Species Status Assessment Report
for the
Berry Cave Salamander
(*Gyrinophilus gulolineatus*)

Version 1.1

Adult Berry Cave salamander from Berry Cave, Roane County, Tennessee
Photograph courtesy Dr. Matthew Niemiller.

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REVISIONS TO VERSION 1.0

Page 21 – Section 3.4 (Water Quantity) was added.

Page 26 (Table 4.1) – High Resiliency Class for Species Abundance - "17 to 24…" was replaced with "17 or more…".

Page 28 (Table 4-2) –Species Abundance designation for AU 1 was adjusted from "High" to "Moderate". This reflects a previous revision of Species Abundance class definitions (i.e., dividing the historic maximum observed population of 24 into thirds). The narrative regarding resiliency of AU 1 on page 28 was revised to reflect this adjustment.

Page 32 (Section 4.4.1) – This section was revised to clarify that three AUs exhibit moderate or high resiliency and three have moderate to low resiliency.

Page 38 (Resiliency description for AU 1) – The narrative was revised to reflect the "High" level of population complexity in recognition of a previous adjustment to definitions of classes for this element (i.e., replacement of "Moderate" value designations with "High" values).

Page 38 (Resiliency description for AU 5) – The narrative "moderate population complexity and" was deleted to reflect the adjustment of class definitions for the population complexity element.

Pages 38 and 39 - Resiliency narratives for AU 1 and AU 5 were revised to reflect adjustment to Table 5-1, as described below.

Page 39 (Table 5-1) – Species Abundance designation for AU 1 was adjusted from "High" to "Moderate", Species Abundance designation for AU 4 was adjusted from "Moderate" to "Low", and Species Abundance designation for AU 5 was adjusted from "Moderate" to "Low". These adjustments reflect the revisions of Species Abundance class definitions. The narrative summarizing Representation in Scenario 1 (page 39) was revised to reflect these adjustments.

Page 41 (Table 5-2) – Species Abundance designation for AU 2 was adjusted from "Moderate to Low" to "Low", Species Abundance designation for AU 4 was adjusted from "Moderate" to "Low", Species Abundance designation for AU 5 was adjusted from "High to Moderate" to "Moderate", and Species Abundance designation for AU 6 was adjusted from "Moderate to Low" to "Low". The narrative summarizing Representation for Scenario 2 (page 41) was adjusted likewise.

Page 43 (paragraph 2) – The acronym "MU" was changed to "AU" to reflect previous revision of the term "management unit" to "analysis unit".

Page 43 – The narrative summarizing Representation under Scenario 3 was revised to clarify trends in projected abundance and potential for extirpation of populations.

Page 46 (last paragraph, second line) – The spelling of "lever" was corrected to "level".

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We would like to recognize and thank Dr. Matthew Niemiller and the numerous individuals assisting him in his survey efforts, including Tennessee Wildlife Resources Agency biologists Chris Ogle and Daniel Istvanko. Dr. Niemiller has also been instrumental in providing substantive information and insights into the species' biology and possible threats.

Suggested reference:

U.S. Fish and Wildlife Service. 2019. Species status assessment report for the Berry Cave salamander (*Gyrinophilus gulolineatus*), Version 1.0. February 2019. Atlanta, GA.

EXECUTIVE SUMMARY

This species status assessment (SSA) document reports the results of a comprehensive status review for the Berry Cave salamander (*Gyrinophilus gulolineatus*), describing the species' historical condition and providing estimates of current and future condition under a range of different scenarios. A status survey was conducted to supplement knowledge of the species (Niemiller et al. 2018b), and ongoing monitoring is anticipated. This cryptic salamander, which has been found to reach a total length of approximately 9.5 inches, has limited apparent mobility. It resides in underground streams of eastern Tennessee and is currently known to occupy six cave systems. The species feeds on invertebrates and other organisms and appears to have a lifespan of 20 years or more.

The SSA process can be categorized into three sequential stages. During the first stage, we used the conservation biology principles of resilience, redundancy, and representation (together, the 3Rs) to evaluate individual Berry Cave salamander life history needs. The next stage involved an assessment of the historical and current condition of the Berry Cave salamander's demographics and habitat characteristics, including the effects of various factors on its current condition. The final stage of the SSA involved making predictions about the species' response to positive and negative environmental and anthropogenic influences. This process used the best available information to characterize viability as the ability of a species to sustain populations in the wild over time.

To evaluate the current and future viability of the Berry Cave salamander, we assessed a range of conditions to allow us to consider the species' resiliency, representation, and redundancy. For the purposes of this assessment, populations were delineated using the six cave systems in which the species is currently known to be extant.

Resilience, assessed at the population level, describes the ability of a population to withstand stochastic disturbance events. A species needs multiple resilient populations distributed across its range to persist into the future and avoid extinction. Resources supporting the species are summarized in Table 2.1, and they include (1) sufficient water availability (quantity), (2) adequate water quality, and (3) suitable habitat (substrate and cover). These resources and the specific factors that influence the species' viability are discussed in greater detail in Chapter 3 and highlighted as six elements (Table 4-1). If a cave's stream ecosystem maintains adequate amounts of water of suitable quality, adequate habitat, and associated invertebrate communities as a forage base, we expect the Berry Cave salamander will remain extant. As we consider the future viability of the species, more populations with high resiliency distributed across its known range would be associated with higher overall species viability.

Redundancy describes the ability of the species to withstand catastrophic disturbance events. For the Berry Cave salamander, we considered whether the distribution of resilient populations is sufficient for minimizing the potential loss of the species due to such an event.

Representation characterizes a species' adaptive potential by assessing geographic, genetic, ecological, and niche variability. The Berry Cave salamander's known current range is limited to six cave systems in the Valley and Ridge Province of eastern Tennessee. Maintaining those populations provides redundancy, and the species is currently represented across most of the known geographic extent of the species. We have assessed the Berry Cave salamander's levels of resiliency, redundancy, and representation currently and into the future by ranking the condition of each population. These rankings are the Service's assessment of the relative condition of salamander populations in cave ecosystems based on the knowledge and expertise of Service and Tennessee Wildlife Resources Agency biologists and information gained during the recent surveys conducted by Dr. Matthew Niemiller (University of Alabama in Huntsville).

Together, the 3Rs comprise the key characteristics that contribute to a species' ability to sustain multiple distinct populations in the wild over time (i.e., viability). Using the principles of resiliency, redundancy, and representation, we characterized both the species' current viability and forecasted its future viability over a range of plausible future scenarios. To this end, we ranked the condition of each population by assessing the relative condition of populations in occupied cave systems using the best available scientific information.

Historic, current, and potential future stressors to the Berry Cave salamander include pollutants (e.g., sediment and toxicants) transported to caves as a result of residential and commercial development and potential road construction, toxic waste leachate from a historic quarry site, and fecal coliforms from livestock. Climate effects and lower salamander population densities resulting from competition, predation, and human collection could exacerbate threats to the species, but conservation measures can counter those effects in some circumstances.

Viability of the Berry Cave salamander depends on maintaining multiple resilient populations over time. We have predicted the species' resiliency, redundancy, and representation under three plausible future scenarios:

(1) Minor improvements in conservation measures for the Berry Cave salamander would be implemented relative to the current situation;
(2) A higher level of conservation measures would be implemented; and
(3) A lower level of conservation measures would be implemented.

For the purpose of this projection, the species' currently occupied populations were divided into six analysis units (AUs). Each AU was then evaluated relative to the six important ecological factors for the species. Currently, the salamander population resiliencies are high for one of the AUs, moderate for two AUs, and low to moderate for three AUs. The Berry Cave salamander is expected to persist in all AUs under each of the three scenarios. However, in the scenario involving a reduced level of conservation, resiliency is predicted to be moderate in only half of the AUs and low in the other half.

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CHAPTER 1 – INTRODUCTION AND ANALYTICAL FRAMEWORK

On January 22, 2003, the Fish and Wildlife Service (Service) received a petition dated January 15, 2003, from Dr. John Nolt, University of Tennessee – Knoxville. He requested listing of the Berry Cave salamander as endangered under the Endangered Species Act (Act). The petition clearly identified itself as such and included the requisite identification information for the petitioner, as required in 50 CFR 424.14(a). In a February 24, 2003, letter to the petitioner, the Service indicated that it had received the petition but higher priority listing actions had precedence and the 90-day finding would be delayed.

The 90-day petition finding was published in the Federal Register on March 18, 2010 (75 FR 13068). The Service found that the information provided in the petition, supporting information submitted with the petition, and information otherwise available in our files did provide substantial scientific or commercial information indicating that listing the Berry Cave salamander may be warranted. In the finding, we stated that the Service was initiating a status review to determine whether listing the species was warranted and that we would issue a 12-month finding. The 12-month petition finding was published in the Federal Register on March 22, 2011 (76 FR 15919). The Service indicated that listing was precluded at that time by higher priority actions. Upon publication of the 12-month petition finding, we added the Berry Cave salamander to our candidate species list and indicated that a proposed rule to list the species would be developed.

The Species Status Assessment (SSA) framework (USFWS 2015, entire) is intended to support an in-depth review of the species' life history and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent of the framework is for the SSA Report to be easily updated as new information becomes available in order to support all functions of the Endangered Species Program, including transition from Candidate Assessment to Listing and Recovery, as well as consultations. As such, this SSA Report will be a living document upon which other decision documents, such as listing rules, recovery plans, and 5-year reviews would be based, if the species warrants listing under the Act.

This SSA Report for the Berry Cave salamander is intended to provide the biological support for the decision of whether or not to propose listing of the species as threatened or endangered and, if so, where to propose designating critical habitat. Importantly, the SSA Report does not result in a decision by the Service on whether this species should be proposed for listing as a threatened or endangered species under the Act. Instead, this SSA Report provides a review of the available information strictly related to the biological status of the Berry Cave salamander. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the Federal Register with appropriate opportunities for public input. For the purpose of this assessment, we generally define viability as the ability of the Berry Cave salamander to sustain natural populations in its habitat (i.e. cave systems) over time. 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 resilience, redundancy, and representation (Wolf et al. 2015, entire).

Resilience describes the ability of populations to withstand stochastic events (i.e., events arising from random factors). We can measure resilience based on metrics of population health, such as population size and birth versus death rates. Highly resilient populations are better able to withstand disturbances such as apparently random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.

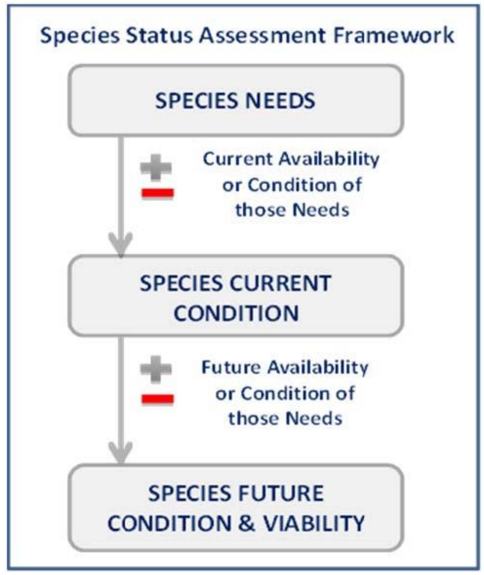


Figure 1-1. Species Status Assessment Framework.

Representation, or diversity, describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is capable of adapting to environmental changes. Greater representation of a species reflects a greater capability for adapting to changes (natural or human-caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range and other factors as appropriate.

Redundancy describes the ability of a species to withstand catastrophic events. Measured by the species' number of populations, resilience of populations, and the populations' distribution (including degree of connectivity), redundancy gauges the probability of a species to withstand or recover from catastrophic events (such as a rare, natural episode involving many populations).

To evaluate the biological status of the Berry Cave salamander, both currently and into the future, we assess a range of conditions to allow us to consider the species' resilience, redundancy, and representation (together, the three R's). This SSA Report provides a thorough assessment of biology and natural history and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the species. The format for this SSA Report includes: (1) the resource needs of individuals and populations (see Chapter 2); (2) the Berry Cave salamander's historical distribution and a framework for determining the distribution of resilient populations across its range for species viability (see Chapter 3); (3) a review of the likely influences on the current and future status of the species and determining which of these risk factors affect the species' viability and to what degree (see

Chapter 4); and (4) a conclusion describing the viability of the species in terms of resilience, redundancy, and representation (see Chapter 5). This document is a compilation of the best available scientific and commercial information and a description of past, present, and likely future risk factors to the Berry Cave salamander.

Figure 2-1. Berry Cave salamander (Photo courtesy Dr. Matthew Niemiller).

CHAPTER 2 – BIOLOGY AND LIFE HISTORY

In this chapter, we provide biological information about the Berry Cave salamander, including its taxonomic history, morphological description, historical and current distribution and range, and known life history. We also discuss the resource needs of individuals.

2.1 Taxonomy

The Berry Cave salamander is a member of the Tennessee cave salamander (*G. palleucus*) species complex that also includes two subspecies of *G. palleucus* (Niemiller et al. 2018, pp. 9-10). The pale salamander (*G. p. palleucus*) is the most widely distributed member of the group and is found in middle Tennessee, northern Alabama, and northwestern Georgia. The Big Mouth Cave salamander (*G. p. necturoides*) is known from several caves in middle Tennessee (Miller and Niemiller 2008), and the Berry Cave salamander (*G. gulolineatus*) (formerly recognized as the subspecies *G. p. gulolineatus*) has been documented at eleven sites, all in the Valley and Ridge Physiographic Province of eastern Tennessee.

Despite morphological differences between these salamander species, the taxonomic status of the Berry Cave salamander was debated after its discovery and subsequent description in 1965. The Berry Cave salamander was recognized as a distinct aquatic, cave-dependent taxon of the Tennessee cave salamander complex by Brandon (1965, pp. 346-352), who described it as a subspecies (*G. p. gulolineatus*). Brandon et al. (1986, pp. 1-2) suggested the Berry Cave salamander should be considered separate from the Tennessee cave salamander based on nonadjacent ranges (it is geographically isolated from other members of the complex), dissimilarity in bone structures of transformed adults, and morphology of neotenic adults. According to Niemiller et al. (2008, p. 2) and based on current taxonomy, the Tennessee cave salamander (*G. palleucus*) and the Berry Cave salamander (*G. gulolineatus*) are recognized as independent species. Most authorities now assign the Berry Cave salamander species-level status (Brandon 1986, pp. 1-2; Collins 1991, p. 43; Niemiller and Miller 2010, p. 1; Simmons 1976, p. 276), so we consider the Berry Cave salamander to be a distinct species.

<u>Genetic Diversity</u>

Niemiller et al. (2009, pp. 3-4) found through genetics study that Berry Cave salamander populations have three unique alleles when compared to the Tennessee cave salamander. The genetic distinction between Berry Cave salamander and spring salamander was also demonstrated during this study, with a low overall level of gene flow between these two species.

However, some molecular evidence has shown that Berry Cave salamanders and spring salamanders (*G. porphyriticus*) interbreed. This was documented during a mitochondrial DNA study of salamanders at Cruze Cave in Knox County, where a small fraction of more than 300 individuals that were morphologically considered spring salamanders also carried alleles typical of Berry Cave salamanders (Niemiller et al. 2018, p. 23).

