the Tennessee River in Marshall County, Alabama. Three sites have historical records, and three sites have current observations (2000–2022). Lake Guntersville accounts for nearly a quarter of land use within the AU. Karst features that may have had suitable habitat for Tennessee cave salamander were inundated during the lake construction in 1939. Abundance at sites is low in Marshall County AU - with a maximum of six salamanders observed in 1995 at Terrell Cave, which is located at Lake Guntersville State Park. All other sites occur on private land. Site-specific threats in this AU are limited and include logging near Guffey Cave and effects from recreational caving in Dunham Cave.

Paint Rock River

The Paint Rock River AU is comprised of six sites along the Western Escarpment of the Cumberland Plateau within the Paint Rock River watershed in southern Franklin County, Tennessee, and western Jackson County, Alabama. Abundance is generally low at most sites, with the exception of the Tony Sinks Cave (24 Tennessee cave salamanders observed at this site in 2007). Some connectivity is known in the Paint Rock River AU; McFarland Cave is hydrologically connected to Tony Sinks Cave. Two sites occur on protected lands, including the most substantial site in the AU. Tony Sinks and McFarland caves occur on The Nature Conservancy's Sharp-Bingham Mountain Preserve, while all other sites occur on lands in private ownership. No site-specific threats are noted, but silvicultural management does occur in the AU.

Lower Elk River

The Lower Elk River AU consists of just one site, which is privately owned – Robinson Sinks Cave in Limestone County, Alabama, in the Lower Elk River watershed. This occurrence is based on a 1983 record and is considered valid. We have assessed the population at this site as extant, as conditions at the site and surrounding area are stable. However, the site has not been surveyed since 1995; and we do not rely on this site or AU as an important component of the species' rangewide viability. The entrance to Robinson Sinks Cave is at the bottom of a sink that leads to a deep pool of water. The water level fluctuates seasonally and may not meet Tennessee cave salamander life history needs in some seasons or years. The substrate is predominantly mud and silt and is not optimal for reproduction or juveniles.

Lower Tennessee River

The Lower Tennessee River AU consists of three sites on the south side of the Tennessee River in Colbert County, Alabama. These sites are well isolated downstream in the Tennessee River Valley from the core of the Tennessee cave salamander distribution. The Tennessee cave salamander was not observed in 2020 in McKinney Pit Cave and has not been reported since the initial observation at the site in 1966. A new Tennessee cave salamander occurrence site was discovered in 2019 at

Trace Cave, which may be hydrologically connected to Thomason Cave. The Trace Cave site occurs on protected lands on the Natchez Trace Parkway, which is owned and managed by the National Park Service. The other two sites are privately owned. The current landowner of Thomason Cave has not allowed access for several years, and no surveys have been conducted at this site since 1995. Water levels at McKinney Pit Cave fluctuate seasonally in response to water levels of Pickwick Lake. The site-specific threat related to the effects of impoundments have affected the McKinney Pit Cave historically.

Greater Huntsville

The Greater Huntsville AU is comprised of six sites within the greater Huntsville metropolitan area in Madison and southeastern Limestone counties in Alabama. All sites are within the Tennessee River – Wheeler Lake watershed. Several sites in this AU have site-specific threats or relevant historical conditions. Tennessee cave salamanders were observed on several occasions in the 1960s at Shelta Cave (Cooper 1968, p. 184; Cooper and Cooper 1968, p. 22). However, the species has not been observed at Shelta Cave since November 1968. The aquatic community at Shelta Cave was decimated in the late 1960s and early 1970s in part by groundwater pollution from adjacent suburban development. The loss of a gray bat colony because of a gate design that did not allow adequate bat movement may have contributed to the decline of the aquatic cave community at Shelta Cave. This bat colony at Shelta Cave is now displaced. The Tennessee cave salamander has not been observed in 20 surveys between 2018 and 2021. Six salamanders were observed at Muddy Cave in 2005 but have not been observed since, despite repeated surveys. A juvenile Tennessee cave salamander was observed in 2019 at Bobcat Cave, confirming presence and reproduction in a site where the species had not been observed since the early 1970s (almost 50 years).

Most sites in this AU occur on protected lands. Shelta Cave is owned and managed by the National Speleological Society. Bobcat and Matthews Caves are owned or managed by the U.S. Army – Redstone Arsenal. Rockhouse Cave is located on the Wheeler National Wildlife Refuge. Muddy Cave is owned and managed by the North Alabama Land Trust. Site-specific threats are present at five of the six sites in this AU. Rockhouse Cave is not gated and receives a high level of trespassing by amateur spelunkers. Groundwater pollution associated with urbanization is the greatest threat to populations in this AU and affects three of the sites in the AU (Matthews, Muddy, and Shelta Caves). Groundwater quality has been closely monitored at Bobcat and Matthews Caves (McGregor et al. 2015, entire). Heavy metals, including lead, cadmium, and chromium, have been detected at Bobcat Cave. Cadmium, heptachlor epoxide, dieldrin, chlordane, DDT, and DDE have been detected in water and sediment samples at Shelta Cave (Service 1993, p. 3, 7–15). Likewise, Muddy Cave is influenced by contaminated runoff from nearby agricultural fields, pasture, and a new housing development. The Tennessee cave salamander has not been observed in Matthews Cave since 1992, although the site was surveyed in 2019 and 2020. This apparent decline and possible loss may be related to groundwater pollution or the overcollection of a co-occurring species with associated environmental and community disruption.

4.4 Current Species Representation

Representation within the SSA framework describes the species’ ability to adapt to changing environmental conditions over time, whether those changes may be the result of natural environmental change, anthropogenic influence, and/or climate change (Service 2016, p. 12).

Adaptive capacity reflects a suite of ecological and evolutionary factors that allow a species to either persist in place or shift in space to withstand changing conditions (Thurman et al. 2020, p. 521). Assessment of a species' representation may be based on many attributes, including those related to demographics, distribution, movement, life history, niche, ecological role, and evolutionary potential within and among populations (Thurman et al. 2020, p. 522). A high degree of diversity in these attributes indicates more adaptability that significantly reduces the probability of a species going extinct due to environmental changes over time (Service 2016, pp. 12–13).

The Tennessee cave salamander occurs in three EPA level III ecoregions–Interior Plateau, Southwest Appalachians, and the Ridge and Valley (figure 2.6, table 4.1). Within the Interior Plateau, 11 sites with Tennessee cave salamander occur in the Inner Nashville Basin EPA level IV ecoregion, 2 sites occur in the Outer Nashville Basin, and 15 sites occur in occur in the Eastern Highland Rim. In the Southwest Appalachian ecoregion, the Tennessee cave salamander occurs at 53 sites in the Cumberland Plateau, 1 site in the Plateau Escarpment, and 7 sites occur in the Sequatchie Valley on the border with the Cumberland Plateau. Within the Ridge and Valley ecoregion, Tennessee cave salamander occurs at 2 sites in the Southern Limestone/Dolomite Valleys and Low Rolling Hills. Caves with Tennessee cave salamander occurrence are often found at the intersection or boundaries of ecoregions, and the geospatial randomizing of occurrence site location to provide site protection during mapping and analysis may lead to a degree of lack of precision in location within ecoregions as shown in SSA maps.

