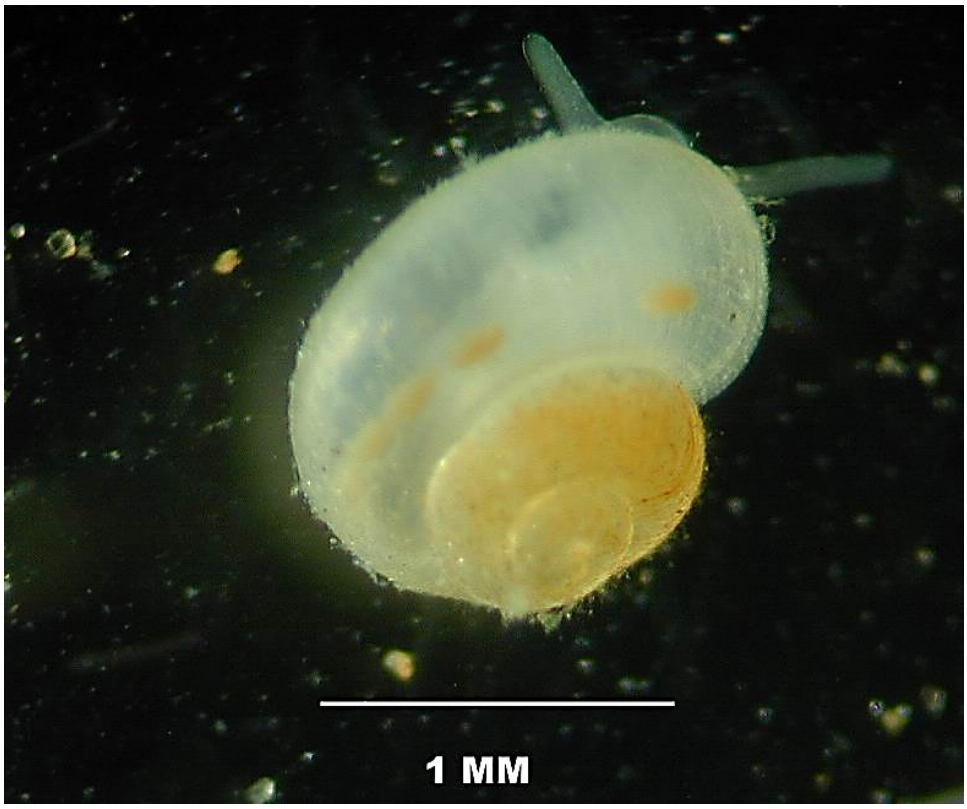
Tumbling Creek Cavesnail
(*Antrobia culveri*)

5-Year Review:
Summary and Evaluation



U.S. Fish and Wildlife Service
Missouri Ecological Services Field Office
Columbia, Missouri

February 2022

STATUS REVIEW
Tumbling Creek Cavesnail (*Antrobia culveri*)

GENERAL INFORMATION

Species: Tumbling Creek Cavesnail (*Antrobia culveri)*

Reviewers:

Tom Aley, President and Senior Hydrologist for the Ozark Underground Laboratory
Dr. David Ashley, Missouri Western State University
Michael Slay, The Nature Conservancy
Dr. Paul McKenzie, former Recovery Coordinator for the TCC and current Tumbling Creek Cave Foundation board member

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Date of listing publication:

Emergency Listing

FR notice: 66FR 66803
Date listed: December 27, 2001
Entity listed: Species
Classification: Endangered

Original Listing
FR notice: 67 FR 52879
Date listed: August 14, 2002
Entity listed: Species
Classification: Endangered

Critical habitat/4(d) rule/Experimental population designation/Similarity of appearance listing:

Critical Habitat Designation

FR notice: 76 FR 37663 37677
Date designated: June 28, 2011

Methodology used to complete the review:

This status review was completed by Vona Kuczynska, Kris Budd, and Gabriela Wolf-Gonzalez in the Missouri Field Office. The review was conducted in close coordination with David Woods with the Ozark Underground Lab and Dr. David Ashley with Missouri Western University, who provided all the data required to compile the status review. In January 2022, the Missouri Field Office solicited peer review of this draft 5-year review from recognized Tumbling Creek Cavesnail experts: Tom Aley, President and Senior Hydrologist for the Ozark Underground Laboratory, Protem, Missouri; Dr. David Ashley; Michael Slay, The Nature Conservancy Fayetteville, Arkansas; and Dr. Paul McKenzie, a former Recovery Coordinator for the Tumbling Creek Cavesnail and current Tumbling Creek Cave Foundation board member. We received comments from all peer reviewers and have incorporated their suggestions in this revised document.