2.2 Species Description

Morphological Description

The Berry Cave salamander is differentiated from other members of the Tennessee cave salamander species complex by a distinctive dark spot or stripe on the anterior portion of the throat, a wider head, flatter snout, and possibly a larger size (Brandon 1965, p. 347). Members of the species complex are related to the spring salamander (*G. porphyriticus*), which often resides in surface waters but also occupies caves. However, unlike the spring salamander, they usually are found in caves and are neotenic (or paedomorphic, meaning that they normally retain larval characteristics as adults). Individuals occasionally metamorphose and lose their larval characters (Simmons 1976, p. 256; Yeatman and Miller 1985, pp. 305-306), and metamorphosis has been induced by exposing them to hormones (Dent and Kirby-Smith 1963, p. 123).

The Berry Cave salamander (Figure 2-1) is a large member of the genus *Gyrinophilus* (Niemiller and Miller 2010, pp. 1-2), with a maximum documented snout-to-vent length (SVL) of 145 millimeters (mm) (5.7 inches [in.]) (Niemiller 2018, pers. comm.); however, most adults range from 80 to 105 mm (3.15 to 4.13 in.) SVL (Brandon 1966, p. 69). Total length can reach up to 240 mm (9.45 in.) and perhaps greater. The head is broad, with a truncated and spatulate snout. Eyes are reduced, with an eye diameter typically 20 to 25 percent the length of tip of snout to the anterior margin of the eye. The gills are long and pinkish but may become bright red when the salamander is handled or otherwise stressed. Gill rami (i.e., supporting branches of gills at the posterior-lateral side of the head, in figure on title page and Figure 2-1) are distinctly marked with purplish flecks. The limbs are relatively slender and moderately long. There are 18 to 19 trunk vertebrae. The tail is laterally compressed and has a distinct caudal fin that extends onto the dorsum, causing the tail to appear oar-like. A dark spot is sometimes present on the chin and extends posteriorly as a throat stripe in many individuals of some populations (e.g., at the type locality, Berry Cave). The dorsum of larger larvae and presumed adults is heavily pigmented dark brown, with the head slightly darker than the body. Smaller larvae are paler in coloration compared to larger larvae and adults and are usually uniformly colored, whereas, larger larvae and adults possess scattered darker spotting in the form of numerous brownish to purplish dots. These markings increase in size and intensity with age and are largest dorsally, becoming progressively smaller along the sides. The venter and undersurfaces of the limbs and ventral third of the tail are flesh-colored. The lateralis system, important for chemoreception and detecting vibrations, is well-developed on the body and apparent in a distinct pattern of unpigmented sensory pores on the head. A row of sensory pores is also present along each side of the body, beginning at the gills and extending onto the basal half of the tail. Premaxillary, prevomerine, and ptergyoid teeth number 23 to 27, 29 to 33, and 16 to 18, respectively.

Gyrinophilus gulolineatus is distinguishable from congeners by body proportions, coloration, and genetics (Brandon 1965, in Niemiller and Miller 2010, pp. 1-2). *G. gulolineatus* can be distinguished from *G. p. palleucus* by having darker dorsal pigmentation and generally fewer trunk vertebrae (18 in 80% of *G. gulolineatus* versus 52% in *G. p. palleucus*), and from *G. p. necturoides* by possessing fewer trunk vertebrae (18 in *G. gulolineatus* versus 19 in *G. p. necturoides*). Moreover, *G. gulolineatus* differs from both subspecies of *G. palleucus* by having a wider head, flatter snout, thinner limbs, and attaining a greater size (up to 136 mm or greater snout-to-vent length). *G. palleucus* lacks the distinctive chin or throat markings observed in some populations of *G. gulolineatus.*

Metamorphosed specimens of *G. p. palleucus* and *G. gulolineatus* differ in tooth counts, relative eye size, and division of the premaxillary bone (Brandon 1965, in Niemiller and Miller 2010, p. 1). In general, metamorphosed *G. p. palleucus* have fewer maxillary, prevomerine, and premaxillary teeth but more parasphenoid teeth relative to *G. gulolineatus*. Additionally, the premaxillary is divided in *G. gulolineatus* but undivided in *G. palleucus;* and the eyes are larger and, therefore, more conspicuous in *G. gulolineatus* when compared to *G. palleucus*.

Few naturally metamorphosed individuals have been observed, and only one has been thoroughly described (Simmons 1976, pp. 255-257). Naturally metamorphosed individuals typically appear gaunt with attenuate limbs. Their dorsal coloration is a dull yellow with irregular but distinct brown dorsal spots, and their venter is a translucent white. A narrow suture separating the anterior ramus divides the premaxillary. Pterygoid teeth are absent, but the nasals, maxillary, and prefrontals are developed. The nasal processes are divided. Nasolabial grooves are developed. Eyes are relatively large with a 0.022:1 ratio of eye diameter to snout-vent length. Gills are completely reabsorbed, but gill scars remain. The large caudal fin on the tail of larviform individuals is completely reabsorbed, and the tail is keeled in appearance. Eggs and embryos have not yet been described.

G. gulolineatus is known to occur syntopically with only one other species of *Gyrinophilus*, the spring salamander (*G. porphyriticus*) (Niemiller et al. 2018, pp. 9-10). *G. gulolineatus* is distinguished from sympatric and allopatric populations of larval *G. porphyriticus* by coloration and relative eye size. Most larval *G. porphyriticus* lack the prominent chin spot or throat stripe characteristic of *G. gulolineatus*. Furthermore, the eyes of *G. porphyriticus* are larger than those of *G. gulolineatus* and have a discernible iris. *G. gulolineatus* also has more sensory pores on the snout and head than *G. porphyriticus*. However, hybridization between *G. gulolineatus* and *G. porphyriticus* complicates identification of larvae in some Knox County caves (e.g., Mudflats Cave and Meads Quarry Cave) where the species co-occur.

2.3 Life History

Life cycle

Life history of the Tennessee cave salamander complex is poorly documented due to the organisms' reclusive natures and the relative inaccessibility of subterranean environments (Niemiller 2006, p. 9). Collections of animals in the same location during mark-recapture studies suggest that Berry Cave salamander territories are small and that the species tends to exhibit site fidelity and limited movement (Miller and Niemiller 2008, p. 11).

Little is known about breeding habits, life spans, or population sizes for any member of the Tennessee cave salamander complex (Miller and Niemiller 2018, p. 2). Timeframes of metamorphosis from larval stage to reproductive adult are currently undocumented. Members of the Tennessee cave salamander complex are paedomorphic and become sexually mature without metamorphosing into an adult form (Brandon 1965, p. 346-347). Females in the Tennessee cave salamander complex are believed to be gravid from late autumn to early winter (Niemiller et al. 2010, p. 39). *Gyrinophilus* species are generalist feeders, and cannibalization of individuals and eggs in early life stages of the same species may cause females of some species to seek isolation from main cave streams for oviposition (depositing eggs) (Niemiller et al. 2010, pp. 38-39). To date, neither eggs nor embryos have been described (Niemiller and Miller 2010, p. 1).

Egg masses have not been found, but it is thought that females lay eggs attached to cover objects such as the sides of rimstone pools and other rocky material in late summer or early autumn. Small hatchlings have been found in December and January (Simmons 1975, in Niemiller et al. 2018, p. 3). Likewise, information about size at sexual maturity is not conclusive, although female and male individuals are generally recognized as sexually mature at 70 millimeters (2.76 in.) snout-to-vent length (Simmons 1975, in Niemiller et al. 2018, p. 5). This is considered the threshold between "juvenile" and "adult" size classes. Also, limited data suggests that individuals greater than 100 millimeters (mm) (3.97 in.) SVL are at least 10 years of age (Niemiller et al. 2018, p. 20).

Growth rates are presumably slow, based on preliminary data, but have not been thoroughly investigated. Niemiller (2018, pp. 19-20) recaptured a salamander at Meads Quarry Cave, which was first captured and marked in April 2008. At initial capture, this individual measured 75 mm (2.95 in.) snout-to-vent length (SVL). The same salamander measured 80.5 mm (3.17 in.) SVL in November 2017, growing only 5.5 mm (0.22 in.) SVL in 9.5 years. Although one individual, this anecdotal observation suggests that some members of the species may be very long-lived.

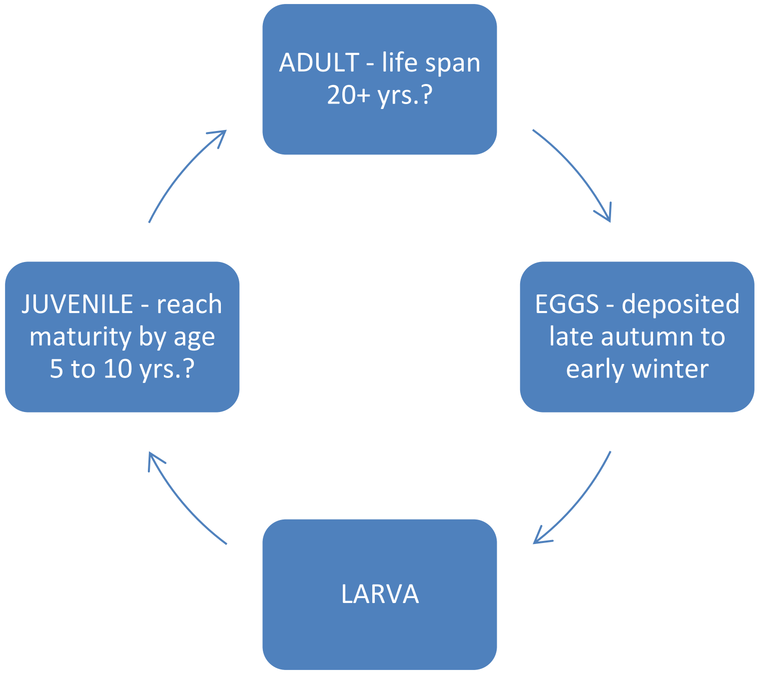


Figure 2-2: Berry Cave salamander lifecycle.

2.4 Resource Needs and Habitat

Habitat

The Berry Cave salamander is associated with subterranean waters within the Appalachian Valley and Ridge Physiographic Province of eastern Tennessee, which is characterized by elongate ridges and valleys that are oriented northeast to southwest. Because of the folding and faulting, lateral flow of water in the permeable formations generally does not occur (Brahana et al. 1986, p. 4). This likely results in restriction of subterranean dispersal and gene flow among populations of aquatic organisms. The East Tennessee aquifer system is isolated from the stratigraphic aquifer systems to the west by a zone of faulting that, likewise, acts as a significant physical barrier for subterranean dispersal between Tennessee cave salamanders and Berry Cave salamanders (Niemiller et al. 2018, p. 17).

Limited information is available concerning habitat requirements of the Berry Cave salamander (See Table 2-1. Berry Cave salamander life stage needs.). Although variable, the pH of streams and pools occupied by the species has been documented in the range of 7.2 to 7.6, and water temperature was within the range of 12.0–14.0 °C. Water quality needs have not been comprehensively evaluated for the species, but these pH values and temperatures may be considered typical water quality ranges for each life stage.

Cave-obligate salamanders benefit from inflow of organic detritus that then supports the invertebrate communities that serve as the forage base for salamanders. The natural amount of detritus that can enter a cave system and act as the energy source for the food web is controlled by the amount and location of vegetation present in the watersheds contributing to the underground system. Increases in detritus are generally thought to improve conditions for the Berry Cave salamander.

Individuals are typically found in low-velocity pools with mud substrate in Knox County populations or in pools with gravel/cobble substrate (See Figure 2-3). Pools vary in depth from a few centimeters to over four meters (13.12 feet [ft.]). Although many individuals have been observed resting on the bottom of pools, others have been found underneath cover, such as rocks, logs, and other organic debris. Juveniles are often found beneath rocks and within the interstices of cobble in riffles (Niemiller et al. 2018, p. 1). The species' ability to escape potential predators will increase at sites with high quality and quantity of rock cover habitat. This material is also likely used as substrate for egg deposition, thereby supporting production of larval salamanders. Substrate materials vary between caves in terms of size and texture, but larger cobble and boulder provide a better substrate for egg deposition than smaller substrates.

Figure 2-3. Berry Cave salamander habitat. Left: Cobble and boulder habitat in Berry Cave, Roane County. Right: Silted, rocky habitat in Meads River Cave, Knox County. Photographs courtesy Dr. Matthew Niemiller.

Water availability is fundamental to survival of the Berry Cave salamander. All life stages rely on sufficient flow as their source of oxygenated water and for habitat availability, especially during low-flow seasons. For example, eggs and larval stages utilize rock substrate generally during winter, extending into spring. Low streamflow (especially during summer and fall) can reduce availability of escape cover material for juveniles and adults in some portions of cave systems, resulting in migration to habitat of greater suitability.

Streams inhabited by Berry Cave salamanders are quite dynamic and vary in depth and velocity depending on local precipitation. For example, water levels at Mudflats Cave varied by approximately two meters over a 14-day period (Niemiller et al. 2018, p. 14). Salamanders presumably seek shelter when streams are in flood and demonstrate a degree of adaptation to significant fluctuations in stream flows. Juveniles have been found in the same habitats as adults, although reports of individuals of small size classes are lacking from most surveys, suggesting either observer bias or that smaller individuals utilize different habitat (Niemiller et al. 2018, p. 17).

Home range sizes have not been estimated but are thought to be small. Simmons (1975, in Niemiller et al. 2018, p. 17) found during mark-recapture studies that most salamanders remain in the same location, and some even under a single boulder. Niemiller et al. (2018, p. 20) obtained sufficient recaptures over reasonable temporal scales to estimate movement parameters for Berry Cave salamanders at Meads Quarry Cave, where they re-captured 27 unique individuals three or more times (± 1.2 SD, with a maximum number of six re-captures), from January 31 to September 10, 2008. Mean distance between recapture locations during that study was 17 meters (55.8 ft.), and mean estimated activity range size was 26 meters (85.3 ft.). No evidence of movement directionality was observed. Additionally, all individuals with at least three recaptures either did not change locations between capture occasions or exhibited overlap with prior movements, suggesting evidence of core territories.

<u>Population Needs</u>

In order to remain viable, each population of the Berry Cave salamander needs to be able to withstand, or be *resilient* to, stochastic events or disturbances. These are events that are reasonably likely to occur and may occur frequently enough that they can drastically alter the ecosystem where they happen. Classic examples of stochastic events include drought, major storms such as hurricanes, fire, and landslides (Chapin et al. 2002, pp. 285-288). To be resilient to stochastic events, populations of Berry Cave salamanders need to be of sufficiently robust density (i.e., abundance) to support 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 all of these factors, a population has an increased likelihood for localized extirpation. Note that we use the term "population" in a general sense here, and we describe its use more thoroughly in Chapter 4. In general, distinct populations are ones that are not expected to undergo noticeable population increases or decreases over two to three generational periods.

<u>Species Needs</u>

For a species to persist and thrive over time, it must exhibit attributes across its range that relate to either representation or redundancy (Figure 2-4). *Representation* describes the ability of a species to adapt to changing environmental conditions over time and encompasses the "ecological and evolutionary patterns and processes that not only maintain but also generate species" (Shaffer and Stein 2000, p. 308). It is characterized by the breadth of genetic and environmental diversity within and among populations. For the Berry Cave salamander to exhibit adequate representation, resilient populations should occur in the ecoregion to which it is

Table 2-1. Berry Cave salamander life stage needs.