Environmental conditions vary among the level IV ecoregions across the species' range. This variability in morphology, habitat conditions, and hydrology of caves with Tennessee cave salamander occurrences may reflect the degree of adaptive capacity of the species. Caves on the Cumberland Plateau are fairly similar and are characterized by cobble/pebble substrate, with a few caves that have more fine sand and silt input due to upstream sand quarries (e.g., Blowing Springs and Crystal caves in the Upper Elk AU). Downstream, in the Highland Rim ecoregion in Alabama (greater Huntsville area and to the west), caves with Tennessee cave salamander occurrences are at the water table or groundwater level and are generally characterized by substrates that are made up of less rock (cobble and pebble) and more silt (e.g., Shelta, Bobcat, Muddy, and McKinney Pit caves). In the Nashville Basin ecoregions, caves differ from those in the Cumberland Plateau and Highland Rim in substrate size, stream flow, and water chemistry. The substrate tends to be more variable and mixed with salamander occurrences in substrates with cobble, pebble, and in muddy habitats. Only two sites occur on the edge of the Ridge and Valley level III ecoregion east of the Cumberland Plateau, and these caves tend to share characteristics with those in the Eastern Highland Rim level IV ecoregion. The Tennessee cave salamander inhabits varying habitat conditions within these caves, with occurrences in streams, lakes, springs, and a wide range of water depth and flow, as well as the substrate differences described above.

Approximately 58 percent of Tennessee cave salamander caves occur along the Cumberland Plateau, including the six sites with the greatest known Tennessee cave salamander abundance. Although the geographic area of the Cumberland Plateau encompasses more of the Tennessee cave salamander sites and individuals than other ecoregions, the distribution of sites is widespread across the range. Cave habitats differ by ecoregion but provide similar quality of habitat that meets the needs of Tennessee cave salamander individuals and populations across the species' range.

Additional life history and demography attributes of the Tennessee cave salamander also reflects potential adaptive capacity of the species. As described in **Life History and Demography**, the Tennessee cave salamander has a relatively long lifespan (9–14 years) and a diverse diet that has been described as "anything that fits in its mouth." Morphological variation in coloration corresponds to geographical distributions and may indicate genetic variation and potential adaptive capacity. These characteristics of demography and ecological role, respectively, may correspond to aspects of representation in the Tennessee cave salamander.

Tennessee cave salamander representation is characterized by populations that occur across the range of the species in multiple cave systems and in multiple drainages. These populations provide adaptive capacity through genetic and ecological condition diversity and buffer against future environmental change. The breadth of morphological, genetic, and ecological setting variation support significant adaptive capacity for the species. We have determined that the Tennessee cave salamander representation is not reduced from historical levels and current representation is moderate for the endemic, cave-dwelling species.

4.5 Current Species Redundancy

Redundancy reflects the ability of a species to withstand catastrophic events. It "guards against irreplaceable loss of representation" (Tear et al. 2005, pp. 835–836; Redford et al. 2011, p. 42) and minimizes the effect of localized extirpation on the rangewide persistence of a species (Shaffer and Stein 2000, p. 309). Redundancy is characterized by the distribution of multiple, resilient populations throughout a species' ecological setting and across its range. Greater redundancy is exhibited when populations are not completely isolated and when dispersal between populations is possible.

Current redundancy of the Tennessee cave salamander is high across the range of the species, with two analysis units in high resiliency and eight analysis units in moderate resiliency. The caves with Tennessee cave salamander occurrences (sites) are distributed across the range of the species. Two sites have historical occurrences but no recent observations; and, although we have not determined the species to be extirpated from these sites, there is likely no contribution to the species' redundancy from these sites. All analysis units with historical occurrences have current observations; redundancy since historical levels has not decreased.

4.6 Current Species Condition Summary

We have defined 12 AUs across the range of the species. These AUs vary in size and number of sites of Tennessee cave salamander occurrence. Two of the 12 Tennessee cave salamander AUs currently exhibit high resiliency, 8 exhibit moderate resiliency, and 2 exhibit low resiliency. Units exhibiting low current resiliency are those in the western periphery of the range in Alabama. Resiliency parameters for analysis units and sites in the Cumberland Plateau are generally in better condition (e.g., Crow-Battle Creek, Upper Elk, Paint Rock, Sauty Creek). Analysis units in the Nashville Basin (e.g., Nashville Basin, Upper Duck, Lower Elk) are more degraded by the effects of urbanization and land use change. Four AUs have high quality sites with high observed abundance and evidence of reproduction/recruitment-Crow-Battle Creek, Upper Elk River, Sauty Creek, and Paint Rock River AUs. These 10 high-quality sites occur in the southern Cumberland Plateau and make up the stronghold of the species' range.

The species has moderate representation as indicated by the environmental variation in morphology, habitat conditions in caves where Tennessee cave salamander occurs, the breadth of diet, and lifespan. We also determined that Tennessee cave salamander has a high level of redundancy as indicated by the rangewide distribution of analysis units in moderate resiliency. The best information available indicates that neither representation nor redundancy has declined from historical levels.

CHAPTER 5 – FUTURE CONDITIONS AND VIABILITY

We have considered what the Tennessee cave salamander needs for viability and the current condition of those needs (Chapters 2 and 4), and we reviewed the factors that are driving the current and future conditions of the species (Chapter 3). We now evaluate the species' future condition under plausible future scenarios. We apply our future projections to the concepts of resiliency, representation, and redundancy to describe the future viability of the Tennessee cave salamander.

5.1 Introduction

The SSA considers the factors that influence viability (Chapter 3) and assesses to what degree they influence risk (Smith et al. 2018, p. 6). Our analysis of the past, current, and future influences on the Tennessee cave salamander viability indicates several threats to the species. These risks are largely related to changes in cave habitats, which can be linked to habitat changes from anthropogenic land uses. Forest cover loss, climate change, and site-specific threats may affect the cave habitats, life-history requirements, and thus, viability of Tennessee cave salamander. However, models that estimate the effects of climate change in cave ecosystems are not available; and we are similarly unable to project the magnitude, imminence, or location for site-specific threats. In addition, the species' responses to the effects of climate change or site-specific threats are not established, and we wish to avoid speculative outcomes in our analyses. Therefore, our analysis of future condition for the Tennessee cave salamander relies on modeled changes in forest cover in the range of the species.

We lack systematic surveys across the range of the Tennessee cave salamander, and surveys of the entirety of Tennessee cave salamander habitat within a site are not feasible due to human access limitations. Therefore, we assessed the future condition of the species by looking at predicted changes in surface habitat that affect cave habitat parameters and influence the viability of the Tennessee cave salamander. We used projections of forest loss due to urban development, energy development, and logging (Forest Retention Index, described later) to assess potential habitat loss and fragmentation. Climate change, particularly prolonged period of drought condition and extreme rain events, are expected to have a negative impact on Tennessee cave salamander.

5.2 Models and Scenarios

We assessed future projections of each threat and the effect on the resiliency, representation, and redundancy of the Tennessee cave salamander to project qualitative changes in the future species' condition in 2040 (18 years) and 2060 (38 years). We describe how current viability of the Tennessee cave salamander may change in the future with respect to projected outcomes from three different scenarios that incorporate the effect of forest cover loss to the species over time periods of 18 and 38 years. We chose these timesteps based on an estimated Tennessee cave salamander's lifespan of approximately 10 years and the reliability of the data used in the future threat projections and analyses. Therefore, we determine 18 years and 38 years in the future to be timesteps that we can reasonably predict the threats to the Tennessee cave salamander and the species' response to those threats. The following subsection describes how the forest cover loss parameter representing land use change was assessed.