In accordance with section 4(c)(2) of the Endangered Species Act of 1973, as amended (Act), the purpose of a status review is to assess each threatened or endangered species to determine whether its status has changed and if it should be reclassified or removed from the Lists of Threatened and Endangered Wildlife and Plants. The U.S. Fish and Wildlife Service (Service) evaluated the biology and status of the Tumbling Creek Cavesnail (*Antrobia culveri)* to inform this status review. Hereafter, we refer to the Tumbling Creek Cavesnail as "the cavesnail" for succinctness.

FR Notice citation announcing the species is under active review: 86 FR 61286 61287. Endangered and Threatened Wildlife and Plants; Initiation of 5-Year Status Reviews of Six Listed Animal and Plant Species. November 05, 2021.

Review History:

USFWS. 2014. Tumbling Creek Cavesnail (*Antrobia culveri)* 5-Year Review: Summary and Evaluation. U.S. Fish and Wildlife Service, Ft. Snelling, Minnesota. February 2014

REVIEW ANALYSIS

Recovery Criteria

Recovery Plan: USFWS. 2003. Tumbling Creek Cavesnail Recovery Plan. U.S. Fish and Wildlife Service, Columbia, Missouri. September 15, 2003

Recovery criteria for downlisting and delisting were developed in the 2003 Recovery Plan (USFWS 2003). The Tumbling Creek Cavesnail may be considered for reclassification from endangered to threatened when the following three criteria have been met.

Criterion 1. The population is stable or increasing for 10 consecutive years with at least 1,500 individuals. The population shall be considered stable when a linear regression analysis of population numbers estimated within an established survey area reveals no significant decline in numbers.

Criterion 2. A minimum of 80% of the surface habitat within the recharge area of Tumbling Creek Cave, including a minimum of 75% of all riparian corridors, sinkholes and losing streams, is appropriately managed, restored, rehabilitated, or stabilized through long term, voluntary, landowner agreements, such as stewardship plans, easements, or memorandums of agreements that promote best management practices.

Criterion 3. Water quality monitoring including, but not limited to, Tumbling Creek, fails to detect levels of any water pollutant that exceeds USEPA recommended water quality or exceed known toxicity thresholds for the species for a period of 10 consecutive years (including criteria for sediment and suspended organic matter deposition).

The Tumbling Creek Cavesnail may be considered for delisting when the following three criteria have been achieved:

Criterion 1. The population is stable or increasing for an additional 10 consecutive years with at least 5,000 individuals. The population shall be considered stable when a linear regression analysis of population numbers estimated within an established survey area reveals no significant decline in numbers.

Criterion 2. A minimum of 90% of the surface habitat within the recharge area of Tumbling Creek Cave, including a minimum of 85% of all riparian corridors, sinkholes and losing streams, is appropriately managed, restored, rehabilitated, or stabilized through long term, voluntary, land owner agreements, such as stewardship plans, easements, or memorandums of agreements that promote best management practices.

Criterion 3. Water quality monitoring including, but not limited to, Tumbling Creek, fails to detect levels of any water pollutant that exceeds USEPA recommended water quality or exceed known toxicity thresholds for the species for an additional 10

consecutive years (including criteria for sediment and suspended organic matter deposition).

The 2003 Recovery Plan criteria remain appropriate based on our current level of understanding of the species. Two of the three criteria have been partly met toward reclassifying the species to threatened.