Life Stage	Resources Needed	Corresponding Information Source
Fertilized Eggs	Solid substrate for egg deposition	Niemiller et al. 2018, p. 3
	Sufficient water quantity	Niemiller et al. 2018, pp. 2 and 17
	Water quality (pH about 7.2-7.6, temperature approximately 12-14 degrees C [53.6 – 57.2 ºF], non-toxic conditions)	Ogden 2005, p. 14; Niemiller et al. 2018, p. 17
Larvae	Sufficient water quantity	Niemiller et al. 2018, pp. 2 and 17
	Invertebrate food source	Niemiller et al. 2018, p. 22
	Water quality (pH and temperature, non-toxic conditions)	Ogden 2005, p. 14; Niemiller et al. 2018, p. 17
Juveniles	Rock and woody cover	Niemiller et al. 2018, pp. 2 and 17
	Sufficient water quantity	Niemiller et al. 2018, p. 17
	Invertebrate food source	Niemiller et al. 2018, p. 22
	Water quality (pH and temperature, non-toxic conditions)	Ogden 2005, p. 14; Niemiller et al. 2018, p. 17
Adults	Rock and woody material for cover and for egg-laying substrate	Niemiller et al. 2018, pp. 2 and 17
	Sufficient water quantity	Niemiller et al. 2018, p. 17
	Invertebrate food source	Niemiller et al. 2018, p. 22
	Water quality (pH and temperature, non-toxic conditions)	Ogden 2005, p. 14; Niemiller et al. 2018, p. 17

native (i.e., the Valley and Ridge); these populations should occur at the widest extent possible across the historic range of the species; and they should occupy multiple cave systems in drainages where they are native. The breadth of morphological, genetic, and behavioral variation should be preserved to maintain the evolutionary variation of the species. Finally, natural levels of connectivity should be maintained between representative populations because movement allows for the exchange of novel and beneficial adaptations where connectivity is high or is the mechanism for localized adaption and variation where the species is naturally more isolated (Figure 2-4).

Redundancy describes the ability of a species to withstand catastrophic events. It "guards against irreplaceable loss of representation" (Redford et al. 2011, p. 42; Tear et al. 2005, p. 841) and minimizes the effect of localized extirpation on the range-wide persistence of a species (Shaffer and Stein 2000, p. 308). Redundancy for the Berry Cave salamander is characterized by having resilience in multiple caves and cave systems across the native range of the species. For this species to exhibit redundancy, it would have multiple resilient populations with connectivity maintained among them. In terms of redundancy, connectivity is important because it allows for migration between populations and increases the likelihood of recolonization should a population become extirpated.

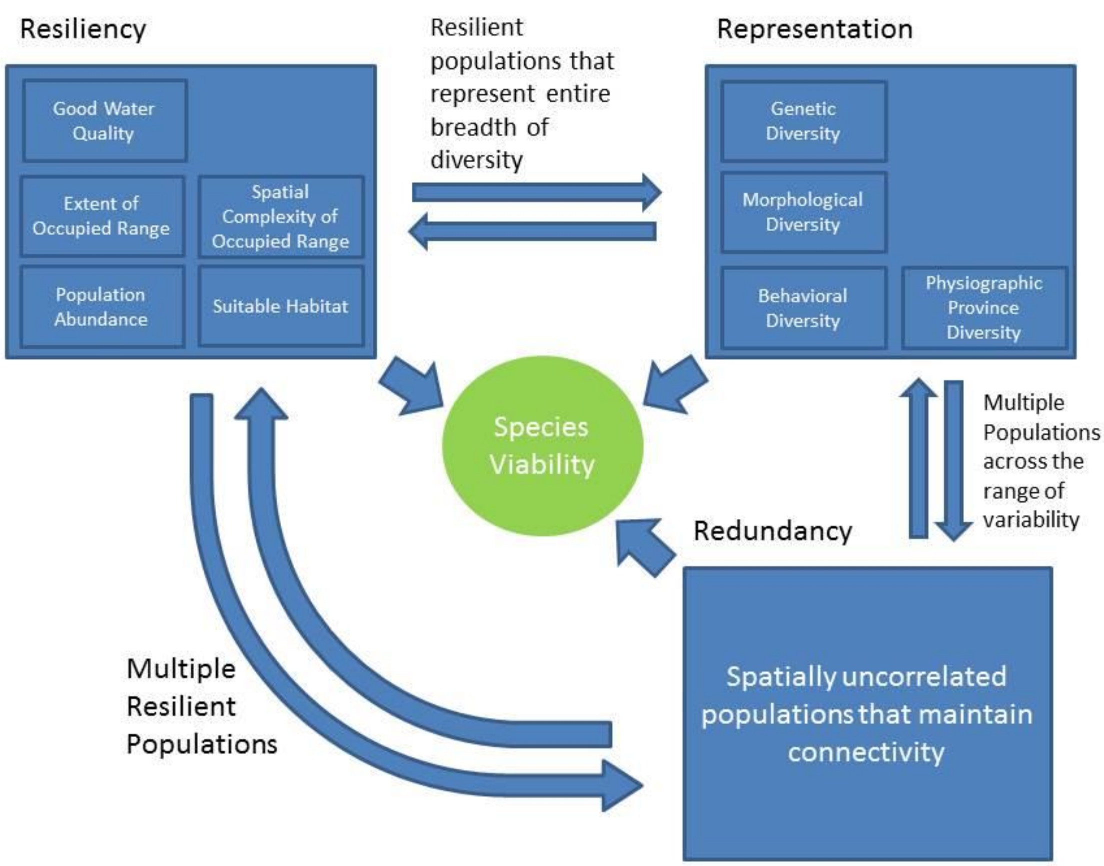
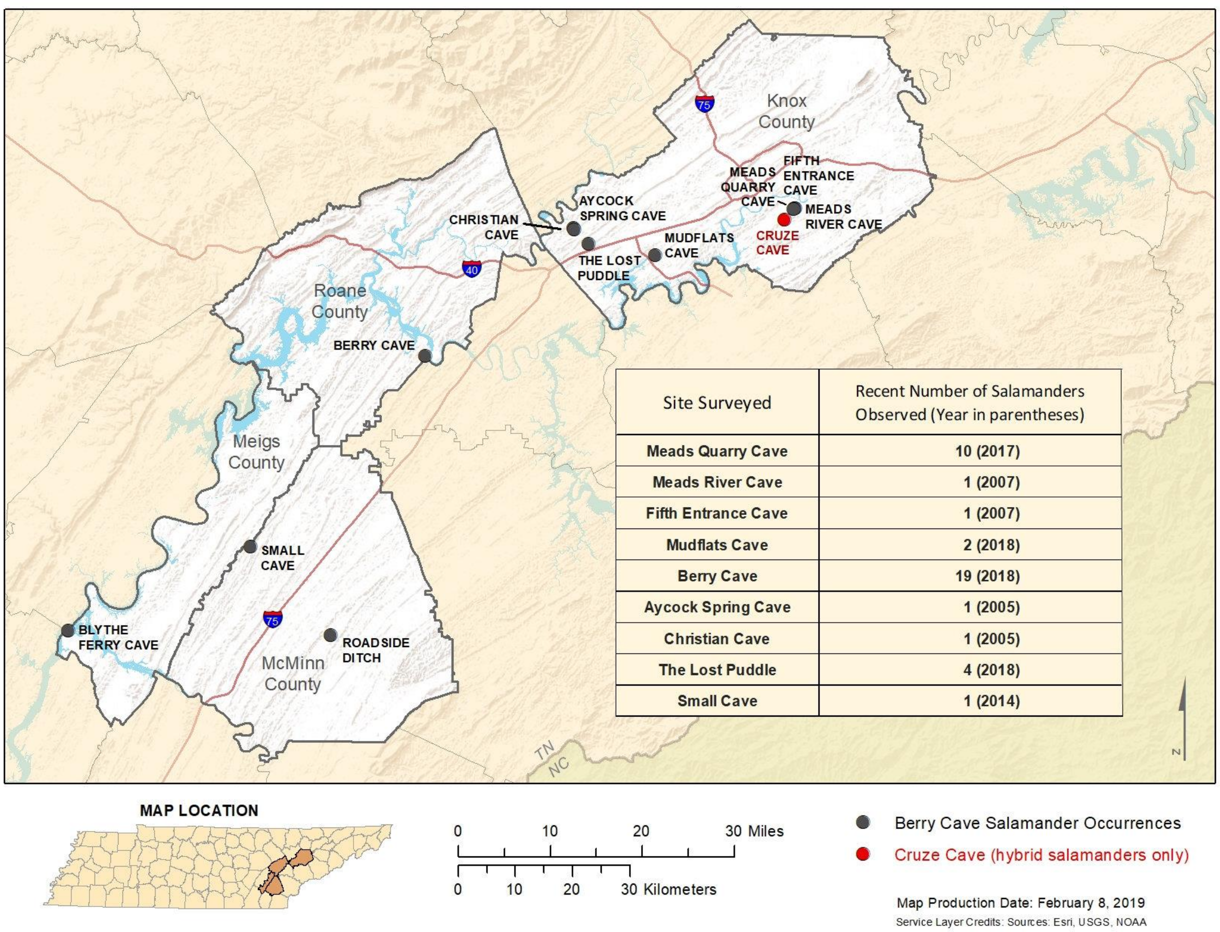


Figure 2-4. How resiliency, representation, and redundancy are related to species viability.

2.5 Range and Distribution

Historic Range and Distribution

The Berry Cave salamander occupies the Clinch River and upper Tennessee River watersheds of the Valley and Ridge Physiographic Province in eastern Tennessee (See Figure 2-5). Until recently, the Berry Cave salamander was known from just eight caves (Niemiller et al. 2009, p. 2) and a roadside ditch. The species was discovered at two new sites since 2009 – Small Cave in McMinn County and The Lost Puddle in Knox County. Although historic occupation of Cruze Cave (near Meads Quarry Cave) by the Berry Cave salamander is not formally recognized, the species' hybridization with the spring salamander, *Gyrinophilus porphyriticus*, was documented at that site through genetics study (Niemiller et al. 2018, p. 23).



Site Surveyed	Recent Number of Salamanders Observed (Year in parentheses)
Meads Quarry Cave	10 (2017)
Meads River Cave	1 (2007)
Fifth Entrance Cave	1 (2007)
Mudflats Cave	2 (2018)
Berry Cave	19 (2018)
Aycock Spring Cave	1 (2005)
Christian Cave	1 (2005)
The Lost Puddle	4 (2018)
Small Cave	1 (2014)

Figure 2-5. Map of Berry Cave salamander known historic and currently occupied sites.

Current Range

Beginning in October 2017, surveys were conducted at localities known to support the Berry Cave salamander to better determine size (abundance) and structure (size classes) of the extant populations. Further, surveys to locate undiscovered populations were (and are being) conducted at caves in the Valley and Ridge Physiographic Province where the species has not been reported. Survey results for the most robust populations (i.e., Meads Quarry Cave system, Mudflats Cave, and Berry Cave) are shown in Appendix A (Niemiller et al. 2018b, pp. 36-38). Presence information for the Berry Cave salamander and spring salamander is itemized by cave in Appendix B for salamander surveys conducted within and near the Berry Cave salamander distributional area (Niemiller 2018, pers. comm.).

Salamander surveys involve slow searches of aquatic habitat for adults and larvae beneath rocks and other debris and within small cobble. Due to variability in the amount of cave that is accessible to surveyors and the type and amount of escape cover available to salamanders, we recognize there is varying probability of salamander detection between caves and a corresponding degree of uncertainty in estimating populations. Caves where the Berry Cave salamander or its hybrids have been found recently are listed here, with an estimate of the amount of linear habitat searched in parentheses: Meads Quarry Cave (980 meters (m)), Meads River Cave (305 m), Fifth Entrance Cave (50 m), Mudflats Cave (90 m), Aycock Spring Cave (75 m), Christian Cave (50 m), The Lost Puddle (50 m), Berry Cave (180 m), Small Cave (90 m), Blythe Ferry Cave (0 m due to no permanent water, but all accessible cave passage searched), and Cruze Cave (280 m).

Since discovery of the Berry Cave salamander in the 1950's, neither significant range expansion nor contraction has been documented (Niemiller et al. 2018, p. 21). Survey numbers at the three sites with greatest densities of Berry Cave salamanders (See Table 2-2) have experienced varying trends. Abundance at the Meads Quarry Cave system appears to have declined since surveys in 2007 and 2008, and Berry Cave experienced increased observed abundance in the same time period. The population trend at Mudflats Cave is unclear, as water levels were highly variable during the winter of 2017-2018 and the following spring. Viewed over the long-term, these three populations do not appear to have suffered an appreciable decline. Other sites at which the Berry Cave salamander is currently considered extant but that appear to have lower abundances include Meads River Cave, Fifth Entrance Cave, The Lost Puddle, Aycock Spring Cave, Christian Cave, and Small Cave.

Based on proximity to each other, half of known occupied sites can be combined as the Meads Quarry/Meads River/Fifth Entrance cave system and the Aycock Spring/Christian cave system as species analysis units. This method of organizing species populations is discussed later in the SSA Report.

Finally, three sites from which Berry Cave salamanders or its hybrids have been documented (i.e., Blythe Ferry Cave, Cruze Cave, and a roadside ditch in McMinn County) are currently not considered to contain viable populations. A search of Blythe Ferry Cave (Meigs County) in 2018, in addition to a number of previous searches, did not result in observation of the species, and suitable habitat appeared limited (based primarily on lack of water). Likewise, Cruze Cave (Knox County) was surveyed for the species in 2018 with unsuccessful results. Further, the area of the 1953 roadside ditch record has been unsuccessfully searched for an underground source for the species. Long-term monitoring of the cave sites is expected to continue.

Table 2-2. Summary of historical and current localities of the Berry Cave salamander (*Gyrinophilus gulolineatus*), indicated dates last surveyed and maximum number of the species observed. Sites of currently extant populations are in bold.

Site (Year Last Surveyed in Parentheses)	Maximum Number of Salamanders Observed (Year in parentheses)	Recent Number of Salamanders Observed (Year in parentheses)
***Meads Quarry Cave (2018)**	**24 (2008)**	**10 (2017)**
Meads River Cave (2018)	**1 (2007)**	**----**
Fifth Entrance Cave (2018)	**1 (2007)**	**----**
Mudflats Cave (2018)	**6 (1984)**	**2 (2018)**
Berry Cave (2018)	**19 (2018)**	**19 (2018)**
Aycock Spring Cave (2018)	**1 (2005)**	**----**
Christian Cave (2005)	**1 (2005)**	**----**
The Lost Puddle (2018)	**4 (2018)**	**3 (2012)**
Small Cave (2014)	**1 (2014)**	**1 (2014)**
Blythe Ferry Cave (2018)	1 (1975)	0 (2018)
Cruze Cave (2018)	----	0 (2018)
Roadside ditch at Athens, TN	3 (1953)	----

*Extant populations in bold.

CHAPTER 3 – FACTORS INFLUENCING VIABILITY

The following discussion provides a summary of the factors that are affecting or could be affecting the current and future status of the Berry Cave salamander throughout all or a portion of its range.