5.2.1 Land Use Change

Conversion of forested lands to other land uses (including urbanization and development, incompatible agriculture, or some degree of silviculture) is the key driver of the Tennessee cave salamander resiliency and viability. Forested lands act as buffers to pollutants and provide necessary detrital input into cave systems (Coxon 2011, pp. 104–106). Other land uses contribute to increased levels of sedimentation and pollutants that degrade water quality in caves where the Tennessee cave salamander occurs. To assess the level of land use change expected in the future, we relied on the Forest Retention Index model developed as part of the Mapping the South's Forest of the Futures Project led by USDA Forest Service and the Southern Group of State Foresters. The effort investigates the ecological, social, and economic processes driving southern forests including conservation priority areas identified by agencies, nongovernment organizations, partnerships, and initiatives (Wear and Greis 2013, entire; Greene et al. 2020, entire). The effort provides spatially explicit products assigned a forest retention likelihood class for all southern forests on a six-point, qualitative Forest Retention Index (FRI), based on forest retention factors (e.g., conservation priority areas, forest industry) and forest loss risks (e.g., urbanization, sea level rise, and energy development). These forest retention indices were generated for the years 2030, 2040, 2050, and 2060, allowing for multiple time horizons in forecasting.

Although climate change has the potential to affect retention of forests in the Southeast (e.g., changes in precipitation and temperature, impacts to fire behavior, etc.), the FRI is unable to discriminate between various forest types, and thus is limited to only assessing the impacts of sea level rise on coastal forests (Greene et al. 2018a, p. 36). Because the Tennessee cave salamander is not predicted to be impacted by sea level rise, the FRI does not directly address the potential impacts of climate change to the species or its habitat. Below, we describe how the FRI integrates factors expected to influence Tennessee cave salamander habitat.

Forest Retention Factors

Protected Lands and Priority Areas

Protected lands are generally buffered from the direct impacts of urban and energy development, and thus are likely to retain forests into the future. To assess protected lands, the FRI used protected lands data from the Protected Areas Database (PAD-US) and National Conservation Easement Database (NCED), and divided this data into two priority tiers (Tier I and II) based on where conservation partners were in the prioritization and acquisition process as follows (Greene et al. 2018a, p. 10):

- Tier I: forested lands that are strategically planned for protection, including lands that are currently in the acquisition process (e.g., Land, Water, and Conservation Fund properties and Nature Conservancy Longleaf Protection Priorities).
- Tier II: forested lands that are regional conservation priorities, where acquisition is more uncertain or opportunistic (e.g., priority areas identified in State Wildlife Action Plans, Forest Legacy areas, high priority areas identified by Southeast Conservation Adaptation Strategy).

Socioeconomics/Forest Management

The FRI evaluated the socioeconomic value of forests from the perspective of drinking water and timber markets by using the Timber Products Output dataset (2012) from the Forest Inventory and

Analysis program which details timber production of each county in the southeastern United States (Greene et al. 2020, pp. 34–35), and the Forest to Faucets data which identified sub-watersheds that are most important to surface drinking water based on water supply, water intake, flow patterns, and landcover data (Weidner and Todd 2011, entire; Greene et al. 2020, pp. 33–34). The FRI uses a quantile analysis to identify the top 40 percent of timber-processing counties and HUC12 sub-watersheds with the highest forest importance, and thus the most likely to be retained as forest in the future.

Forest Loss Factors

Urbanization and Development

Urban development has been described as a threat to the species historically (Petranka 1998, p. 282), and areas of urbanization continue to drive habitat and land use conditions. The effects of urbanization and development are most notable in the Greater Huntsville AU. To capture the potential extent of future urbanization, the FRI uses SLEUTH models (Slope, Land use, Excluded, Urban, Transportation, and Hillshade) for the years 2030, 2040, 2050, and 2060. SLEUTH models the rate and pattern of urbanization using four growth rules (spontaneous growth, new spreading centers, edge growth, and road-influenced growth) to project future urbanization.

Energy Development

The FRI uses a risk assessment for future energy development developed by the Appalachian Landscape Conservation Cooperative (LCC) and The Nature Conservancy to identify forests at high (>90 percent) risk of development for coal, shale, or wind energy production (Dunscomb et al. 2014, entire). Results indicate approximately 7.6 million acres (71 percent forested acres) within the Appalachian LCC that encompasses the Tennessee cave salamander range have a high (>90 percent) probability of energy development, with high-risk areas concentrated on the Allegheny and Cumberland Plateaus (Dunscomb et al. 2014, p. 27). Although coal, shale, and wind energy development are not listed as threats to the species, these activities have the potential to remove forested cover, and thus negatively impact Tennessee cave salamander habitat.

Forest Retention Index

The FRI integrates protected status, conservation priority, threats, and socioeconomic value datasets to provide a gradient of future forest retention on currently forested lands. The FRI does not distinguish between forest age, forest condition, or forest management actions. Forested areas that are not Tier I or Tier II conservation priorities lands are not categorized further; therefore, forests that are not Tier I or Tier II priorities but are managed for conservation are characterized in the same structured decision-making pathway as forests managed for timber products.

- Currently forested lands, as determined by using the 2011 National Land Cover Database (Homer et al. 2015, entire), were divided into six classes ranging from Very High (i.e., almost certain to remain forested) to Very Low (i.e., forest almost certain to be lost) using a decision tree (figure 5.1). These six classes are described as follows (Greene et al. 2018b, p. 1):
- Very High: currently protected forest not at risk of being lost to sea level rise.

- High: forests that are protected, or which are regional conservation priorities with low urbanization risk and high socioeconomic value.
- Moderate-High: regional conservation priorities with low urbanization risk or high socioeconomic value, or unprioritized forest with low urbanization risk and high socioeconomic value.
- Moderate-Low: regional conservation priorities with moderate urbanization risk and without socioeconomic value, or unprioritized forest with low urbanization risk or high socioeconomic value.
- Low: unprioritized forest with moderate urbanization risk and without socioeconomic value; high risk of energy development.
- Very Low: forest at high risk of urbanization or loss to sea level rise.