With 60.2% of surface area habitat and 69.6% of riparian corridors considered protected, Criterion 2 is continuing to progress toward the 80% surface area and 75% riparian area threshold for downlisting. More information regarding Criterion 2 can be located in the "Habitat" Section of this review.

Criterion 3 was assessed as part of the 2014 5-Year Review and Tumbling Creek Cave Foundation (TCCF) has continually monitored water quality in the cave since the last 5-year review. Data loggers and probes are serviced monthly, but it has been a few years since the data was compiled and analyzed. An update will be provided as part of the next 5-year review. However, TCCF regularly enters the cave and has not seen any obvious cause for concern regarding the water quality since the last 5-year review. As a result of appropriately managed sinkholes, riparian corridors, and sinking streams in the protected portions of the recharge area, the water quality in Tumbling Creek has improved (USFWS 2014). Thus, the criterion is considered partially met.

Although much of the second and third criterion for possible downlisting are closer to meeting their criteria, the species is a long way from achieving the first criterion related to a stable or increasing population with a minimum of 1,500 individuals. In fact, the minimum of 1,500 individuals has not been met one year let alone 10 consecutive years. A summary of population trends is provided in the "Population Demographics" section of the review.

Updated Information Relevant to the Current Species' Status

The Tumbling Creek Cavesnail has had one 5-year review since it was an emergency listed in August 2002. The 2014 5- year review recommended no status change because none of the three criteria required for downlisting had been met (USFWS 2014).

Although we did not receive any information from the public in response to our Federal Register notice announcing this 5-year review, new survey data and conservation measures enacted to recover the cavesnail have been put in place since the last review. A summary of the surveys and recovery work completed since 2013 are provided in this review.

Biology and Habitat: There have been no new study results regarding the life history requirements of this species since the previous five-year status review in 2014 (USFWS 2014). Information regarding the species' biology and life history can be found in the species' recovery plan (USFWS 2003) and in the 2014 status review (USFWS 2014).

Range and Distribution: The Tumbling Creek Cavesnail is restricted to a single cave stream in Tumbling Creek Cave in Taney County, southwestern Missouri (Figure 1). The cave occurs in

the southeastern portion of the recharge area and north of the Bull Shoals reservoir. No new information indicates that this species is found anywhere outside of Tumbling Creek Cave and associated underground aquatic karst and/or springs.