3.1 Land Use and Associated Impacts

Historic Quarry Operation and Residual Effects

Meads Quarry Cave is located at the site of a marble quarry that was operable in the 1930's and 1940's. During the quarry operation, a large volume of lime material was deposited on the surface of the site, the location of which correlates with white leachate that has been deposited within Meads Quarry Cave (Figure 3-1). In January 2008, Niemiller and Benjamin Fitzpatrick (Niemiller et al. 2018, pp. 12-13) measured pH and oxidation-reduction potential (ORP) of the stream within the cave. ORP is an expression of the ability of water to break down contaminants by the reduction of a chemical through acquisition of electrons. The value of ORP in interpreting water quality information is greatly enhanced if coupled with other common parameters. For example, excess chlorine in wastewater effluent can result in a large positive ORP value, and the presence of hydrogen sulfide can be reflected in a large negative ORP value. The pH was 7.4 upstream of the deposition site in 2008 and reached 10 to 12.5 in a pool immediately down-slope of the deposit. ORP showed a similar pattern. It averaged -25 mV upstream of the deposit and -80 mV (millivolts) downstream of the deposit, reaching -320 mV in the pool immediately downstream. Niemiller et al. have observed burn-like lesions on salamanders near the site of the deposit (2018, p. 22) and documented dead, metamorphosed salamanders in the same area (2018, p. 20).

Other Chemical Toxicants

Due to the proximity to cave systems, a variety of human-related activities may contribute inputs to streams occupied by the Berry Cave salamander. Inappropriate or excessive chemical application in residential areas (e.g., glyphosate) and stormwater runoff from roads are likely to introduce salts, oils, and other substances to the water quality constituents of streams occupied by the species. For example, residential development during the last decade in the immediate vicinity of Aycock Spring Cave and Christian Cave is of concern in this regard. New houses are located adjacent to Christian Cave, increasing the potential for introduction of toxicants into the cave system. Likewise, fertilizers and livestock waste can contribute pollutants that alter groundwater quality, with subsequent influences on cave bioenergetics.

Figure 3-1. Quarry leachate deposit in Meads Quarry Cave, Knox County. Photograph courtesy Dr. Matthew Niemiller.

Sediment

Soil disturbance and sediment transport are associated with several activities within the range of the Berry Cave salamander. The initial stage of residential and commercial development projects tends to result in a pulse of sediment transport to downstream areas, including potential embeddedness of salamander habitat within groundwater systems and negative influences upon prey item availability for the species. Depending on the spatial and temporal extent of development (and effectiveness of sediment containment practices), any particular activity could chronically impact salamander habitat through covering of rocky substrate.

Fecal Coliform Bacteria

Livestock (i.e., cattle and horses) and residences with septic systems occupy the watershed draining to Berry Cave, the type locality for Berry Cave salamander. Fecal coliform bacteria that may accompany these inputs likely affect the stream in this cave to varying degrees, depending on factors such as bacterial sources and dilution effects associated with precipitation events. Atypical nodules that were observed on Berry Cave salamanders at the type locality have been attributed to possible parasites (Niemiller 2017, pers. comm.). Fecal coliforms could conceivably contribute to stress of salamanders with a corresponding increase in parasite growth. Although the presence of fecal coliform bacteria has not been researched at sites occupied by the Berry Cave salamander, its detection would not be unexpected.

Detrital Input

Detrital input to caves provides an important energy source for production of invertebrates, a primary food source for Berry Cave salamanders. Among sites occupied by the species, forested habitat (versus grassed, developed, or aquatic habitat) within one-half mile of caves ranged from 38 percent at Christian and Aycock Spring Caves to 70 percent at Small Cave. Forest coverage for the other cave systems were: Berry Cave – 47 percent, The Lost Puddle – 51 percent, Meades Quarry Cave system – 67 percent, and Mud Flats Cave – 41 percent.

Detrital input to cave systems can be reduced as a result of various watershed perturbations, including residential and commercial development, road projects, and impacts to forested riparian zones. Reduction in the number of trees and other vegetation in the vicinity of cave entrances can eliminate sources of detritus, which can limit the transport of organic matter into cave systems and have negative effects on cave food webs. Although this habitat element can be difficult to monitor precisely within caves, significant decreases or increases could affect salamander population dynamics.

Urbanization

Urbanization refers to a transition from rural landscape (e.g., forested or agricultural) to a more urban setting with increased density of residential and/or commercial infrastructure. Urbanization introduces a multitude of stressors into lotic systems that co-vary and have synergistic effects that are difficult to differentiate (Matthaei and Lang 2016, p. 179). Streams affected by urbanization have been described as exhibiting an "urban stream syndrome" (Matthaei and Lang 2016, p. 180; Wenger et al. 2009, p. 1090; Walsh et al. 2005, p. 707). This syndrome consistently manifests as more variable stream flows, higher amounts of pollutants, and altered channel stability and morphology, and it may also result in reduced baseflow and increased suspended solids. A reduction in number of aquatic species and increase in number of tolerant species are often associated with urban streams (Walsh et al. 2005, p. 712; Paul and Meyer 2001, p. 349). Due to increased amounts of impervious surfaces in urban areas, the storm discharge of urban streams can be twice that of rural streams draining a watershed of similar size (Pizzuto et al. 2000, p. 81; Rose and Peters 2000, p. 1454), and the frequency of channel-forming events can be ten times that of pre-development conditions (Booth and Jackson 1997, p. 1078). Therefore, stressors such as altered stream flows, higher pollutant load, and alteration of the salamander forage base are likely to increase as a result of urbanization.

Cave systems occupied by the Berry Cave salamander occur in watersheds that vary in the amount of urbanization present. Two of the cave systems (Meads Quarry and Mudflats) are immediately adjacent to developed parts of metropolitan Knoxville. Christian Cave and Aycock Spring Cave, which are located approximately 0.3 mile from each other, are immediately adjacent to an area that has recently undergone residential development. The other Berry Cave salamander population sites (Berry Cave, Lost Puddle, and Small Cave) are near but not immediately adjacent to areas that are becoming more populated and urbanized.

3.2 Cave Visitation

Human visitation rates among caves occupied by the Berry Cave salamander are generally not documented but are thought to be highly variable (Niemiller et al. 2018, pp. 22-23). Potential impacts resulting from human visitation include direct physical crushing (resulting in injury or death of individual salamanders or eggs), introduction of a pathogen such as chytrid fungus or ranavirus, and disturbance that leads to decreased success in egg deposition.

Although the Berry Cave salamander is elusive, it is relatively easy for an experienced collector to capture (Miller and Niemiller, unpubl. data), and it can be a target for collection. Therefore, the potential for depletion of salamander populations at some sites is significant. A few searches over a several-day period would likely result in finding many of the larger salamanders, even though Berry Cave salamanders potentially use sections of stream channel that are inaccessible to humans. Removing significant numbers of salamanders from any particular site could greatly diminish a breeding population, many of which are already low in density. For a species with potentially low reproductive rates, this could jeopardize populations at some sites. Increased residential development, in particular, can result in increased visitation when proximal to occupied sites.

3.3 Predation and Competition

Predation

Gyrinophilus salamanders are aggressive and cannibalistic toward other members of the same species (Niemiller et al. 2018, p. 20). Co-occurrence of *G. gulolineatus* and *G. porphyriticus* (spring salamander) has been documented in the Meads Quarry Cave system, Mudflats Cave, and Small Cave, and inter-specific predation (including other faunal types such as fish and crayfish) may occur but has not yet been documented. However, predation has not been demonstrated as a threat to either species.

Competition and Hybridization

Cruze Cave (Knox County) is a site at which Berry Cave salamanders may have previously occurred along with the spring salamander (*Gyrinophilus porphyriticus*). Inter-breeding between these species was demonstrated during a mitochondrial DNA study of salamanders at Cruze Cave (Niemiller et al. 2009, p. 4), where a small number of spring salamanders carried alleles typical of Berry Cave salamanders (Niemiller et al. 2018, p. 23). More than 360 observations of spring salamanders were made there from October 2004 to July 2006, but presence of the Berry Cave salamander was not confirmed during the surveys (Miller and Niemiller 2008, pg. 20). Based on the genetic data from spring salamanders at Cruze Cave, it appears that the species may occasionally interbreed with Berry Cave salamander, which may lead to hybridization of these species. If this were to happen at other sites, there is potential for hybridization to become a threat to the Berry Cave salamander.

Although hybridization between these two species was demonstrated at Cruze Cave, the reason for current absence of the Berry Cave salamander is not entirely clear. Spring salamanders often occupy surface habitats that support invertebrate communities with higher levels of productivity than typically observed in cave environments. This species may simply have an advantage over the Berry Cave salamander in the ability to compete for food resources, resulting in higher population densities. It is also possible that the Berry Cave salamander has not had an established population at the site historically. Because of the typical separation in ecological niches between the two species, hybridization with the spring salamander is not currently thought to have significant impacts on the Berry Cave salamander.

3.4 Water Quantity

Decreased streamflow can result in reduced availability of salamander habitat. However, anthropogenic influences upon flow have not been documented in the range of the Berry Cave salamander. Metropolitan Knoxville could possibly affect cave ecosystem dynamics in a situation where groundwater was an important source for domestic or commercial water supplies, but the city utilizes a surface source (i.e., the Tennessee River) instead. Well water sources for rural residences are also considered to be of minimal influence on groundwater dynamics across the species' range, and many households in rural areas are beginning to utilize public water utilities as supply systems extend into less-populated portions of eastern Tennessee. Likewise, no other potential water uses such as irrigation are known to cause significant impacts to cave systems in areas occupied by the species.

3.5 Climate and Weather

Streamflow within caves occupied by Berry Cave salamanders has potential implications for viability of individual populations and the species as a whole. Climate has potential long-term implications on the flow regime of any particular cave system, affecting various aspects of the Berry Cave salamander's life history and habitat. Greater extremes in temperature and precipitation are projected for the region, which increases the likelihood that the species will be affected.

Drought is of particular concern as it would likely accelerate drying of aquatic habitats, potentially exceeding the adaptive capacity of some species (Glick et al. 2015, p. 32). Effects of drought conditions are realized most readily as impacts to various stages of the Berry Cave salamander's life cycle (Glick et al. 2015, p. 97). Although demonstrating some degree of adaptability to drought conditions, the species may be negatively affected by significant changes in climate. For example, reduced wetted surface area of rock substrate would provide less area for egg deposition, and lower water levels within cobble habitat in riffles would result in less cover habitat for use by larval salamanders. Drought conditions would also expectedly affect other environmental variables such as invertebrate community dynamics and water quality (e.g., temperature, dissolved oxygen, and concentration of toxicants).

Flooding could also be deleterious to the Berry Cave salamander in terms of flushing of individuals from subterranean habitat, as observed at a site near Athens, Tennessee in 1953 when three salamanders were found in a roadside ditch. Transport of salamanders from preferred sites to areas within cave systems that have lower habitat value could also act as a stressor as a result of either increased frequency of flooding or increased volume associated with particular flooding events. Silt deposition in association with high-precipitation events can cover rock substrate with effects upon invertebrate food sources, egg deposition, and escape cover (i.e., boulders, cobble, and bedrock with cracks).

3.6 Synergistic Effects

Use of conservation measures can potentially curtail the effects of sediment load, toxicants, and other inputs to caves, but climate effects such as drought can compound the stress caused by pollutants. Salamander populations that already exhibit lower densities due to predation, human collection, or other means can be especially sensitive to such stressors, and multiple simultaneous or chronic stressors could result in negative, synergistic effects on viability of the Berry Cave salamander.

3.7 Conservation Actions

Gates and fencing

Entrances to Christian Cave and the Meads Quarry / Meads River Caves complex are gated and managed by private entities to restrict human visitation into those areas. The entrance to Blythe Ferry Cave has been fenced by the owner, the Tennessee Valley Authority.

Conservation Management Agreement

The owners of Berry Cave worked with the Service, Tennessee Wildlife Resources Agency, and The Nature Conservancy to develop a conservation management agreement, which was signed in 2003. The agreement was developed to express the intent of the partners to manage the cave proactively for conservation of the Berry Cave salamander and other fauna. The primary focuses of the effort are management of human visitation, non-permitted removal of salamanders from the cave, and management of water quality inputs to the stream within the cave.

Management of water quality constituents

Forested riparian buffer zones associated with caves occupied by Berry Cave salamanders are being managed to some degree, and ongoing management activities vary from site to site.

Various aspects of management specific to riparian zones and adjacent areas include: improvement of forested zone widths, livestock removal and/or incorporation of best management practices (e.g., fencing and use of ponds to control waste transport), road improvements (or lack thereof), development of greenways along riparian zones, and stabilization of eroding sites. Presence of waste material at the Meads Quarry site is a specific concern that could possibly be addressed through some degree of treatment or containment to minimize the transport of leachate into underground waters.

3.8 Summary of Factors Influencing Viability

In summary, any factor that impacts the Berry Cave salamander's physical habitat, water quality of the streams it inhabits, or that otherwise affects population densities will likely have a deleterious effect upon the species. Impacts to streams' physical environment (i.e., substrate and water quality) are considered the primary sources of stressors on the Berry Cave salamander. Impacts to substrates affect egg success and health of invertebrate communities (i.e., the salamander's forage base), and water quality is crucial to success of all stages of the salamander's life cycle. Pollutants (especially sediment and toxicants) associated with various land-use activities are important stressors to the Berry Cave salamander. They are transported from residential and commercial development areas and road construction projects into caves. Waste leachate from a historic quarry appears to have caused salamander mortality at the Meads Quarry Cave site, and fecal coliform bacteria from livestock and/or septic systems may act as a stressor in the Berry Cave watershed. Stressors and their association with potential for increased disease are a concern among amphibians in general, although not yet demonstrated as a factor for this species.

Although negative effects due to drought and flooding have not been demonstrated, these potential stressors are likely to result in episodic impacts to populations. Further, removal of salamanders from populations through human collection may exacerbate threats to the species at those sites. Likewise, detrital input to underground waters is a consideration relative to impacts. It has not been a focus of survey efforts, but severe restriction of detrital input can result in impacts to invertebrate communities and can have subsequent effects on salamander populations.

Conservation measures may counteract some sources of stress to Berry Cave salamander populations (Walsh et al. 2005, pp. 716-719; Wenger et al. 2009, pp. 1090-1093). Efforts to minimize sediment transport improves physical habitat and water quality. Forested stream buffer zone enhancements tend to boost detrital input, buffer water temperatures, and reduce pollutant transport. Gating and fencing of cave entrances usually limit human visitation, with expected reduction in salamander injury and collection.

CHAPTER 4 – POPULATION AND SPECIES NEEDS AND CURRENT CONDITION

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

For this analysis, we divided the Berry Cave salamander's range into six Analysis Units (AUs) based on locations of caves and cave complexes where the species has been known to occur (Figure 2-5). Although movement of Berry Cave salamanders from one cave to another within these units has not been documented, such movement is believed likely due to the close proximity of some of these caves to each other. The frequency of dispersal of the species between the AUs is unknown, but it is likely infrequent based on the small home ranges observed (Niemiller et al. 2018, p. 20) and due to the relatively large distances between documented sites (i.e., AUs). The minimum distance between analysis units is approximately three miles, while the greatest distance is approximately 25 miles, with an average distance of approximately 12 miles. Where we might normally use the term "population" in an SSA Report, we chose to use Analysis Unit instead for this SSA Report, because we lack information on the species' mobility and the degree of interbreeding that occurs between AUs (if any). However, we acknowledge that there is some uncertainty related to the isolation of the occupied habitats, which might show that all of AUs comprise a single population or that the AUs represent multiple populations.

Current habitat and population conditions are described below. This chapter details specific stressors acting within the occupied habitats. Additionally, collection history and qualitative abundance data are provided. Current population resilience is assessed for each location and Analysis Unit (AU), followed by a summary of range-wide redundancy and representation.