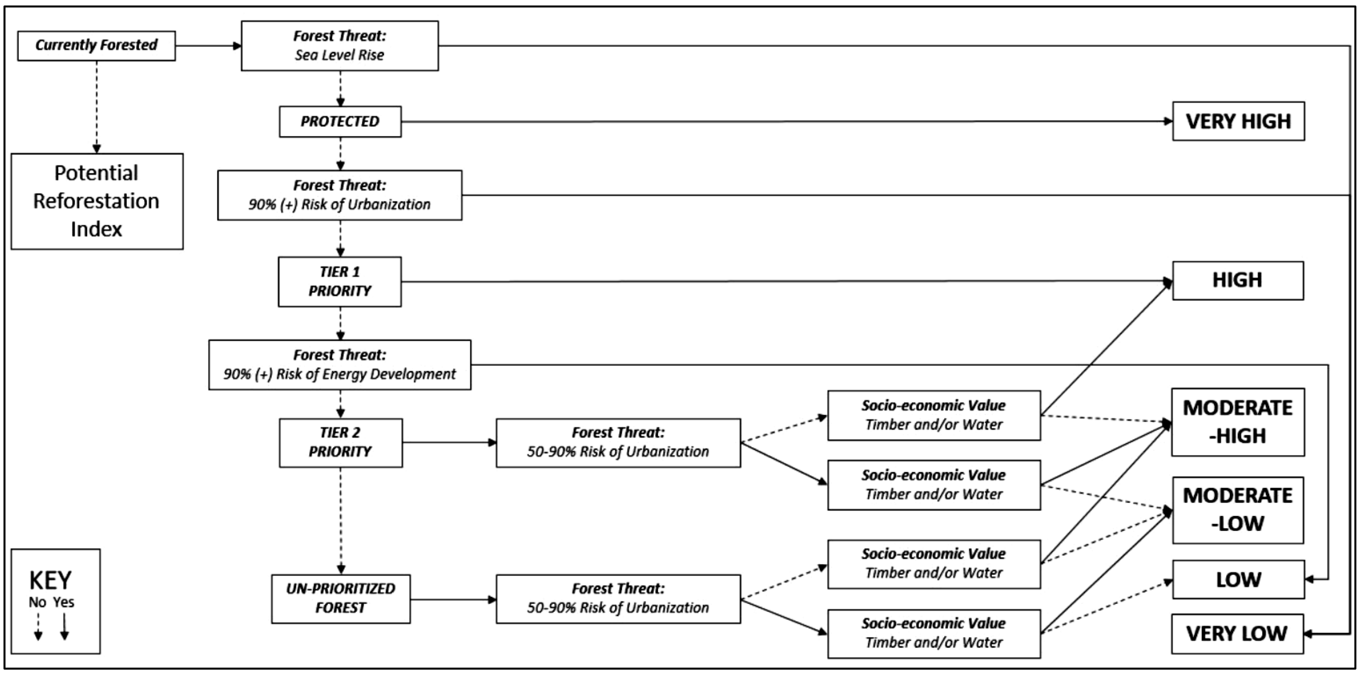


Figure 5.1. Decision tree for Forest Retention Index (from Greene et al. 2018a, p. 13).

In each scenario, we used the FRI as a filter to remove suitable habitat pixels that are at the highest risk of losing forest from the current forested area (2019 NLCD deciduous, evergreen, and mixed forest). We then categorized the change in the percentage of forested area within the 4-km site buffers and applied a resiliency adjustment to the current resiliency score (table 5.1). The predicted forest retention/forest loss represents the influences of urbanization and development and other land use changes. We expect that land use change, specifically loss of forest cover near Tennessee cave salamander occurrences, is the primary driver of the species' future condition.

The FRI model does not assess potential increases in forest cover (potential reforestation index); therefore, increases in forest cover cannot increase over current levels in the model. This may introduce a minor source of uncertainty in the forest loss projections, although we are not aware of large-scale or landscape level forest restoration efforts in the range of the Tennessee cave salamander.

5.3 Future Scenarios and Resiliency Projections

To assess Tennessee cave salamander future condition, we developed three plausible future scenarios that bound the impacts of threats related to habitat influences from land use change, specifically the loss of forest cover. The scenarios: (1) status quo minimum, (2) status quo maximum, and (3) increased impacts are summarized below (table 5.2). These scenarios capture the range of plausible Tennessee cave salamander viability at each timestep. Resiliency, representation, and redundancy were projected under each scenario.

We project the future resiliency change for each analysis unit as reduced from current, no change expected, or increased from current based on impacts from projected changes in forest cover. Levels of projected change in resiliency rely on a qualitative measure of the impact of decreased detrital input, increased sedimentation and pollutants, and negative impacts to cave habitat associated with loss of intact forest cover (table 5.1, Appendix B). In the following sections, we describe the plausible future condition scenarios and the levels of the key driver of species' viability associated with each

Table 5.1. Relationship of projected forest cover change within a 4-km buffer around Tennessee cave salamander occurrences and projected effect on AU resiliency in 2040 and 2060.

Forest Cover Change	Effect on Resiliency
0 to 10% Decrease	No Change
10.1 to 24.9% Decrease	Slight Decrease
>25% Decrease	Decrease
Increase	Increase

Scenario 1: Status Quo Minimum

We assessed the effects of projected changes in land use on Tennessee cave salamander using the risk of forest loss characterized in the Forest Retention Index model. Under Scenario 1, habitat projected to be lost in the FRI classes of low and very low was removed from the current forest habitat acres in 4-km buffers around sites with Tennessee cave salamander occurrence. The low and very low classes in the FRI are those with a low or very low likelihood of retention are those most likely to be converted to another land cover or land use.

- Low: unprioritized forest with moderate urbanization risk and without socioeconomic value; high risk of energy development.
- Very Low: forest at high risk of urbanization or loss to sea level rise.

Scenario 2: Status Quo Maximum

Under Scenario 2, habitat projected to be lost in the FRI classes of moderate-low, low, and very low was removed from the current forest habitat acres in 4-km buffers around sites with Tennessee cave salamander occurrence. The low and very low classes in the FRI are those that have a low or very low likelihood of retention and that are most likely to be converted to another land cover or land use. In Scenario 2, we remove habitat projected to be lost in the moderate-low FRI class, as well as the low and very low classes. The moderate-low class includes those areas of currently forested habitat that is part of regional conservation priorities with moderate urbanization risk and without socioeconomic value, or unprioritized forest with low urbanization risk or high socioeconomic value.

Scenario 3: Increased Impacts

Under Scenario 3, habitat projected to be lost in four FRI classes of moderate-high, moderate-low, low, and very low likelihood of retention was removed from the current forest habitat acres in 4-km buffers around sites with Tennessee cave salamander occurrence. In Scenario 3, we remove habitat projected to be lost in the moderate-high FRI class as well as the moderate-low, low, and very low classes. The moderate-high class includes those areas of currently forested habitat that are part of regional conservation priorities with low urbanization risk or high socioeconomic value, or unprioritized forest with low urbanization risk and high socioeconomic value. In Scenario 3, we assess the effect of forest loss in all FRI classes except high or very high likelihood of retaining forest cover. The greater level of forest loss reflects a scenario of increased impacts due to urbanization, energy needs, and socioeconomic factors.

Table 5.2. Three plausible future scenarios used to assess Tennessee cave salamander future condition and the levels of the primary threat to the species incorporated in the model.

Scenario	Forest Retention Index (6 classes)
Scenario 1: Status Quo Minimum	2 classes (very low and low) most likely to be converted
Scenario 2: Status Quo Maximum	3 classes (very low, low, moderate-low) likely to be converted
Scenario 3: Increased Impacts	4 classes (very low, low, moderate-low, moderate-high) likely to be converted

5.4 Future Conditions

Scenario 1: Status Quo Minimum

In the first timestep (2040) under Scenario 1, 11 of 12 Tennessee cave salamander AUs are projected to have no change in resiliency (less than 10% loss of forest cover) (figure 5.2, table 5.3). One AU is projected to decrease slightly in resiliency (Lower Tennessee AU). In 2060, 8 AUs are projected to have no change in resiliency, while 3 AUs are projected to decrease slightly in resiliency. The Crow-Battle Creek and Paint Rock AUs, the stronghold of the species range, are not projected to change resiliency in 2040 or 2060 under Scenario 1.