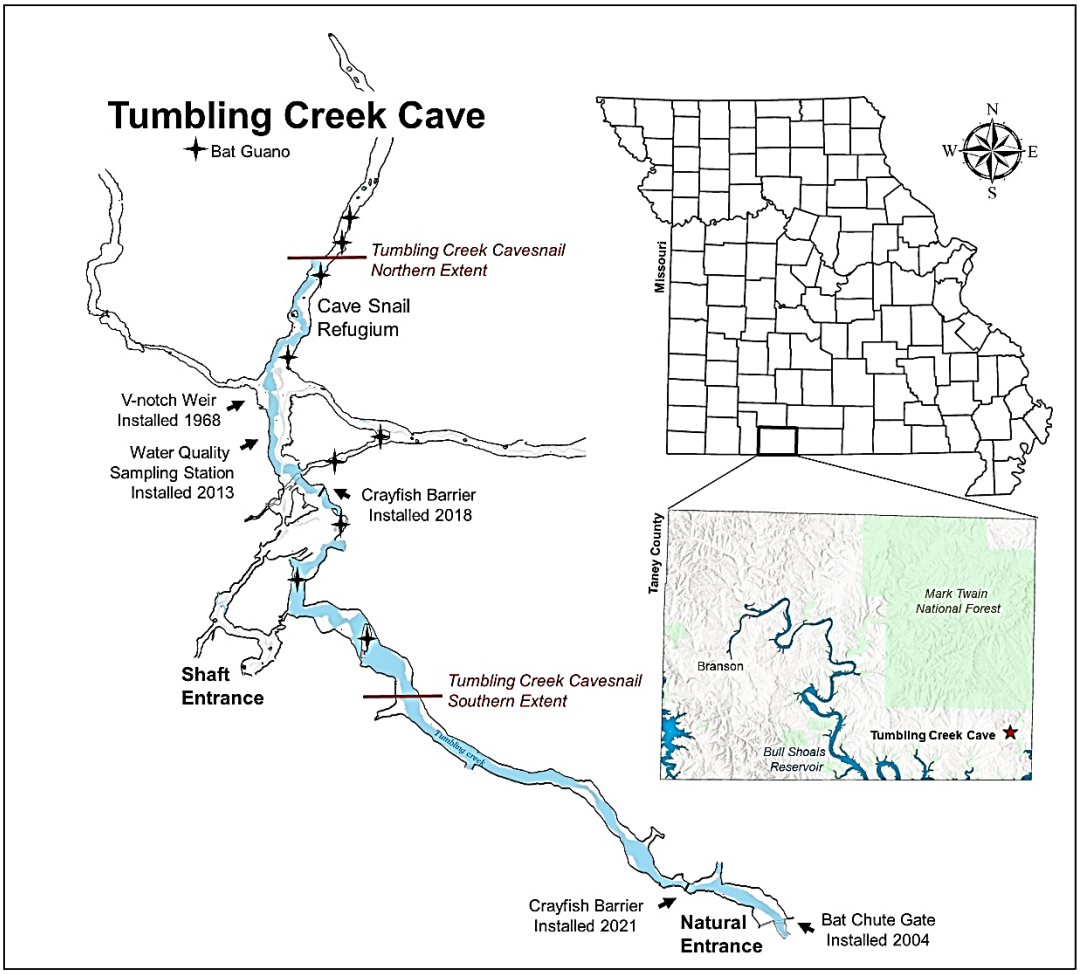

Figure 1: The distribution of the Tumbling Creek Cavesnail within the Tumbling Creek Cave in Taney County, Missouri. The southern and northern extent of the cavesnail's range within the underground stream and passages are delineated.

Population Demographics: Population monitoring efforts for the Tumbling Creek Cavesnail have been ongoing since 1996. Seven sampling stations representative of cavesnail habitat are surveyed and the population is estimated from these data each year (Ashley 2021).

The Tumbling Creek Cavesnail Recovery Team has been conducting annual surveys, often across multiple seasons each year. Seasons are grouped into three months: Spring (March, April, May), Summer (June, July, August), Fall (September, October, November) and Winter (December, January, February). Annual population estimates plummeted in the early 2000s, warranting emergency listing in 2001 and then listing as endangered in 2002 (Figure 2; Ashley 2021). See Table A1 in the Appendix for raw survey data. These data demonstrate that in some

years, there are no cavesnails observed along survey transects. Additionally, there are very large fluctuations in the number of cavesnail across years and seasons (Figure 2 and Figure 3).

We attempted to assess if seasonality influences the number of snails present but, surveys are not consistently conducted across every season each year. Thus, it is not possible to confidently compare cavesnail numbers across seasons. However, there were many surveys that took place both during the Fall and Spring seasons. Surveys from these years suggest that cavesnails typically occur in larger numbers in the Fall than the Spring (n = 8), but the pattern is not consistent across every year of sampling. The pattern held true from 2002 until 2018 but was reversed in 1998 and 2019 (Figure 3). Surveys conducted at times of high-water levels may yield differing results than surveys during low water conditions. It would be beneficial to further examine this difference and determine the range of water depth by season.

Population numbers remained above 300 cavesnails each year from 2014 to 2019 and dropped precipitously by 2020 to zero snails in 2021 (Figure 2). To our knowledge, there were no events (e.g., severe floods, siltation, and reduced dissolved oxygen levels) that occurred in 2019 that could be the culprit for the dramatic decline in cavesnail numbers in 2020 and 2021. While the estimated population change is a potential cause for concern, it is not uncommon for the number of snails to fluctuate across years. Cavesnail numbers also declined sharply from 2000 to 2001. One potential explanation is that the cavesnail population is experiencing a boom-and-bust cycle. At this time, there is not enough data to definitively determine if cavesnail populations go through repeated and regular periods of boom followed by bust, but continued surveys would aid in discerning this question. Another explanation for the sudden decline may be that an environmental factor is having a negative influence on the population and reducing the number of cavesnails.