To qualitatively assess the species' current viability, we considered six elements (Table 4-1) that influence survival and reproduction of the Berry Cave salamander ("Population Elements") or constitute the physical and biotic environmental factors that contribute to survival and reproduction of the species ("Habitat Elements"). Population elements included observed Berry Cave salamander abundance and population demographic complexity; the habitat elements evaluated were water quality (constituents of which include toxicants, fecal coliforms, and sediment), availability of rock habitat, detrital load, and evidence of human visitation.

4.1 Population Elements

To evaluate population elements, we used data from an ongoing survey of the species and other species records from the past 45 years (Niemiller et al. 2018, entire). The ongoing survey is being conducted primarily at sites where Niemiller previously observed the species, and other sites of potential occupation are being investigated. A tagging/recapture study is currently being conducted at sites that exhibit the greatest potential for recapture. The survey efforts are standardized and employ methods that specifically target salamanders across all size classes.

The *Species Abundance* element categorizes relative salamander abundance at each AU based on quantitative survey results. AUs with higher numbers of salamanders are more likely to have higher resiliency than AUs with lower numbers of salamanders. We recognize, however, that there is some level of uncertainty related to salamander abundance categories due to (a) the variability in the amount of cave passage that can be surveyed at each AU and (b) the type and amount of habitat available.

The *Population Demographic Complexity* element categorizes the demographic characteristics of each AU. AUs with observations of larval or juvenile life stages are indicative of a reproducing population. AUs demonstrating reproduction are, therefore, more likely to have higher resiliency and representation than non-reproducing AUs.

4.2 Habitat Elements

The *Water Quality* element is a qualitative estimate of water quality at each AU. Suitable water quality is more likely to occur in AUs with watersheds that have natural or semi-natural landscapes. AUs in watersheds that are heavily degraded (e.g., urban areas) are more likely to have current and/or future water quality impairments that would negatively affect Berry Cave salamanders and their habitat. Some of the known water quality stressors and water quality-related effects on the Berry Cave salamander are discussed in Sections 3.1 and 3.7 above.

The *Rock Habitat* element is a qualitative estimation of the quality and quantity of cover habitat available for juveniles and adults at each AU. Rock material that cannot be occupied by salamanders (i.e., that has interstices that are too small or that is significantly imbedded with smaller material) is not considered suitable habitat. AUs with a high quality and quantity of rock habitat are likely to be more resilient, while AUs with little or no rock habitat tend to have few salamanders and are likely to be less resilient.

The *Detrital Load* element is a qualitative estimation of the likelihood that the detrital load (i.e., food availability) at each AU is suitable for supporting a resilient population of Berry Cave salamanders. A suitable detrital load is more likely to occur at AUs where the landscape surrounding the AUs contains diverse vegetation types in close proximity to the cave opening(s); AUs where the vegetation has been removed (i.e., especially no tree cover), degraded (e.g., urban areas), or simplified (e.g., agricultural fields or pastures) are less likely to support resilient Berry

Cave salamander populations due to changes and/or reductions in natural food webs. Active documentation of this element has received relatively little attention. Therefore, it is considered in this report generally to be moderate at each of the analysis units.

The *Likelihood of Human Visitation* element is a qualitative estimate of the likelihood that human disturbance through direct visitation of caves will result in negative effects on salamander and/or salamander habitat at each AU. AUs where such human disturbance is controlled via agreements, cave gates, or other means are more likely to maintain their populations than AUs where human disturbance is not controlled. Human disturbance can lead to a variety of negative

	Resiliency Classes			
Elements	**High**	**Moderate**	**Low**	**Unsuitable**
Species Abundance	17 or more salamanders observed in one day	9 to 16 salamanders	1 to 8 salamanders	None observed
Population Complexity (70 millimeters snout-to-vent length threshold)	Juveniles or larvae present	Not applicable	Neither juveniles or larvae observed	Not applicable
Water Quality (toxicants, fecal coliforms, sediment, etc.)	No salamander mortality, transformation, or evidence of coliform presence	Some mortality, transformation, or coliform presence	Substantial salamander mortality or coliform presence	Unable to support survival of the species
Rock Habitat	Rock substrate readily available	Rock substrate available in patches	Small amount of rock substrate available	Unable to support survival of the species
Detrital Load	Readily observed throughout cave	Detritus scattered	Difficult to detect	Unable to support survival of the species
Human Visitation	Little evidence of visitation	Some evidence of visitation observed	Visible physical damage to habitat or salamanders	Unable to support survival of the species

Table 4-1. Definitions of classes (high to unsuitable) of population elements and habitat elements used to assess conditions for the Berry Cave salamander.

effects on salamanders and salamander habitat, as described in Section 3.2. Like detrital load, this element has received little quantitative observation and is generally considered moderate at each of the analysis units.

4.3 Analysis Units and Population Resiliency

A group of Berry Cave salamanders within any particular cave or the underground void known to be associated with a particular cave entrance has historically been considered a "population" (e.g., the Meads Quarry Cave "population" and the Fifth Entrance Cave "population"). However, this approach has emphasized human access to underground voids, resulting in lack of focus on the potential underground distributional ability of salamanders. Therefore, caves that appear likely to be connected hydrologically with other caves have been combined as common AUs, and salamander populations at each AU are described.

For the Berry Cave salamander to exhibit a high degree of representation, it would exist across its native range in resilient AUs. The species would occur in numbers supporting viable populations throughout a large portion of each AU that was historically occupied. Any population losses at an AU would reduce representation of the species. Conversely, conservation actions implemented in an effort to improve the species' ability to maintain healthy, viable populations would be expected to boost representation.

High redundancy for the Berry Cave salamander would be characterized by multiple, resilient and representative populations distributed across the species' range. Increased connectivity between caves would improve potential for redundancy by increasing the likelihood of reinforcing existing populations and re-establishing populations that may decline or become extirpated. Likewise, documentation of "new" salamander populations would boost the known redundancy of the species.

AU 1: Meads Quarry/Meads River/ Fifth Entrance

Recent survey efforts documented continuing persistence of the species, with 10 individuals found at the cave in 2017 (See Appendix A for relative abundance data). However, the population trend has been downward since the overall high survey count of 24 individuals in 2007 and again in 2008. The entrance to Fifth Entrance Cave is located within boulder material along the wall of the abandoned quarry and has been difficult to access during the last decade. This portion of the cave system was explored in 2018, but a survey of the small amount of stream passage that was accessible did not result in observation of the Berry Cave salamander. The species' demographic complexity level for this AU is currently high.

Meads Quarry Cave and Meads River Cave contain the largest surveyed sections of a cave system associated with the former Meads and Ross Marble Quarry. The entrances, exposed during active quarry operations in the 1930's and 1940's, are currently gated, and the caves are managed by Ijams Nature Center as part of Knoxville's Urban Wilderness. The habitat within one-half mile of this cave system is 67 percent forested.

High-pH leachate from historic quarry operations is an ongoing threat to the Berry Cave salamander at AU 1. Niemiller and Fitzpatrick studied oxidation-reduction potential and pH in 2008 (Niemiller et al. 2018, pp. 12-13), documenting salamander mortality in the immediate vicinity of the leachate source. Urban encroachment has likely resulted in surface sediment transport to caves and subsequent degradation to Berry Cave salamander habitat at this site, as evidenced by silt deposits of up to 0.5 meter (1.64 feet) in depth in Meads Quarry Cave.

Overall, water quality of this AU is considered moderate, rock habitat is moderate to low, and detrital load is moderate. Gates on the entrances to Meads Quarry Cave and Meads River Cave limit human visitation to a degree, but these structures have been breached. Visitation does not appear to have resulted in significant degradation of cave resources.

The relative population abundance has decreased in the last decade, but population demographic complexity has remained at a high level. Resiliency of the population at the Meads Quarry/Fifth Entrance/Meads River AU is currently considered <u>moderate</u> (Table 4-2) due to water quality concerns (i.e., toxicants and sediment).

Analysis Unit	1 Meads Quarry Meads River Fifth Entrance	2 Aycock Spring Christian	3 Berry Cave	4 Mudflats	5 Lost Puddle	6 Small
Species Abundance	Moderate	Low	High	Low	Low	Low
Population Complexity	High	Low	High	Low	High	Low
Water Quality	Moderate (toxicants)	Moderate	Moderate (coliforms)	Low (sediment)	High	Moderate
Rock Habitat	Moderate to Low	Moderate	High	Low	Moderate	Moderate
Detrital Load	Moderate	Moderate	High	Moderate	Moderate	Moderate
Human Visitation	High to Moderate	Moderate	High	High to Moderate	Moderate	Moderate
Population Resiliency	**Moderate**	**Moderate to Low**	**High**	**Moderate to Low**	**Moderate**	**Moderate to Low**

Table 4-2. Current resiliency of Berry Cave salamander populations at the analysis units as determined through analysis of salamander population elements and habitat elements.

AU 2: Aycock Spring/Christian Caves

Aycock Spring Cave and Christian Cave were last surveyed for Berry Cave salamanders in 2005, when one individual of sub-adult/juvenile status was found at each site. The entrances to these caves are located approximately 0.3 mile from each other. Although possible, a sub-surface hydrological connection between the caves has not been documented. Christian Cave is gated, and Aycock Spring Cave is somewhat difficult to enter through a crawlway that is often filled with water. Since the last surveys, significant residential development has encroached on the watershed of these caves. The current condition of the salamander population is unknown, and permission to conduct salamander surveys has not yet been provided by the owners.

The current level of knowledge of stressors to this population is relatively low. However, considering recent reduction of residential development in the area, it is possible that water quality and rock habitat currently support a viable salamander population. The habitat within one-half mile of these caves is 38 percent forested. The substantial wooded buffers surrounding the cave entrances most likely provide a level of detrital input that supports invertebrates and the salamanders depending on them as a food source. Human visitation is considered to be low at the caves of AU 2 because of the difficulty in accessing them, and corresponding benefits to biota are anticipated.

Although the salamander populations of Aycock Spring Cave and Christian Cave have not been thoroughly surveyed since 2005, resiliency of AU 2 is cautiously considered moderate to low.

AU 3: Berry Cave

Relative population abundances of up to 19 individuals were documented during successive salamander surveys at Berry Cave in 2017 and 2018 (including a tagging effort), and population demographic complexity was high. This site exhibits possibly the best habitat for the Berry Cave salamander in its range relative to abundance of gravel and boulder material and minimal sediment deposition. Further, the owners of the entrances to this cave are highly protective of its resources, and the resulting level of human visitation is considered low.

The water quality rating for this cave is currently considered to be moderate. Grazing has been an important land use component of the Berry Cave watershed, but smaller numbers of cattle and horses were observed by Service biologists in 2018 relative to field observations conducted a decade earlier. Livestock and a growing rural, residential human population with associated septic waste systems may contribute to water quality declines that promote parasites as a stressor. Nodules were observed on Berry Cave salamanders during survey efforts in 2005 that appeared parasitic in origin. Nodules were observed again in 2018 but at a lesser degree of prevalence. However, the habitat within one-half mile of this cave system is 47 percent forested. The buffer zone surrounding the stream that flows into Berry Cave provides substantial detritus as the foundation for this cave's food web, as evidenced by a high detrital load.

Due to the high relative abundance of the species, coupled with high to moderate habitat quality, resiliency of the population at the Berry Cave AU is considered high.

AU 4: Mudflats Cave

Berry Cave salamanders have been observed in the "Lake Room" of this cave regularly over the last 40 or more years, and two individuals were found in the cave in March 2018. A maximum number of six salamanders was observed in 1984 at this site during a single survey, but evidence of reproduction has been low. Persistence of the species at this site is encouraging, and the level of disturbance due to human visitation appears low.

This cave appears to have a strong hydrologic influence from the Ten Mile Creek watershed and adjacent Fort Loudon Reservoir, with subsequent effects on water levels within the cave (Niemiller et al. 2018, pg. 13). Much of the highly-developed, western portion of Knoxville drains to Ten Mile Creek, and subsequent sediment transport to the cave is evident. The habitat within one-half mile of this cave system is 41 percent forested, providing a degree of protection to the cave system. Fluctuating water levels have complicated salamander survey efforts, with difficulty in accurately assessing the population trend and reproductive capacity of the species. Continued monitoring will be especially important because of the low relative abundance and low demographic complexity of the species, low water quality level, low level of rock habitat, and moderate detrital load.

Although recent survey efforts have been hampered by precipitation events and high water levels, persistence of the species supports a resiliency rating of moderate to low for the Mudflats Cave population.

AU 5: The Lost Puddle

A maximum number of four Berry Cave salamanders has been observed at this site, and the observed population trend has remained steady since the species was first surveyed there. Evidence of reproduction was documented through observation of two juveniles in 2018, when four Berry Cave salamanders were found within the only habitat that is accessible (i.e., a 50-meter-long pool).

Although this site is near a residential development, water quality is high. Rock habitat and detrital load are moderate. The cave appears to be buffered to a degree against potential stressors by a block of forest that is several hundred feet wide, and the habitat within one-half mile of this cave system is 51 percent forested. There is no evidence of apparent impacts due to human visitation or input of sediment, pesticides, or fecal coliform bacteria.

The long-term trend in viability of the Berry Cave salamander at this AU is somewhat unknown relative to that of other AUs since The Lost Puddle was first surveyed in 2012. Although continued surveys during the next decade may demonstrate strong viability, we focus on the low current population abundance in assigning a resiliency of moderate for AU 5.

AU 6: Small Cave

A survey in 2014 represents the only formal search for Berry Cave salamanders at this cave. One juvenile individual was documented, and a larval spring salamander was found during the same survey. The current knowledge of stressors to this population is relatively limited, but the levels of water quality, rock habitat, and detrital load are all considered moderate. The cave can be freely accessed and appears to undergo some human visitation.

Small Cave is separated from other extant populations of the Berry Cave salamander by more than 25 miles. Habitat within one-half mile of this cave system is 70 percent forested. Although some residential construction has been initiated approximately one mile from this cave, the resulting impacts to the cave's resources appear minimal, and the overall level of development in the immediate vicinity is relatively low.

The Small Cave AU has not been surveyed recently. Considering observations of the population and habitat conditions in 2014, resiliency of the population at this AU is considered moderate to low.

Other Sites – Cruze Cave (Knox County), Blythe Ferry Cave (Meigs County), and a roadside ditch near Athens, Tennessee (McMinn County) are considered sites of previous occupancy by the Berry Cave salamander or its hybrid with another species. The species is not currently known to be extant at any of these three sites, but continued monitoring of salamanders at the two caves is anticipated.

Cruze Cave, although located near the Meads Quarry/Meads River/Fifth Entrance Caves complex, is not known to be connected to it. While the Berry Cave salamander is considered to have been present historically at Cruze Cave (Caldwell and Copeland 1992 in Miller and Niemiller 2008, p. 14), its previous population density and viability are unknown. The species' presence was detected during a limited genetics study, but recent documentation of its presence is not available (Miller and Niemiller 2008, p. 14). Berry Cave salamanders were not found during surveys of Cruze Cave between October 2004 and July 2006, but more than 360 reports of spring salamanders were documented for the same surveys in a 280-meter length of cave (Miller and Niemiller 2008, p. 21).

One individual of the Berry Cave salamander was documented at Blythe Ferry Cave in 1975, but the species has not been documented there since. A few small areas within the cave contain moisture that is sufficient to provide at least periodic protection for the species, but the vast majority of habitat in this cave has been too dry during recent surveys to support a viable salamander population.

Three Berry Cave salamanders were found in 1953 at the site of a roadside ditch located southwest of Athens, Tennessee. This incident occurred in conjunction with a rain event that is thought to have flushed the individuals from an unidentified cave system. Because follow-up searches did not identify any caves or cave entrances that could be surveyed and additional Berry Cave salamanders have not yet been found, this occurrence area is not currently considered to contain an extant population of the species.