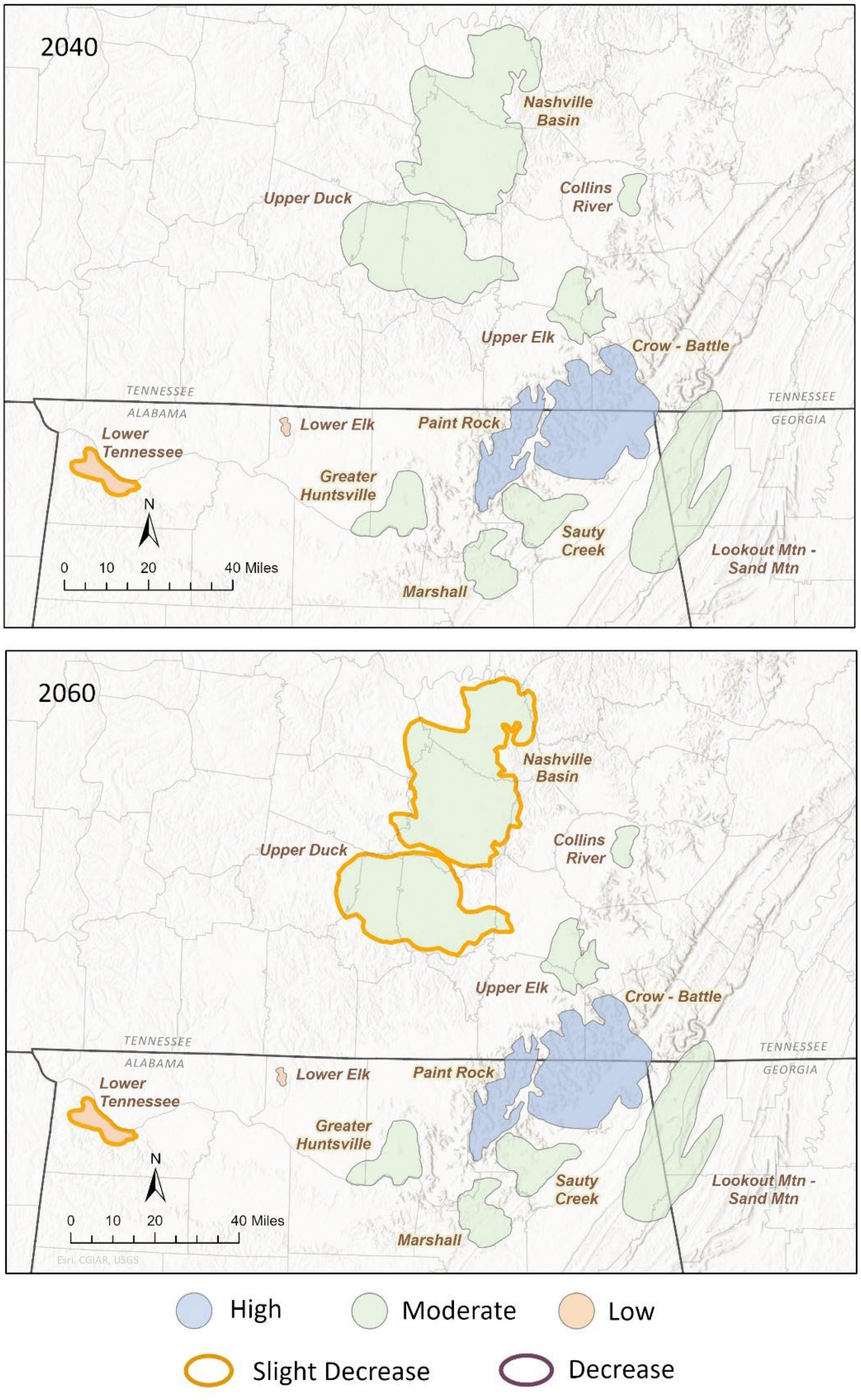


Figure 5.2. Scenario 1 future changes in resiliency of Tennessee cave salamander analysis units in 2040 (upper) and 2060 (lower). Analysis units projected to decrease in resiliency are outlined in plum and units projected to decrease slightly in resiliency are outlined in orange/gold.

Table 5.3. Future resiliency changes of Tennessee cave salamander analysis units under Scenario 1:Status Quo/Lower Development.

Analysis Unit	**Current**	**2040**	**2060**
Collins	Moderate	No Change	No Change
Crow-Battle Creek	High	No Change	No Change
Greater Huntsville	Moderate	No Change	No Change
Lookout-Sand	Moderate	No Change	No Change
Lower Elk	Low	No Change	No Change
Lower Tennessee	Low	Slight Decrease	Slight Decrease
Marshall County	Moderate	No Change	No Change
Nashville Basin	Moderate	No Change	Slight Decrease
Paint Rock	High	No Change	No Change
Sauty Creek	Moderate	No Change	No Change
Upper Duck	Moderate	No Change	Slight Decrease
Upper Elk	Moderate	No Change	No Change

The Tennessee cave salamander is present in all AUs in the current range of the species. Therefore, we expect Tennessee cave salamander representation to remain at the current moderate level under Scenario 1 in 2040 and 2060. Under Scenario 1, redundancy of the Tennessee cave salamander will remain high with only slight decreases in resiliency projected for 1 and 3 AUs, respectively. In addition, the species remains distributed across the range under Scenario 1 in both timesteps.

Scenario 2: Status Quo Maximum
In the first timestep (2040) under Scenario 2, 2 Tennessee cave salamander AUs are projected to experience a slight decrease in resiliency and one AU (Lower Tennessee) is expected to decrease in resiliency (figure 5.3, table 5.4). Under Scenario 2 in 2060, 1 AU is projected to experience a slight decrease in resiliency; and 2 AUs are expected to decrease in resiliency (Lower Tennessee and Nashville Basin). The Crow-Battle Creek and Paint Rock AUs, in the Cumberland Plateau stronghold of the species range, are not projected to change resiliency class under Scenario 2.