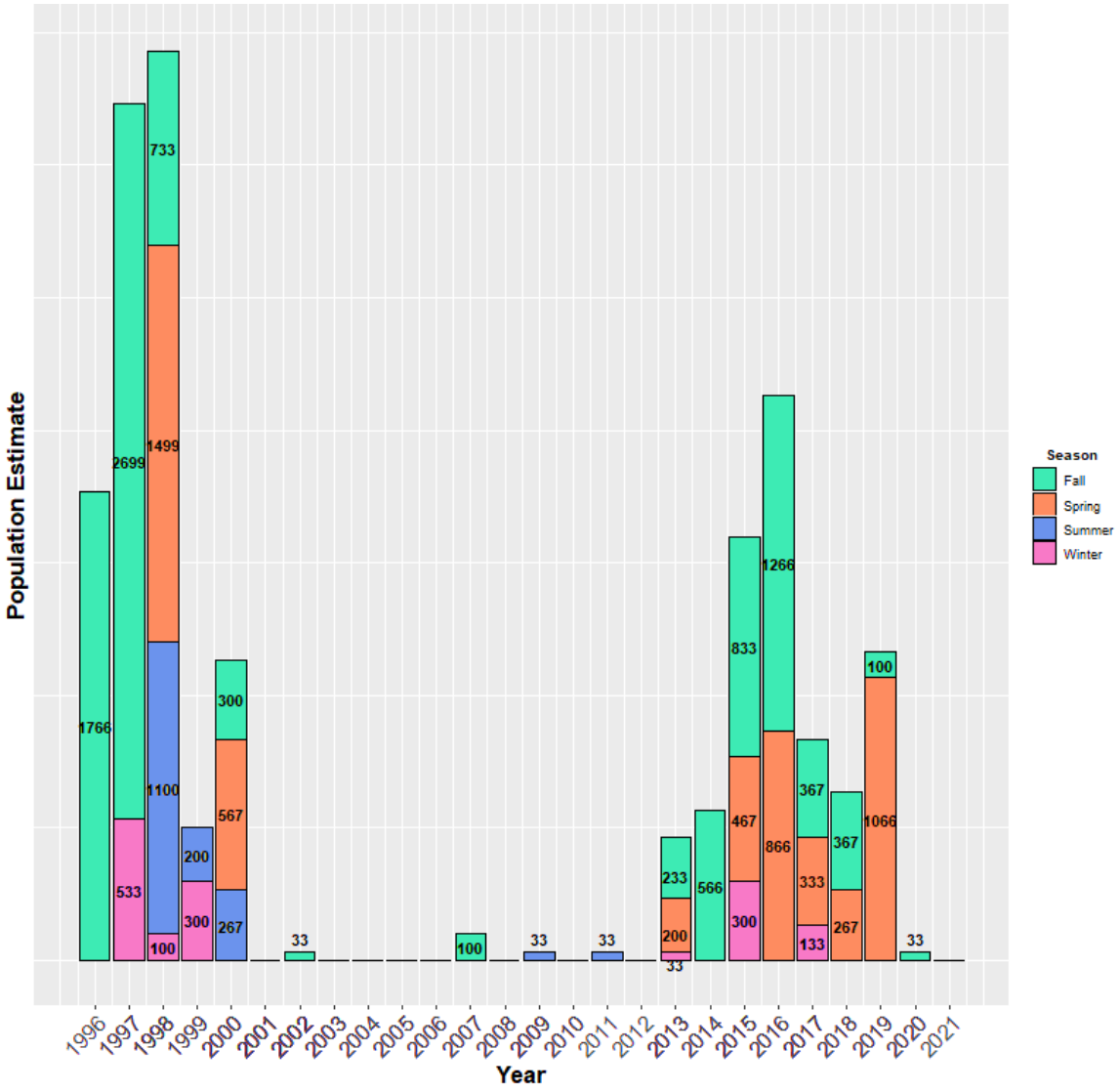

Figure 2: Cavesnail population estimates from the sampling transect of Tumbling Creek Cave (1996 to 2021). Color coded stacked bars depict the number of snails counted each year across seasons. Note: Surveys occurred every year between 1996 and 2021 for one or more season but not necessarily across every season. Population estimates of 0 are marked with a thin black line for the corresponding year and are not labeled "0" in the Figure. For more detailed population estimate information in the designated transect survey area, see Table A1.