4.4 Current Species Level Status

4.4.1 Current Species Redundancy

Redundancy reflects the ability of a species to withstand catastrophic events. It "guards against irreplaceable loss of representation" (Redford et al. 2011, p. 42; Tear et al. 2005, p. 841) and minimizes the effect of localized extirpation on the range-wide persistence of a species (Shaffer and Stein 2000, p. 308). It is characterized by the distribution of multiple, resilient populations throughout a species' ecological setting and across its range. Greater redundancy is exhibited when a species' populations are not completely isolated and when movement between populations is achievable.

The Berry Cave salamander's range contains six AUs, three of which exhibit moderate or high resiliency and three having moderate to low resiliency. Some migration between cave complexes is possible within the species' range, but there are significant barriers to migration, primarily distance and geological constraints that hinder movement from isolated sites (e.g., Small Cave and Berry Cave). Further, the species' entire range is relatively small. Therefore, the Berry Cave salamander as a whole exhibits <u>moderate to low</u> redundancy.

4.4.2 Current Species Representation

Representation reflects the ability of a species to adapt to changing environmental conditions over time and encompasses the "ecological and evolutionary patterns and processes that not only maintain but also generate species" (Shaffer and Stein 2000, p. 308).

The subterranean streams in which the Berry Cave salamander resides are typically viewed as fragile ecosystems that are often highly variable. Given the natural range of variability in environmental conditions, the species would be expected to exhibit a degree of adaptability. As discussed in Chapter 2, Niemiller et al. (2009, pp. 3-4) found that Berry Cave salamander populations have three unique alleles when compared to the Tennessee cave salamander. However, genetic diversity across the range of the species is slight. Due primarily to its naturally limited range within a single physiographic province, the species as a whole is considered to have <u>low</u> overall adaptive potential and, therefore, does not exhibit high representation.

CHAPTER 5 – FUTURE CONDITIONS AND VIABILITY

We have considered what the Berry 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 consider what the species' future condition is likely to be. We apply our future forecasts to the concepts of resiliency, representation, and redundancy to describe the future viability of the Berry Cave salamander.

5.1 Introduction

In this chapter, we describe how current viability of the Berry Cave salamander may change over time in respect to the projected outcomes from three different scenarios that consider the major stressors to the species. Our future scenarios depict projections with a snapshot of conditions at the periods of 11 and 61 years. The 11-year period represents the near future and the species' estimated generation time (i.e., the average difference in age between parent and offspring). We use the 61-year time frame to represent two to three life spans for the species. These time-steps were selected based on the biology of the species and information available for the SLEUTH predictive model (based on Slope, Land use, Exclusion, Urban extent, Transportation, and Hill shade), which is based on a 95% confidence interval in demonstrating projected change through time. As in the Current Condition discussion, we evaluate species viability in terms of resiliency at the population scale, and representation and redundancy at the species scale (3 R's). Here we describe plausible future scenarios and whether there would be a change from current conditions to any of the three R's under each scenario.

Our future scenarios differ by considering variations that are predicted for three scenarios that are projected to capture the range of likely outcomes on Berry Cave salamander viability by the year 2080. "Urbanization" (i.e., residential and commercial development), climate change, and implementation of conservation measures can all affect viability of the species. Urbanization is the primary negative influence, and conservation measures can be implemented to counteract negative effects. The level at which conservation measures are implemented acts as a variable between the scenarios because of the real potential for benefit to the species. Urbanization and climate change occur across the range of the species in a manner that likely does not vary between the projected scenarios.

5.2 Models and Scenario Descriptions

Based on the SLEUTH urbanization model for the Valley and Ridge area of Tennessee, a significant level of increase in development is anticipated for the northeast portion of the species' range adjacent to Knoxville (i.e., at AU 1 and AU 4) and in areas adjacent to AU 2, AU 3, and AU 5 (Figures 5-1 and 5-2). The model projection for the area near AU 6 suggests that development would initiate approximately 0.3 mile from the cave system and progress in a direction away from the cave, contributing little to no water quality impacts at the cave site. Given the proximity to growing cities like Knoxville and Loudon, Tennessee, and availability of existing highways such as Interstates 75 and 40, the region occupied by Berry Cave salamander exhibits strong potential for development based on the SLEUTH model. The increase in impervious surfaces is expected to result in flashier hydrology and additional habitat degradation. More development will bring with it higher levels of contaminants in runoff to the streams that could impact sensitive species (Diamond et al. 2016, entire). The level of impact from development varies in the scenarios presented below.

Conservation work in watersheds occupied by the Berry Cave salamander has been limited. Some caves have been gated to limit human access, and a road expansion project that could impact AU 1 has been postponed due to local opposition. In the future, expansion of forested buffer zones along streams and attentiveness in applying best management practices could improve water quality in cave aquifers. Prudent management of livestock and removal of waste material from the site of a previous quarry operation could benefit the species. Precautionary measures could also be taken to minimize the spread of potential pathogens such as chytrid fungus.

In the southeastern U.S., clear trends in climate predictions are limited. Variability in weather is predicted to increase during the next century, resulting in more frequent and more extreme dry years and wet years; and increases in variability are already being seen (Mulholland et al. 1997, entire, Ingram et al. 2013, entire). Average and extreme temperatures are also expected to increase over time. Increases in stress due to drought will increase the likelihood that Berry Cave salamander habitat is impacted by reduced groundwater flow, resulting in possible reduction in population abundances. Greater frequency of precipitation events that are more extreme would result in increased streambank erosion and sediment deposition within areas typically occupied by the Berry Cave salamander. Higher dispersal rates of individual salamanders could also result from increased stream flow. Higher temperatures would tend to result in lower dissolved oxygen levels and could increase the risk of fungal or bacterial infection of salamanders and their eggs. We recognize a moderate change in climate over our projected time span in the prediction of future scenarios.

We note that detrital load, human visitation, and competition between spring salamanders and the Berry Cave salamander are not expected to vary greatly within any particular analysis unit. Therefore, we de-emphasize these factors in our predictive analyses. Further, climate is not expected to vary between the scenarios.

5.3 Results

5.3.1 Scenario 1

Residential and commercial development would proceed through the duration of this scenario in accordance with SLEUTH model projections. Habitat degradation associated with currently developed areas would generally continue the current trend at a moderate level (confidence level of 85% or lower) to the year 2030 (Figure 5-1). Growth would diminish by the year 2080 in those areas (Figure 5-2). However, developed areas in the range of the Berry Cave salamander that are outside of metropolitan Knoxville are expected to double in the next six decades, with corresponding, long-term degradation of water quality and habitat.

Occasional drought and flooding episodes are anticipated as a result of climate change, which may result in episodic decreases in salamander population abundance. Overall, given the historic range of variability in environmental conditions, Berry Cave salamanders would be expected to respond to drought and flooding conditions in a manner that results in continuing viability.

Conservation measures would be slightly improved relative to the current existing level, overcoming urbanization effects to an extent that boosts water quality and habitat quality to the benefit of Berry Cave salamanders at some sites. The degree of improvement of conservation measures within Scenario 1 is only slight because it reflects improved technologies among actions (e.g., implementation of best management practices) and not improvements that would be realized as a result of major changes in types of conservation measures (e.g., containment of large quantities of toxicants).

5.3.2 Scenario 2

Like Scenario 1, development would proceed through the duration of this scenario in accordance with SLEUTH model projections. In this scenario, drought and flooding levels are the same as assumed for Scenario 1, and there is an increase in the conservation measures that are implemented to benefit the species. Specific conservation measures will be implemented to reduce agricultural water quality impacts (e.g., livestock fencing and/or installation of waste-containment structures), restore detrital load through expansion of forested riparian zones, and address specific water quality issues (e.g., removal or containment of quarry waste materials). Collectively, implementation of these conservation measures would ameliorate some of the effects of urbanization and climate change, thus buffering AUs and boosting resiliency.

5.3.3 Scenario 3

As in Scenarios 1 and 2, development would proceed in accordance with SLEUTH model projections through the year 2080. Drought and flooding levels are also the same as assumed for Scenarios 1 and 2. In this scenario, conservation measures are greatly reduced compared to Scenarios 1 and 2, leading to corresponding degradation of water quality and habitat and population reductions at some AUs. Chronic effects of recurring drought conditions would contribute to lower salamander population abundance and complexity at sites of marginal habitat due to negative synergistic effects upon life history stages such as egg and larvae.

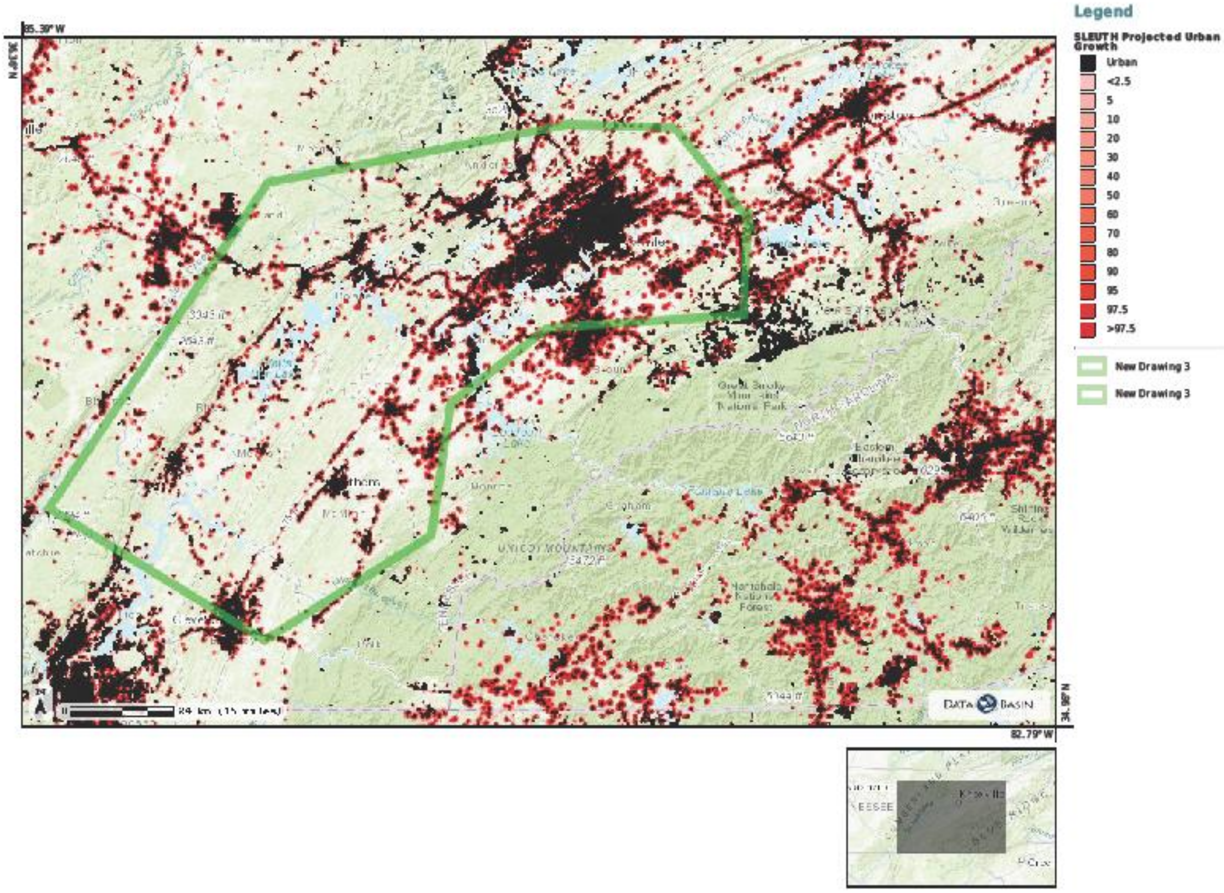


Figure 5-1. SLEUTH model showing predicted extent of urban development in 2030. Blackened areas represent the current extent of development; and the darker the red, the higher the certainty of development. The green polygon outlines the Berry Cave salamander's range.

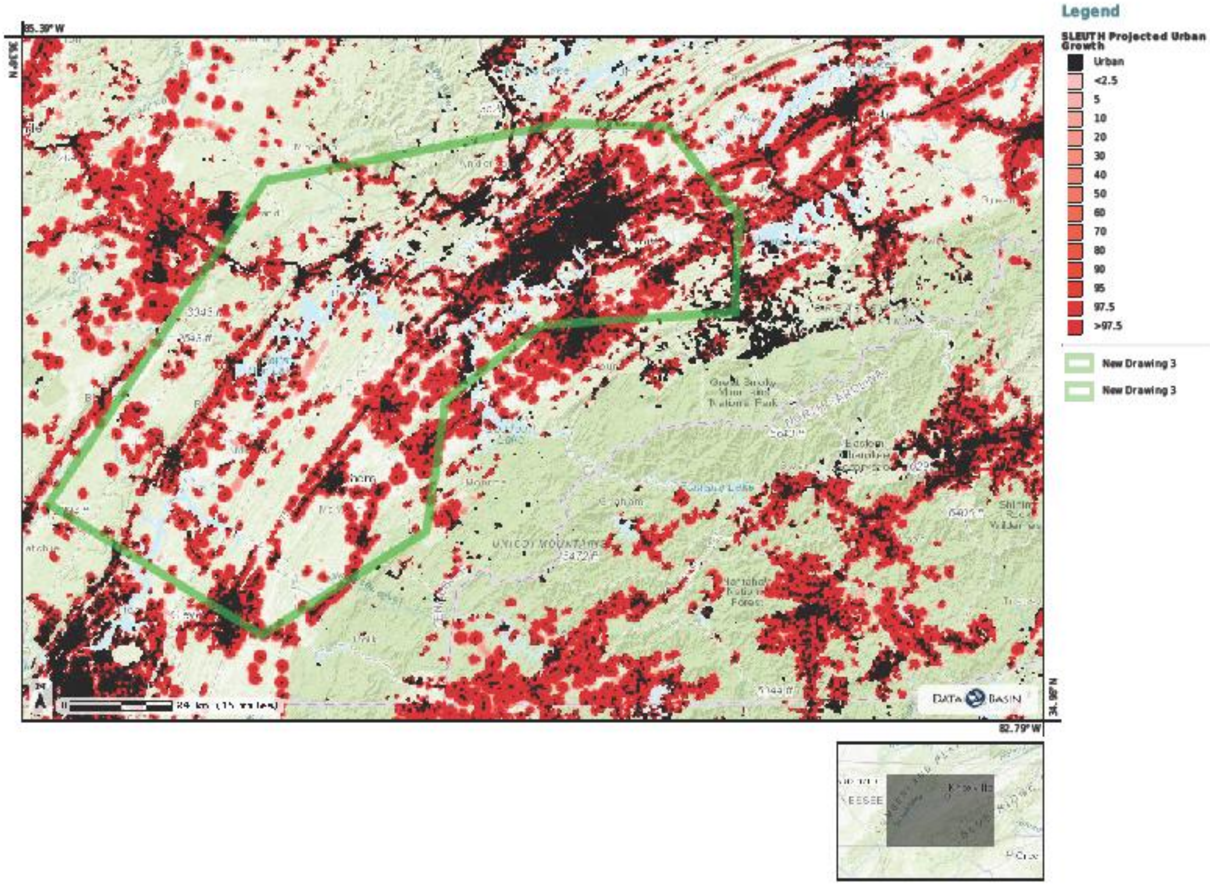


Figure 5-2. SLEUTH model showing predicted extent of urban development in 2080. Blackened areas represent the current extent of development; and the darker the red, the higher the certainty of development. The green polygon outlines the Berry Cave salamander's range.