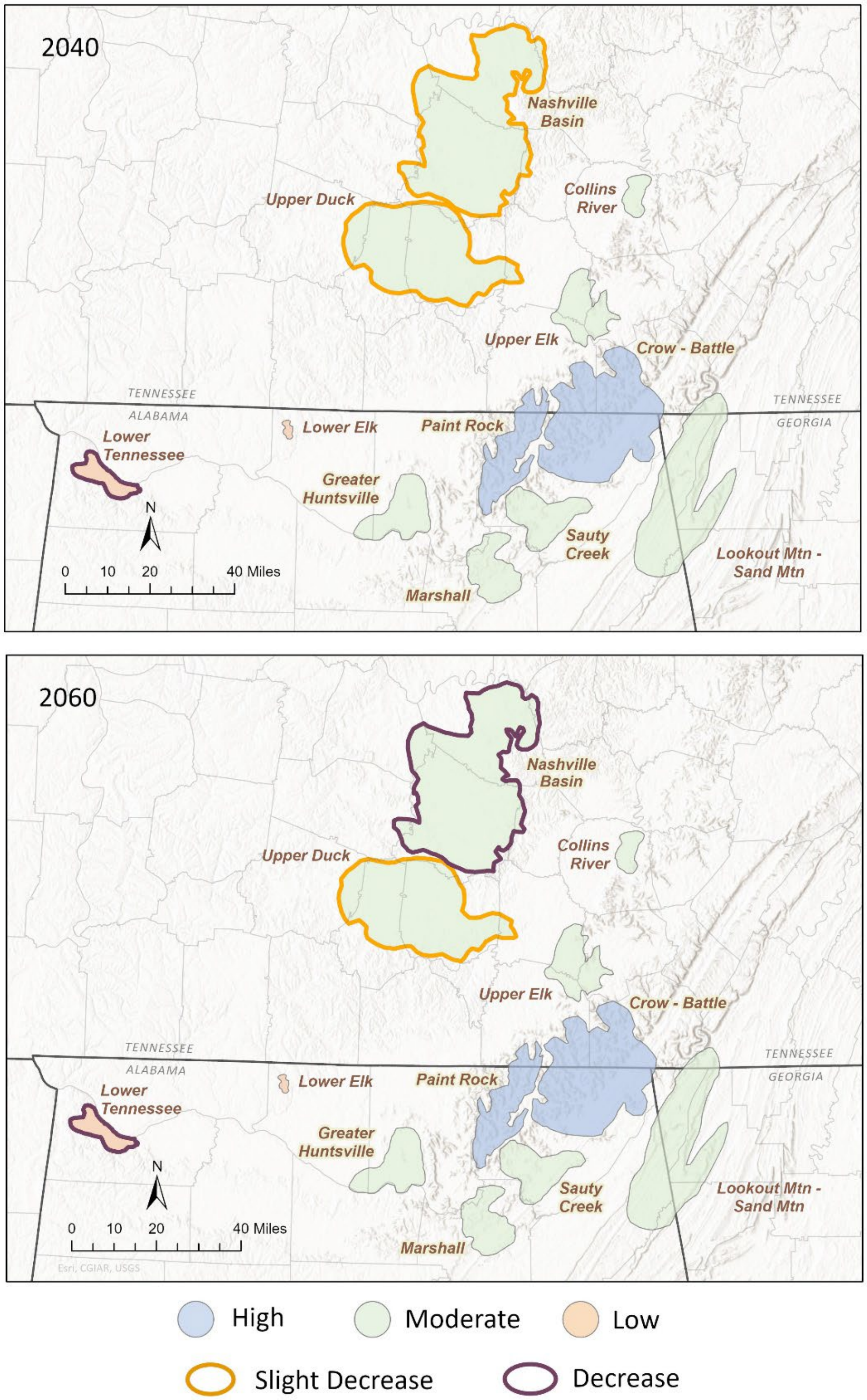


Figure 5.3. Scenario 2 future changes in resiliency of Tennessee cave salamander analysis units in 2040 (upper) and 2060 (lower). Analysis units projected to decrease in resiliency are outlined in plum and units projected to decrease slightly in resiliency are outlined in orange/gold.

Table 5.4. Future resiliency changes of Tennessee cave salamander analysis units under Scenario 2: Status Quo Maximum**.**

Analysis Unit	**Current**	**2040**	**2060**
Collins	Moderate	No Change	No Change
Crow-Battle Creek	High	No Change	No Change
Greater Huntsville	Moderate	No Change	No Change
Lookout-Sand	Moderate	No Change	No Change
Lower Elk	Low	No Change	No Change
Lower Tennessee	Low	Decrease	Decrease
Marshall County	Moderate	No Change	No Change
Nashville Basin	Moderate	Slight Decrease	Decrease
Paint Rock	High	No Change	No Change
Sauty Creek	Moderate	No Change	No Change
Upper Duck	Moderate	Slight Decrease	Slight Decrease
Upper Elk	Moderate	No Change	No Change

Species-level representation for the Tennessee cave salamander is expected to remain at the current moderate level in 2040 and 2060, with populations remaining in all AUs. Under Scenario 2, redundancy of the Tennessee cave salamander may be reduced slightly from current levels in 2040 and 2060, with 1 and 3 AUs expected to decrease in resiliency. In addition, the species remains distributed across the range under Scenario 2 in both timesteps.

Scenario 3: Increased Impacts

In the first timestep (2040) under Scenario 3, 6 Tennessee cave salamander AUs are projected to experience no change in resiliency. One AU is projected to slightly decrease in resiliency, and 5 AUs are projected to decrease in resiliency (figure 5.4 and table 5.5). In 2060, 5 AUs are projected to experience no change in resiliency. Two AUs are projected to slightly decrease in resiliency, and 5 AUs are projected to decrease in resiliency. The stronghold AUs (Crow-Battle Creek and Paint Rock) on the Cumberland Plateau are not projected to change resiliency in 2040 or 2060 under the increased impact scenario.