In addition to transect surveys, periodic surveys are conducted within an additional area referred to as the "Refugium" (for location, see Figure 1). In the Refugium, clay tiles are used as a substitute substrate for surveys to reduce potential disturbance during monitoring. A total of 32 clay tiles were deployed in 2006 within two stations, each having 16 tiles. Station 1 is upstream, at the stream entry to Tumbling Creek Cave while station 2 is downstream, close to the tour trail. Cavesnail counts occurred on an annual basis except when water levels and turbidity were too high or when endangered bats were present (USFWS 2014; Ashley 2020). Figure 4 displays the

number of cavesnails present during surveys at Station 1 and 2 across years. See Table A2 and Table A3 in the Appendix for raw survey data. Because surveys are not seasonally determined and we do not know if seasonality could impact cavesnail abundance, it is difficult to determine if population numbers are stable across seasons and years. However, surveys occur in the Fall season regularly. Since 2008, Fall sampling did not occur only in 3 years (2011, 2012, and 2014). Since 2015, Fall surveys show relatively stable and consistent numbers (Figure 3). Based on consistent Fall sampling, cavesnails on tiles in the Refugium appear to be relatively stable. However, the number of cavesnail counts are very low and concerning in the transect population during certain years (Ashley 2020). Despite recovery efforts, there is no indication that snail numbers at the Refugium are steadily increasing. Another noteworthy observation is that Station 1 consistently has higher numbers of cavesnails than Station 2, even though both stations have the same number of tiles (Figure 4). One potential explanation for the difference is the water depth and flow velocity differences between the two stations. The stream substrate composition also seems to differ between the two tile stations. The upstream station is characterized by extensive cobble and small rocks. The downstream station is characterized by the distribution of large slabs of rock that cannot be moved.