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

5.4.1 Scenario 1

Under this scenario, residential and commercial development would proceed to the year 2080 in accordance with SLEUTH model projections. The developed area in the range of the Berry Cave salamander that is outside of the metropolitan Knoxville area is expected to double in the next 61 years, but with limited change in the next decade. Development would result in continued, but somewhat limited effects on water quality through the year 2080. A significant amount of development is predicted to advance through 2030 in areas adjacent to but not surrounding cave systems at AUs 2, 3, and 5, and that development would continue to the year 2080.

The current trends in climate continue with significant periods of drought and flooding in the 11-year timeframe. In the 61-year timeframe, drought would negatively affect marginal habitat areas. Conservation measures, in the form of forested riparian habitat maintenance and a low level of improvement, are expected to occur.

For AUs 1 and 2, habitat has been altered in areas surrounding the site/s of Berry Cave salamander occupation, with a buffer around the cave/s. At AUs 3, 5, and 6, development is being initiated in areas adjacent to but not surrounding the cave systems. Varying degrees of forested buffering would remain between caves and developed areas. Forested parts of the landscape adjacent to caves will remain in the current habitat condition, with minimal improvements to forested riparian zones.

Resiliency

AU 1: Meads Quarry/Meads River/Fifth Entrance – Episodic decreases in salamander abundance would occur, but the overall viability of the population would continue with moderate species abundance and high population complexity. Toxicant input from the quarry waste area would continue, contributing a moderate level of stress to the species. This AU would reflect a moderate level of resiliency under Scenario 1 (Table 5-1).

AU 2: Aycock Spring/Christian Caves – This population would continue to be viable throughout the modeling period, but at a low level of abundance and complexity. Although nearby development and presence of residences may result in spikes in lower water quality, this factor would contribute to a viable population. Resiliency would be moderate to low.

AU 3: Berry Cave – The salamander population at AU 3 would continue at a high level of abundance and complexity. Water quality would undergo occasional negative effects due to the presence of livestock, with stress to the salamander. However, ongoing implementation of conservation measures would aid in maintaining the current level of population viability at this site. AU 3 would continue to represent the greatest resiliency across the species' range, with a designation of high.

AU 4: Mudflats Cave – Chronic water quality challenges due to the current level of habitat disturbance (especially the presence of sediment) would impact the species up to the year 2030 and beyond. Although the population would likely persist, the potential for increase in the species' relative abundance is questionable; and population complexity would remain low. Resiliency would be moderate to low for this AU.

AU 5: The Lost Puddle – Although the small size of this cave system may negatively influence the salamander density to some extent, the species' abundance would be maintained at the current level under this scenario. The steep slope surrounding this cave system minimizes the potential for development, supporting maintenance of an excellent forest buffer. Therefore, water quality is expected to be maintained at its current high level. Resiliency would be moderate for this AU.

AU 6: Small Cave – As in AU 2, this population would continue to be viable throughout the modeling period, but at a low level of abundance and complexity. Nearby initiation of development is not expected to degrade water quality or habitat integrity at this cave. Therefore, resiliency of the population at this AU would be moderate to low.

Table 5-1. Resiliency under Scenario 1.

Analysis Unit	1 Meads Quarry Meads River Fifth Entrance	2 Aycock Spring Christian	3 Berry Cave	4 Mudflats	5 Lost Puddle	6 Small
Species Abundance	Moderate	Low	High	Low	Low	Low
Population Complexity	High	Low	High	Low	High	Low
Water Quality	Moderate (toxicants)	Moderate	Moderate (coliforms)	Low (sediment)	High	Moderate
Rock Habitat	Moderate to Low	Moderate	High	Low	Moderate	Moderate
Detrital Load	Moderate	Moderate	High	Moderate	Moderate	Moderate
Human Visitation	Moderate	Moderate	High	Moderate	Moderate	Moderate
Population Resiliency	**Moderate**	**Moderate to Low**	**High**	**Moderate to Low**	**Moderate**	**Moderate to Low**

Redundancy – With persistence of all six populations, the species overall redundancy would be moderate to low during the next decade and remain at that level up to the year 2080 for Scenario 1, with three populations exhibiting moderate to high resiliency.

*Representatio*n – Species abundance would be high or moderate at two of the AUs under Scenario 1, with low abundance at four of the AUs. Although the current level of conservation effort is expected to outweigh climate change that might cause stress to the species, representation would remain low for the species overall for Scenario 1.

5.4.2 Scenario 2

In this scenario, as in Scenario 1, development would continue to the year 2080 as predicted by the SLEUTH model, with a limited range-wide change by 2030, but a doubling of developed areas outside of metropolitan Knoxville in the next 61 years. Forested habitats that will not be developed adjacent to caves are expected to remain in a condition similar to that of Scenario 1. Drought and flooding, also occurring at the same level as in Scenario 1, would result in episodic reductions in salamander population abundances, with continued or improved trends in population abundance and reproduction at most sites.

Conservation measures would be implemented to a greater extent than in Scenario 1 in order to reduce pollutant inputs to streams (i.e., sediment, toxicants such as lawn care chemicals, fecal coliforms, and high-pH quarry waste material). Measures to be implemented may include livestock fencing and/or installation of waste-containment structures, expansion of forested riparian zones, and removal of quarry waste materials. These measures would benefit water quality and assist in mitigating negative effects of climate change.

Resiliency

AU 1: Meads Quarry/Meads River/Fifth Entrance – Habitat alteration is predicted to surround the area of Berry Cave salamander occupation, with a significant cave system buffer maintained by the Ijams Nature Center as part of Knoxville's Urban Wilderness. The majority of development would occur up to the year 2040 and then level off until 2080. Although sediment transport and stormwater runoff would impact salamanders to a degree during this time frame, including the near-term period of 2018 to 2030, the population would remain stable. Removal of the quarry waste material or otherwise addressing its negative effects would result in lower salamander mortality and associated larval recruitment into the population, thereby boosting salamander abundance. Overall resiliency for this AU would be high to moderate for Scenario 2 (Table 5-2).

AU 2: Aycock Spring/Christian Caves – Residential development in an area northeast of the cave would continue to 2030 and continue at a steady rate until 2080. Maintenance of a significant buffer between the caves and developed area would minimize transport of sediment and toxicants such as lawn-care chemicals, supporting continuation of this viable, but low-density salamander population. Resiliency would be moderate overall for this AU.

AU 3: Berry Cave – Residential development in the area northwest of Berry Cave would occur up to year 2030, continuing steadily to 2080. A forested buffer would be retained and even improved between residences and local streams, maintaining water quality at a level that supports a viable salamander population. Decreased input of fecal coliforms would result from improved livestock management practices in the watershed upstream of Berry Cave, with reduced stress on individual salamanders and a likely increase in abundance. This AU would exhibit high overall resiliency.

AU 4: Mudflats Cave – Urbanization and its associated habitat alteration have already reached a peak in the vicinity of Mudflats Cave. The habitat would remain altered at the current level of impact, affecting the Berry Cave salamander to a degree up to 2030 because of limited reproduction. That level of impact would continue to 2080, and the population is expected to be stable, albeit at low abundance and with sporadic increases during the entire 61-year model period. Moderate to low resiliency would be observed.

AU 5: The Lost Puddle – A small degree of continuing development would continue to occur south of this cave system. Impacts to the cave are expected to be buffered substantially due to the steep slope and associated forest along which the cave is located. Although a significant increase in salamander population abundance is not projected, the population would plateau and remain stable up to 2080, with high to moderate overall resiliency.

AU 6: Small Cave – Residential development would occur in an area southwest of the cave through the year 2030, continuing steadily until 2080. The originating site of development is approximately 0.3 mile from the cave entrance and would expand directly away from Small Cave. Viability of Berry Cave salamander at this site would remain stable, and slight fluctuations in this low-density population would be observed. This AU would exhibit moderate to low overall resiliency.

Redundancy – Overall, the species' level of redundancy would remain moderate to low across its range during the next decade and continue to remain at that level up to the year 2080 due to a low number of populations with resiliency generally higher than the other two scenarios.

Representation – Conservation measures would overcome some effects of climate change in Scenario 2. AUs 1, 3, and 5 exhibit a high or moderate level of representation, but the populations of AUs 2, 4, and 6 remain at low abundance. Because of the species' narrow endemism, overall representation would remain low for this scenario.

Table 5-2. Resiliency under Scenario 2.

Analysis Unit	1 Meads Quarry Meads River Fifth Entrance	2 Aycock Spring Christian	3 Berry Cave	4 Mudflats	5 Lost Puddle	6 Small
Species Abundance	High	Low	High	Low	Moderate	Low
Population Complexity	High	Low	High	Low	High	Low
Water Quality	High to Moderate	Moderate	High to Moderate	Low	High to Moderate	Moderate
Rock Habitat	Moderate	High to Moderate	High	Low	High to Moderate	High to Moderate
Detrital Load	Moderate	Moderate	High	Moderate	Moderate	Moderate
Human Visitation	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate to Low
Population Resiliency	**High to Moderate**	**Moderate**	**High**	**Moderate to Low**	**High to Moderate**	**Moderate To Low**

5.4.3 Scenario 3

The urbanization rate projected by the SLEUTH model for this scenario would be the same as for Scenarios 1 and 2, with ongoing effects upon water quality through the year 2080. Those effects would be more noticeable in this scenario than in Scenario 2, especially where significant development that is predicted to proceed to the year 2030 adjacent to but not immediately surrounding cave systems at three of the analysis units outside of metropolitan Knoxville. Development would double in those areas by 2080. Forested habitats that will not be developed adjacent to caves are expected to remain in a condition similar to those of Scenarios 1 and 2 at most of the AUs, depending on the practicality of development and potential for implementation of conservation measures.

Drought and flooding would occur at the same rates as predicted under Scenarios 1 and 2. Effects due to development and climate change will not be offset by conservation measures, which would be implemented minimally under Scenario 3. Urbanization is expected to plateau in the vicinities of AU 1 and AU 4 by the year 2040, with subsequent effects due to storm runoff. With the exception of these two AUs, urbanization under Scenario 3 is projected to impact Berry Cave salamander populations primarily in terms of chronic, long-term effects.

Resiliency

AU 1: Meads Quarry/Meads River/Fifth Entrance – Development would continue, plateauing in 2040. The extent of habitat alteration would surround the area of this cave system, with a significant buffer continuing to be maintained by the Ijams Nature Center as part of Knoxville's Urban Wilderness. The Berry Cave salamander population would undergo episodic decreases in abundance and complexity, especially as a result of stress due to continued leachate from the existing quarry waste material. However, continued protection of the watershed by Ijams Nature Center would provide for maintenance of long-term population viability. The overall resiliency for this AU would be moderate under Scenario 3 (Table 5-3).

AU 2: Aycock Spring/Christian Caves – Chronic water quality stress due to ongoing sediment inputs and lawn care chemicals would continue. Very low population abundance and population complexity would continue as a result, with a slight possibility of the species' extirpation at this AU. Overall resiliency for this AU would be low.

AU 3: Berry Cave – Residential development in the watershed that drains to Berry Cave is expected to result in stress to the salamander population. Although abundance would be reduced somewhat, inherent species' resilience is expected to result in maintenance of this population. Resiliency would be moderate for this AU.

AU 4: Mudflats Cave – Continued presence of sediment in the watershed of AU 4 is expected to overwhelm this species. Although an individual would be found occasionally, recruitment and foraging would be severely depressed to the extent that potential for extirpation by the year 2080 is high. Low overall resiliency is projected for this AU.

AU 5: The Lost Puddle – A small degree of continuing development would occur south of this cave system, but the steep terrain and associated forested habitat are expected to buffer the cave from significant impacts to water quality and the salamander population. Resiliency would be moderate for this AU.

AU 6: Small Cave – Very low population abundance would likely continue, but without measures to boost viability, there is a possibility of this population's extirpation. Overall resiliency would be low.

Table 5-3. Resiliency under Scenario 3.

Analysis Unit	1 Meads Quarry Meads River Fifth Entrance	2 Aycock Spring Christian	3 Berry Cave	4 Mudflats	5 Lost Puddle	6 Small
Species Abundance	Moderate	Low	Moderate	Low	Low	Low
Population Complexity	High	Low	High	Low	High	Low
Water Quality	Moderate to Low (toxicants)	Moderate to Low	Moderate to Low (coliforms)	Low (sediment)	High	Moderate
Rock Habitat	Moderate	Moderate	High to Moderate	Low	Moderate	Moderate
Detrital Load	Moderate	Moderate	High	Moderate	Moderate	Moderate
Human Visitation	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate to Low
Population Resiliency	**Moderate**	**Low**	**Moderate**	**Low**	**Moderate**	**Low**

Redundancy – Decreasing population abundances would threaten the species' redundancy overall. Overall, the species would exhibit a moderate to low level of redundancy under this scenario due to the challenges in maintaining the existing six populations.

*Representatio*n – Analysis units with extant salamander populations continuing to exhibit suitable water quality conditions would likely have low resiliency and be vulnerable to extirpation. Population abundance would be maintained at five of the AUs, but abundance would trend downward at AU 3, with *potential* for extirpation at AUs 2, 4, and 6. Overall, representation across the species' range would remain low for Scenario 3.

Overall Summary

The Berry Cave salamander is currently considered extant in nine caves within the Valley and Ridge Province of eastern Tennessee. Because of the lack of perceived genetic diversity within the species, ecological and natural history distinctiveness are used to describe differences between populations and representation of the species. Due to the limited apparent amount of movement between cave systems, the species has been divided into six AUs for the purpose of analysis. One of the AU's salamander populations currently exhibits high resiliency, populations at two of the AUs are considered moderately resilient, and three are considered to be of low to moderate resiliency. Other "populations" of Berry Cave salamander (Blythe Ferry Cave, Cruze Cave, and another apparent population represented by documentation of the species in a roadside ditch in the vicinity of Athens, Tennessee) are not currently considered extant as a result of negative results for the species during ongoing surveys and due to minimal suitable habitat.

The primary threats to this species are water quality influences (e.g., toxicants, sediment, and fecal coliforms) associated with various aspects of land use. Our future scenarios assessment took the current viability of the species into account in order to project likely future viability, given plausible scenarios of development ("urbanization"), conservation efforts, and climate change. The Berry Cave salamander is expected to persist in all currently occupied AUs under each of the three scenarios. However, resiliency in Scenario 3 is predicted to be moderate in only half of the AUs (i.e., 1, 3, and 5) and low in the other half.

Uncertainty

Our analysis of current and future conditions contains uncertainty because of limitations in knowledge about the current status of the Berry Cave salamander. The projections of future scenarios are based on the most recent trends in the species' populations and habitats. Uncertainties that we recognize include:

- Some life history aspects of the Berry Cave salamander remain unknown (e.g., needs for successful emergence from eggs, habitat use by larval salamanders and juveniles, and life expectancy).
- Because of human inaccessibility to portions of cave systems occupied by salamanders, the extent of the species' occupancy of caves within the range of the species is unclear. Therefore, our ability to identify populations and accurately estimate population sizes is limited.
- Lack of permission to access Aycock Spring Cave, Christian Cave, and Small Cave has hindered our ability to keep up-to-date on population trends at those sites.
- There are limitations in the ability to predict future urbanization rates.
- The dynamics of climate change relative to future drought and flooding events is unknown. Other than to acknowledge potential for these types of events along with some

unknown degree of adaptation from the species, we do not attempt to predict the level of impacts associated with these events.