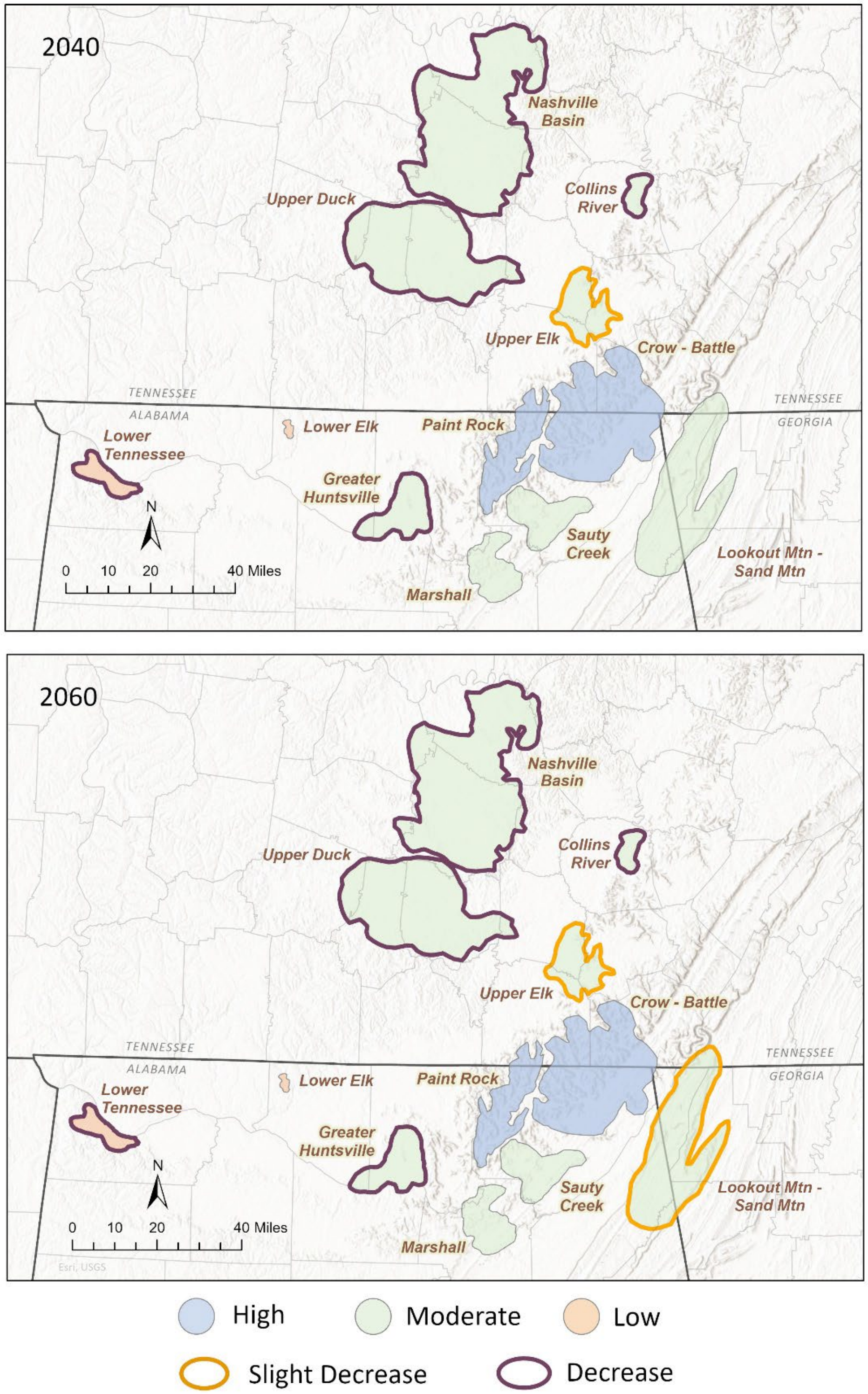


Figure 5.4. Scenario 3 future change in resiliency of Tennessee cave salamander analysis units in 2040 (upper) and 2060 (lower). Analysis units projected to decrease in resiliency are outlined in plum and units projected to decrease slightly in resiliency are outlined in orange/gold.

Table 5.5. Future resiliency changes of Tennessee cave salamander analysis units under Scenario 3: Increased Impacts in 2040 and 2060.

Analysis Unit	Current	2040	2060
Collins	Moderate	Decrease	Decrease
Crow-Battle Creek	High	No Change	No Change
Greater Huntsville	Moderate	Decrease	Decrease
Lookout-Sand	Moderate	No Change	Slight Decrease
Lower Elk	Low	No Change	No Change
Lower Tennessee	Low	Decrease	Decrease
Marshall	Moderate	No Change	No Change
Nashville Basin	Moderate	Decrease	Decrease
Paint Rock	High	No Change	No Change
Sauty Creek	Moderate	No Change	No Change
Upper Duck	Moderate	Decrease	Decrease
Upper Elk	Moderate	Slight Decrease	Slight Decrease

Species-level representation for the Tennessee cave salamander is expected to be remain at current levels in 2040 and 2060, with the species distributed across the current and historical range. Under Scenario 3, redundancy of the Tennessee cave salamander may be reduced from the current high level in 2040 and 2060 with reductions in resiliency projected in 6 and 7 AUs, respectively. However, the species remains distributed across the range under Scenario 3 in both timesteps.

5.5 Summary of Future Conditions

We predicted the future resiliency of Tennessee cave salamander analysis units at two timesteps (2040 and 2060) using three future scenarios that take incorporate a range of impacts from future urbanization and land use change through the Forest Retention Index model of forest cover loss. The scenarios in our analysis included: (1) Status Quo Minimum, (2) Status Quo Maximum, and (3) Increased Impacts. Impacts to Tennessee cave salamander analysis unit resiliency increase across scenarios and time steps from Scenario 1 to 3, respectively. Resiliency is not expected to increase in any units based on modeling projections. Future species' representation was predicted under these three scenarios and two time-steps by assessing the distribution of Tennessee cave salamanders in the level IV ecoregions in the range, as a proxy for environmental variation and other life history characteristics that may indicate adaptive capacity. Future species' redundancy was predicted by assessing the number of moderately resilient and representative AUs distributed across the species' range and the changes projected to AU resiliency.

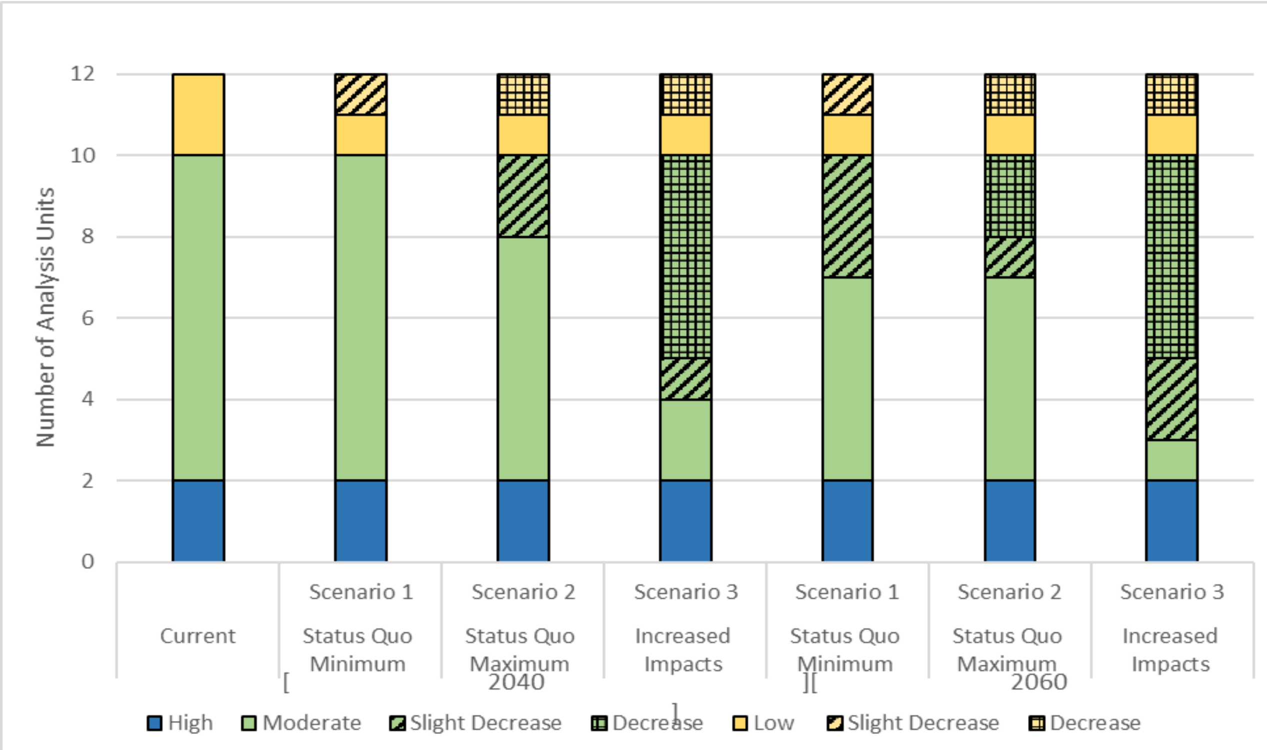


Figure 5.5. Future changes in resiliency of Tennessee cave salamander analysis units under three plausible future scenarios in 2040 and 2060. The number of analysis units projected to have no change in resiliency (less than 10 percent loss of forest cover), a slight decrease (10–24.9 percent loss), and a decrease (greater than 25 percent loss) are shown as overlays on the vertical bars.