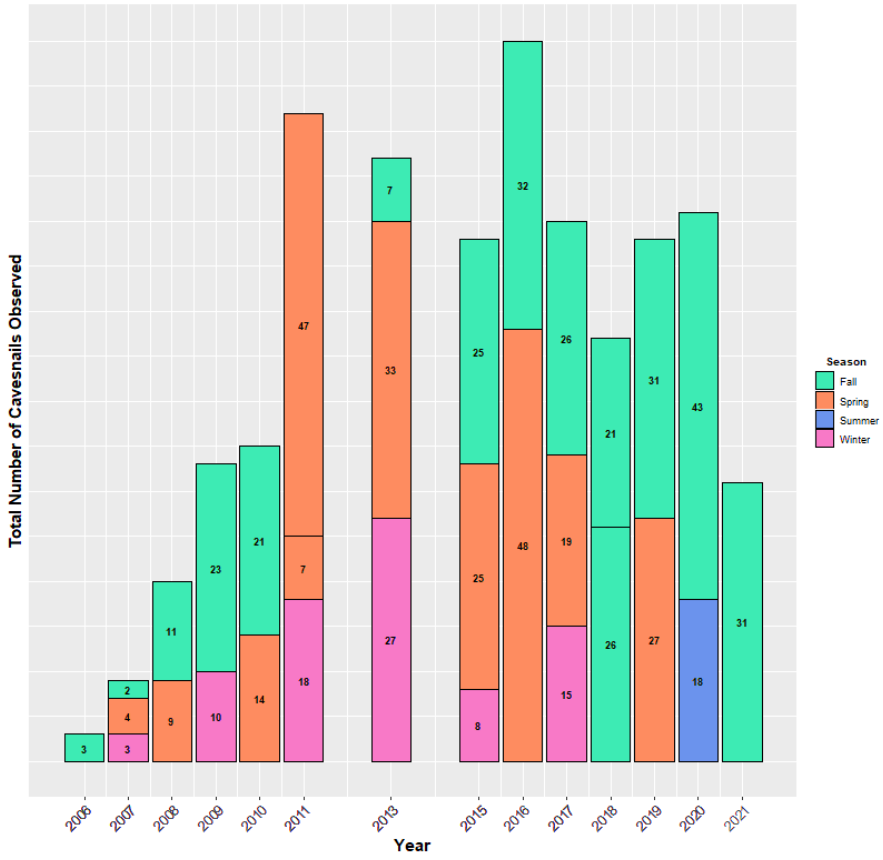

Figure 3. Tumbling Creek Cavesnail Counts in the Refugium (2006-2021). Counts from Station 1 and 2 are summed (across 32 tiles; 16 per Station). No counts occurred in 2012. One count conducted in Spring 2014 had zero cavesnails because surveyers were able to visit the downstream station (Station 2), but were unable to visit Station 1 due to the presence of roosting endangered bats.

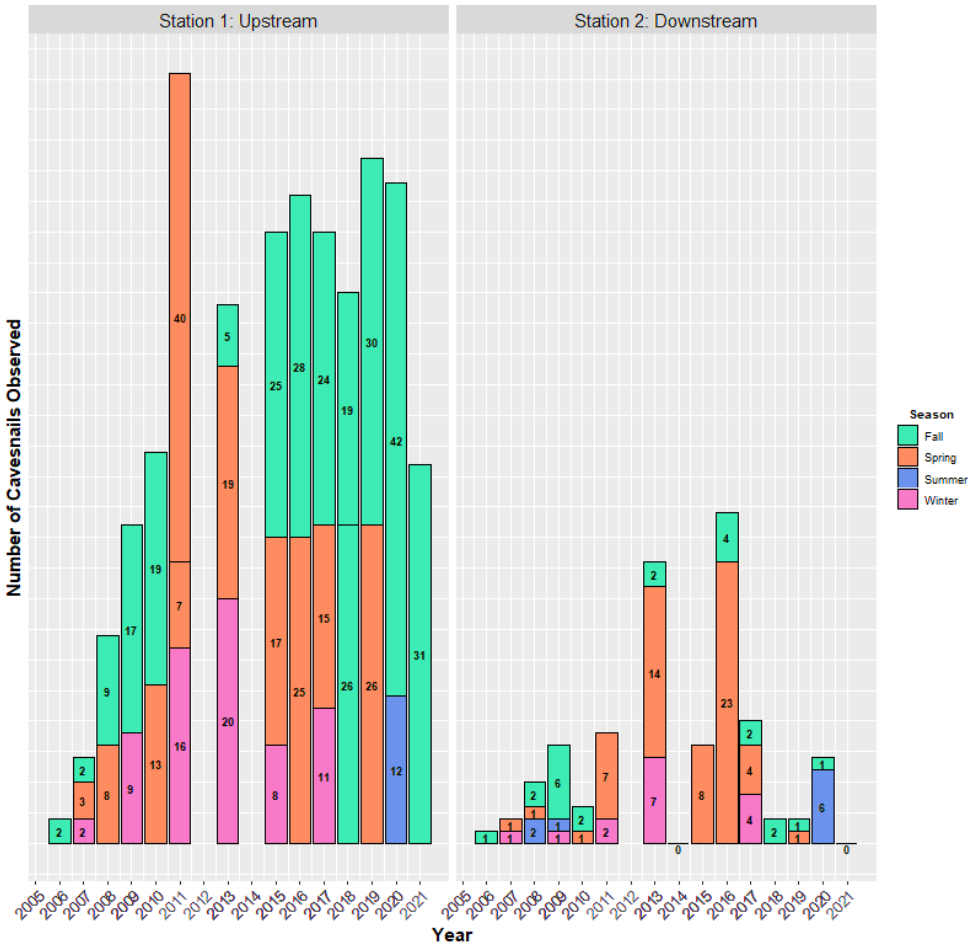

Figure 4: Tumbling Creek Cavesnail Counts per Station in the Refugium (2006-2021). Counts are separated by Tile Stations. Station 1 is upstream; Station 2 is downstream.