- We are not certain of the Berry Cave salamander's potential response to conservation measures and synergistic effects that might be realized as a result of drought and/or flooding events.
- We are not certain about the factor(s) affecting presence of the spring salamander and the apparent absence of the Berry Cave salamander at Cruze Cave considering the historic documentation of hybridization between these species.
- Although a distinct species, the genetic distinction between populations (i.e., the AUs) has not been demonstrated.

Future Viability

The future scenarios assessment was conducted in pursuit of understanding of the Berry Cave salamander's viability as it may change over the course of 61 years in terms of resiliency, redundancy, and representation. To account for considerable uncertainty associated with future projections, we described three plausible scenarios that would capture the breadth of changes in the Ridge and Valley physiographic province to which the Berry Cave salamander may be exposed. These scenarios considered three elements of change: development ("urbanization"), implementation of conservation measures, and climate change. While we consider these scenarios plausible, we acknowledge that each has a different probability of occurrence at the modeled timeframes (i.e., 11 years versus 61 years, or approximately two to three or more generational periods for the Berry Cave salamander). To account for this difference in probability, probability categories (Table 5-4) were used to describe the likelihood that a scenario will occur (Table 5-5).

In Scenario 1, we predicted the level of development as projected by the SLEUTH model, that climate change would affect caves with potential for episodes of significant drought and flooding, and that conservation efforts would occur on a limited basis. Based on these criteria, it was anticipated that resiliency of salamanders at each AU would remain at the current levels - three as high or moderate, and three would be moderate to low. Overall representation and redundancy would also remain unchanged. This scenario is considered very likely for the short term and as likely as not over the next six decades, given increased landscape disturbance, apparent adaptability of the species, and past levels of conservation in the area.

Table 5-4. Explanation of confidence terminologies used to estimate the likelihood of a scenario (after IPCC guidance, Mastrandrea et al. 2011).

Confidence Terminology (Probability Category)	**Description**
Very likely	Greater than 90% certain
Likely	70-90% certain
As likely as not	40-70% certain
Unlikely	10-40% certain
Very unlikely	Less than 10% certain

Table 5-5. Likelihood of Scenarios 1, 2, and 3 occurring at 11 and 61 years.

Scenario	**1**	**2**	**3**
11 years	Very Likely	Likely	Unlikely
61 years	As likely as not	As likely as not	As likely as not

Under Scenario 2, the development would occur across the range of the Berry Cave salamander as projected by the SLEUTH model, but conservation measures would be implemented to counteract it. Climate change would provide for episodes of significant drought and flooding. Conservation efforts are predicted to result in benefits to four AUs, with high to moderate resiliency, but two AUs would have moderate to low resiliency. Overall, resiliency increases for this scenario, but representation and redundancy remain unchanged. The positive conservation efforts predicted for the long-term in this scenario are practical, but only to a limited extent. The practicality for realization of this scenario is considered likely during the next decade and as likely as not over the long-term. As a precautionary statement, we stress the need for prudent implementation of conservation measures in management of watersheds that act as water sources for the AUs.

Under Scenario 3, development would continue as projected by the SLEUTH model, and implementation of conservation measures at a lesser level of intensity (relative to that of Scenario 1, in which measures are implemented on a limited basis) would result in significantly greater impacts than predicted in the other two scenarios. Further, climate change would exacerbate the effects of the other stressors to some degree. This could potentially result in extirpation of half of the salamander populations. Overall, resiliency decreases for this scenario, with no change in representation or redundancy. Occurrence of this scenario is expected to be unlikely during the next decade and as likely as not over the long-term because, even if urbanization were to overcome conservation efforts, the species would be expected to persist as a result of the inherent adaptability that it has demonstrated to date. The presence of six widely-separated AUs, expressed as redundancy of the species, supports this outcome, and documentation of previously undiscovered (i.e., “new”) salamander populations would provide additional support. Because there is potential for implementation of conservation actions, our confidence in Scenario 3 transpiring for the species as a whole is less than for Scenario 2.

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APPENDIX A (NIEMILLER ET AL. 2018B)

Results of salamander surveys at Meads Quarry Cave system (Meads Quarry Cave, Fifth Entrance Cave, and Meads River Cave), Mudflats Cave, and Berry Cave. Codes for caves are specified under "Cave" column and number of Berry Cave salamanders represented under "GGUL" column.

Cave	Date	Surveyors	GGUL
Meads Quarry Cave (TKN28)	23 Oct 2004	ML Niemiller, BT Miller, C Kerr	11
Meads Quarry Cave (TKN28)	4 Nov 2006	ML Niemiller, BM Fitzpatrick	11
Meads Quarry Cave (TKN28)	22 Apr 2007	ML Niemiller, RG Reynolds	14
Meads Quarry Cave (TKN28)	9 Sep 2007	ML Niemiller, RG Reynolds, M Ogle, P Colclough	24
Meads Quarry Cave (TKN28)	8 Nov 2007	ML Niemiller, BM Fitzpatrick	5
Meads Quarry Cave (TKN28)	24 Nov 2007	ML Niemiller, BM Fitzpatrick	6
Meads Quarry Cave (TKN28)	24 Jan 2008	ML Niemiller, BM Fitzpatrick, M Simmons, S Young	7
Meads Quarry Cave (TKN28)	31 Jan 2008	ML Niemiller, BM Fitzpatrick, P Hudson, B Moxley	18
Meads Quarry Cave (TKN28)	1 Mar 2008	ML Niemiller, P Shah, N Turnbough, J Turnbough	10
Meads Quarry Cave (TKN28)	6 Mar 2008	ML Niemiller, BM Fitzpatrick	4
Meads Quarry Cave (TKN28)	30 Mar 2008	ML Niemiller, RG Reynolds, D Dittrich-Reed, R Lawton, M Post	16
Meads Quarry Cave (TKN28)	10 Apr 2008	ML Niemiller, BM Fitzpatrick	11
Meads Quarry Cave (TKN28)	30 Apr 2008	ML Niemiller, BM Fitzpatrick, N Davidai, K Hanksnecht	17
Meads Quarry Cave (TKN28)	15 May 2008	ML Niemiller, BM Fitzpatrick, M Todd-Thompson, J Welch	7
Meads Quarry Cave (TKN28)	4 Jun 2008	ML Niemiller, BM Fitzpatrick, R Quasney	24
Meads Quarry Cave (TKN28)	27 Jun 2008	ML Niemiller, BM Fitzpatrick	8
Meads Quarry Cave (TKN28)	30 Jul 2008	ML Niemiller, M Todd-Thompson	15
Meads Quarry Cave (TKN28)	10 Sep 2008	ML Niemiller, R Dave	17
Meads Quarry Cave (TKN28)	5 Oct 2013	ML Niemiller, ET Carter, Z Marion	5
Meads Quarry Cave (TKN28)	22 Nov 2017	ML Niemiller, ET Carter, NS Gladstone	10
Meads Quarry Cave (TKN28)	13 Jan 2018	ML Niemiller, SW Keenan	5
Meads Quarry Cave (TKN28)	10 Mar 2018	ML Niemiller, ET Carter, LE Hayter	8
Meads Quarry Cave (TKN28)	17 Jun 2018	ML Niemiller, A Paterson, H Nichols, L van der Fleet	2

Meads Quarry Cave (TKN28)	23 Sep 2018	ML Niemiller, ET Carter, L Hayter, J Clothier	9
Fifth Entrance Cave (TKN167)	23 Oct 2004	ML Niemiller, BT Miller, C Kerr	0
Fifth Entrance Cave (TKN167)	8 Nov 2007	ML Niemiller, BM Fitzpatrick	1
Meads River Cave (TKN151)	23 Oct 2004	ML Niemiller, BT Miller, C Kerr	0
Meads River Cave (TKN151)	22 Apr 2007	ML Niemiller, RG Reynolds	0
Meads River Cave (TKN151)	8 Nov 2007	ML Niemiller, BM Fitzpatrick	0
Meads River Cave (TKN151)	24 Nov 2007	ML Niemiller, BM Fitzpatrick	1
Meads River Cave (TKN151)	2 Dec 2007	ML Niemiller, BM Fitzpatrick	0
Meads River Cave (TKN151)	10 Sep 2008	ML Niemiller, R Dave	0
Mudflats Cave (TKN9)	20 Nov 2004	ML Niemiller, C Kerr	5
Mudflats Cave (TKN9)	6 Jan 2005	ML Niemiller, BT Miller, N Mann, C Kerr	3
Mudflats Cave (TKN9)	30 Dec 2005	ML Niemiller, BM Fitzpatrick, R Fitzpatrick	5
Mudflats Cave (TKN9)	12 Nov 2006	ML Niemiller, RG Reynolds	2
Mudflats Cave (TKN9)	7 Jun 2007	ML Niemiller, RG Reynolds, P Shah	5
Mudflats Cave (TKN9)	5 Apr 2014	ML Niemiller, AS Engel, S Engel, SW Keenan	1
Mudflats Cave (TKN9)	20 Oct 2014	ET Carter, BC Eads, RA Hunt	1
Mudflats Cave (TKN9)	8 Jan 2015	ET Carter, BM Fitzpatrick	1
Mudflats Cave (TKN9)	29 Oct 2017	ML Niemiller, ET Carter, LE Hayter, MJ Ravesi	0
Mudflats Cave (TKN9)	25 Nov 2017	ML Niemiller, ET Carter, KDK Niemiller, C Kendall	0
Mudflats Cave (TKN9)	27 Feb 2018	ML Niemiller, KDK Niemiller	0
Mudflats Cave (TKN9)	16 Mar 2018	ML Niemiller, ET Carter, NS Gladstone, LE Hayter	2
Mudflats Cave (TKN9)	10 May 2018	ML Niemiller	0
Mudflats Cave (TKN9)	18 Jun 2018	ML Niemiller	0
Berry Cave (TRN3)	17 Dec 2004	ML Niemiller, BT Miller, N Mann	1
Berry Cave (TRN3)	5 Mar 2005	ML Niemiller, BM Glorioso, G Moni, A Moni	4
Berry Cave (TRN3)	28 Jun 2014	ML Niemiller, ET Carter, CDR Stephen, AS Engel, S Engel, A Paterson, J Carter	3
Berry Cave (TRN3)	14 Feb 2016	ET Carter, LE Hayter, NS Gladstone, BC Eads, RA Hunt, JL Wessels	2
Berry Cave (TRN3)	30 Oct 2017	ML Niemiller, ET Carter, D Pelren, T Pierson, DR Istvanko	9
Berry Cave (TRN3)	4 Dec 2017	ML Niemiller, ET Carter, C Ogle, T Burkhardt	10
Berry Cave (TRN3)	6 Jan 2018	ML Niemiller, ET Carter, NS Gladstone, LE Hayter	6

Berry Cave (TRN3)	17 Feb 2018	ML Niemiller, ET Carter, NS Gladstone, LE Hayter, E Pieper	3
Berry Cave (TRN3)	16 Mar 2018	ML Niemiller, ET Carter, NS Gladstone, LE Hayter	3
Berry Cave (TRN3)	13 Apr 2018	ML Niemiller, NS Gladstone, JG Phillips	6
Berry Cave (TRN3)	10 May 2018	ML Niemiller, ET Carter, NS Gladstone, E Pieper	5
Berry Cave (TRN3)	18 Jun 2018	ML Niemiller, NS Gladstone, E Pieper	3
Berry Cave (TRN3)	20 Jul 2018	ML Niemiller, NS Gladstone, KDK Niemiller	4
Berry Cave (TRN3)	12 Aug 2018	ML Niemiller, ET Carter, NS Gladstone, KDK Niemiller	5
Berry Cave (TRN3)	15 Sep 2018	ML Niemiller, ET Carter, NS Gladstone, LE Hayter	19
Berry Cave (TRN3)	16 Oct 2018	ML Niemiller, NS Gladstone, LE Hayter	5

APPENDIX B

Caves surveyed for salamanders within and near the range of Berry Cave salamander (X denotes the species' presence).

County	Cave	Berry Cave salamander	Spring salamander
Anderson	Blowing Springs Cave		
Anderson	Carters Pit		
Anderson	Demarcus Cave		X
Anderson	Martin Cave		
Anderson	Rieders Lost Creek Cave		
Anderson	Robert Smith Cave		
Anderson	Springhill Saltpeter Cave		
Anderson	Wallace Cave		
Anderson	Weaver Cave		
Blount	Tuckaleechee Caverns		
Campbell	Panther Cave No. 1		
Campbell	Panther Cave No. 2		
Carter	Carter Saltpeter Cave		
Carter	Rockhouse Cave		
Claiborne	Buis Saltpeter Cave		X
Claiborne	Coonsies Creek Cave		
Claiborne	Fools Cave		
Claiborne	Kings Saltpeter Cave		X
Claiborne	Sour Kraut Cave		
Grainger	Indian Cave		X
Hamblen	Miller Cave		
Hamblen	Soard Cave		
Jefferson	Silo Pit Cave		
Jefferson	Tater Cave		
Knox	Aycock Spring Cave	X	
Knox	Blowing Hole Cave		
Knox	Brents Cave		
Knox	Burnett Cave		X
Knox	Campbell Cave		
Knox	Carter Cave		X
Knox	Cherokee Bluff Cave		
Knox	Cherokee Caverns		
Knox	Chriscroft Cave		
Knox	Christian Cave	X	
Knox	Conner Creek Cave		

Knox	Cruze Cave		X
Knox	Ebenezer Rising Cave		
Knox	Fifth Entrance Cave	X	
Knox	Heiskell Pit		
Knox	Keller Bend Cave		
Knox	Kirkpatrick Cave		X
Knox	Meads River Cave	X	X
Knox	Meads Quarry Cave	X	X
Knox	Mudflats Cave	X	X
Knox	Pedigo Cave		
Knox	Pedigo Cave No. 2		
Knox	Steamboat Crawl		
Knox	The Lost Puddle	X	
Knox	Unreported Cave		
Loudon	Benjos Cave		
Loudon	Blankenship Cave		
Loudon	Melton Hill Spring Cave		
Loudon	Ghost Cave		X
McMinn	McCorkle Cave		
McMinn	Small Cave	X	X
McMinn	Too Small Cave		
Meigs	Blythe Ferry Cave	X	
Meigs	Sensabaugh Cave		X
Monroe	Alans Hideaway Cave		
Monroe	Gay Cave		
Monroe	Lick Creek Cave		
Monroe	Morgan Cave		
Monroe	Nobletts Cave		X
Monroe	The Lost Sea		
Rhea	Clear Creek Cave		
Rhea	Dayton Quarry Cave		
Rhea	Grassy Creek Cave		
Rhea	Piney River Cave		
Rhea	Starve Rock Cave		
Roane	Berry Cave	X	
Roane	Big Cave		
Roane	Cave Creek Cave		X
Roane	Chimney Cave		
Roane	Eblen Cave		X
Roane	Marble Bluff Cave		
Sevier	Two County Cave		

Sullivan	Bristol Caverns		X
Union	Big Cave		X
Union	Big Coon Caverns		
Union	Ellison Hollow Cave		
Union	Little Coon Cave		
Union	Mossy Spring Cave		
Union	Oaks Cave		X
Union	Rogers Hollow Cave		
Union	Wright Cave		