In all scenarios and timesteps, the loss of forest cover within the buffers around Tennessee cave salamander occurrences was the key driver of future resiliency. We note that the percentage of forest loss may overestimate the effect to the species resiliency and viability in areas that have high levels of urbanization currently. In these cases, the magnitude of projected loss is less and is expected to have less impact on the condition of the Tennessee cave salamander.

The projected extirpation risk for analysis units with lower levels of current forest cover may overestimate the risk attributed to loss of forest cover. This potential overestimation of forest loss applies to the Huntsville and Collins River AUs. The magnitude of projected loss may not adequately account for potential mitigating factors (e.g., conservation measures that could be applied to offset impacts). Further, the impacts of forest cover loss on habitat condition and the Tennessee cave salamander response to these changes have not been quantified. Therefore, forest cover loss may not fully explain changes in habitat condition due to land cover change. Other land cover types (e.g., pasture) may provide a benefit to the species through maintenance of water quality (although detrital input is reduced in these land cover types). Thus, the future reductions in resiliency projected for Huntsville and Collins River may overestimate loss of resiliency.

Cave ecosystems are difficult to fully assess, and we are unable to determine the full extent of suitable habitat for Tennessee cave salamander within the karst landscapes in its range. The Nashville Basin and Upper Duck AUs were noted by a species expert as areas that are likely to have additional habitat suitable for Tennessee cave salamanders that cannot or has not been explored. Thus, the future reductions in resiliency projected for the Nashville Basin and Upper Duck may be mitigated by additional habitat or potentially, species' occurrences.

5.6 Uncertainty

- Our analysis of current and future conditions includes inherent uncertainty and assumptions because of limitations in available information about the Tennessee cave salamander life history, extent of occupancy, and response to threats. The projections of future scenarios are based on the most recent trends in the species' AUs and habitats. The following uncertainties are recognized in the appropriate section and summarized here:
- Many life history aspects of the Tennessee cave salamander are unknown, including reproductive biology, habitat use by larval salamanders and juveniles,and generation time.
- The extent and size of populations at sites is unclear, as we can only survey portions of cave systems accessible to humans. Tennessee cave salamanders likely occupy habitats inaccessible to human exploration and survey.
- Likewise, Tennessee cave salamanders may occupy additional sites that remain to be discovered within some AUs (e.g., the Nashville Basin and Upper Duck AUs).
- Lack of permission to access several sites limits our ability to access temporal and spatial trends in abundance and stressors.
- The dynamics and impacts of climate change as well as potential adaptive response by Tennessee cave salamanders to changing environmental conditions is notdefinitively known.
- The precise degree to which agricultural-related activities, urbanization, and chemical production facilities affects groundwater quality and results in subsequent impacts to Tennessee cave salamanders is unknown but assumed to be detrimental to varying degrees.
- Genetic variation across the range of the species has not been determined.
- The FRI does not distinguish between types of forest, conservation management actions, and forest restoration. The projections of forest loss may overestimate the impact to the species and introduce uncertainty into the future condition results.

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Appendix A. Calculations of current resiliency scores by analysis unit.

Analysis Unit	# sites	Abundance Category	Abund Score	Reproduction/ Recruitment (% sites)	Repro Score	Percent Ag (in site buffers)	Water Quality Score	Percent Forest (in site buffers)	Detrital Input Score	Resiliency Score	Resiliency Category
Crow-Battle Creek	35	M	3.38	0.27	2	13.6	4	78.1	4	**13.38**	High
Upper Elk River	7	M	3.71	0.71	3	34.0	2	58.6	3	**11.71**	Moderate
Upper Duck River	4	L	2.25	0.50	3	38.7	2	49.8	2	**9.25**	Moderate
Nashville Basin	8	L	2.00	0.38	2	34.1	2	52.1	3	**9.00**	Moderate
Collins River	5	L	2.25	0.75	4	48.2	1	41.0	2	**9.25**	Moderate
Lookout-Sand Mountain	4	L	3.00	0.00	1	15.0	3	65.3	3	**10.00**	Moderate
Sauty Creek	5	M	2.00	0.67	3	21.7	3	51.9	3	**11.00**	Moderate
Marshall County	7	L	2.25	0.33	2	12.8	4	61.4	3	**11.25**	Moderate
Paint Rock River	6	H	4.00	0.25	2	11.4	4	83.6	4	**14.00**	High
Lower Elk River	1	VL	1.00	0.00	1	39.7	2	43.4	2	**6.00**	Low
Lower Tennessee River	3	L	2.00	0.00	1	42.6	1	38.6	2	**6.00**	Low
Greater Huntsville	6	L	2.50	0.33	2	19.2	3	16.4	1	**8.50**	Moderate

Appendix B: Future forest cover change in 4-km buffers around species' occurrences under three plausible scenarios in 2040 and 2060.

	2040 Sc1: Status Quo-Lower Emissions		2040 Sc 2: Status Quo-Higher Emissions		2040 Sc 3: Increased Impact		2060 Sc1: Status Quo-Lower Emissions		2060 Sc 2: Status Quo-Higher Emissions		2060 Sc 3: Increased Impact	
BUFFER	% Forest Loss	Future Resiliency Change	% Forest Loss	Future Resiliency Change	% Forest Loss	Future Resiliency Change	% Forest Loss	Future Resiliency Change	% Forest Loss	Future Resiliency Change	% Forest Loss	Future Resiliency Change
Collins River	0.06	No Change	7.91	No Change	69.38	Decrease	0.67	No Change	8.60	No Change	69.39	Decrease
Crow-Battle Creek	0.69	No Change	0.80	No Change	4.99	No Change	1.43	No Change	1.52	No Change	5.43	No Change
Greater Huntsville	4.13	No Change	5.54	No Change	31.57	Decrease	9.21	No Change	9.23	No Change	32.32	Decrease
Lookout-Sand Mtn	2.86	No Change	5.38	No Change	8.87	No Change	5.90	No Change	8.25	No Change	11.34	Slight Decrease
Lower Elk	0.01	No Change	0.01	No Change	0.02	No Change	0.41	No Change	0.41	No Change	0.41	No Change
Lower Tennessee	11.34	Slight Decrease	55.37	Decrease	69.93	Decrease	20.51	Slight Decrease	60.23	Decrease	73.47	Decrease
Marshall	0.84	No Change	1.02	No Change	5.56	No Change	2.08	No Change	2.21	No Change	6.50	No Change
Nashville Basin	5.12	No Change	21.87	Slight Decrease	79.49	Decrease	13.50	Slight Decrease	28.02	Decrease	80.00	Decrease
Paint Rock	0.00	No Change	0.00	No Change	0.00	No Change	0.00	No Change	0.00	No Change	0.00	No Change
Sauty Creek	2.47	No Change	2.74	No Change	2.74	No Change	5.24	No Change	5.28	No Change	7.26	No Change
Upper Duck	6.52	No Change	21.02	Slight Decrease	64.72	Decrease	12.15	Slight Decrease	24.35	Slight Decrease	65.27	Decrease
Upper Elk	0.56	No Change	0.56	No Change	21.92	Slight Decrease	1.54	No Change	1.54	No Change	22.38	Slight Decrease