In summary, populations of the Tumbling Creek cavesnail are regularly monitored in two areas of Tumbling Creek cave across multiple seasons. The transect area has been monitored since 1996 and the Refugium since 2006. Consistent population monitoring in both the transect area and the Refugium show low cavesnail numbers despite the previous population growth reported in the 2014 Tumbling Creek cavesnail 5-Year review. Despite protection and ongoing restoration efforts within the recharge area of Tumbling Creek Cave, the minimum of 1,500 individuals has not been met for any one year (Figure 2; Table 1).

Genetics: Molecular studies of hydrobioid snails (species in the family Hydrobiidae and similar families) have helped to clarify the taxomomy of many cavesnail species. For instance, *Amnicola stygia* (MO endemic) and *A. cora* (AR endemic) were elevated from Hydrobiidae to the family Amnicolidae. All members of the genus *Fontigens* were placed in the family Fontigentidae. There is consensus that molecular techniques, coupled with morphology, are necessary to define species and relationships for these difficult to observe snails. Wilke et al. (2001) summarizes the problems with using only morphological information: 1.) morphological simplicity due to miniaturization, 2.) anatomical character variation, 3.) unknown phylogenetic significance of anatomical characters, and 4.) high degree of homoplasy (shared characteristics) in anatomical

characters. In a similar fashion, many other taxonomic groups have benefitted from integrating molecular and morphological information. More importantly, having genetic sequence data for *A. culveri* available would be the basis for any future eDNA studies that might be considered. Although there has been some effort to survey caves in the vicinity of Tumbling Creek Cave for additional cavesnail populations, these visual census surveys have not identified any new locations. eDNA surveys may be a useful tool to confirm single site endemism or perhaps additional locations. Given the population variation observed from previous surveys and the current very low numbers, molecular sampling requires population sizes similar to that observed from 2014 – 2019; as removing five individuals for a molecular assessment would be unlikely to be a detriment to the population.

Taxonomic and nomenclature: The Tumbling Creek Cavesnail Recovery Plan provided the taxonomic classification of *Antrobia culveri* as understood by Hershler and Hubricht (1988) with the cavesnail considered a member of the Chochliopina group in the subfamily Littoridininae of the family Hydrobiidae. Subsequently, the subfamily placement within Hydrobiidae was re-evaluated, and *A. culveri* was referred to the subfamily Chochliopinae (Hershler and Thompson 1992). *Antrobia culveri* shares morphological affinities with another monotypic cavesnail, *Antroselates spiralis*, with similarities in protoconch sculpture and the oviduct complex (Hershler and Hubricht 1988), and *A. spiralis* was likewise referred to the subfamily Chochliopinae (Hershler and Thompson 1992). More recently, molecular phylogenetic studies have clarified relationships between many snail taxa formerly considered part of the family Hydrobiidae, although none of these studies include species occurring in the Ozarks (Lui et al. 2001; Wilke et al. 2001; Wilke et al. 2013; Gladstone and Whelan 2022). For example, using DNA sequence data generated for the cytochrome c oxidase subunit I (COI) mitochondrial gene, members of the genus *Fontigens* where elevated from subfamily to the family Fontigentidae (Gladstone and Whelan 2022). Similarly, members of the genus *Amnicola* are currently referred to the family Amnicolidae (Wilke et al. 2001). Relevant to *Antrobia culveri*, the subfamily classification (Chochliopinae) was elevated to family level (Chochliopidae), putting the Tumbling Creek Cavesnail into a distinct family category relative to other cavesnails in the Ozarks (Wilke et al. 2001; Wilke et al. 2013). Of note, *Antroselates spiralis*, which shares morphological affinities to *Antrobia culveri*, is now considered a member of the family Amncolidae (Lui et al. 2001; Wilke et al. 2013). Future molecular studies that include DNA sequences from *A. culveri* may also demonstrate that this cavesnail is a member of the family Amnicolidae. However, currently the Tumbling Creek Cavesnail is considered a member of the family Chochliopidae (MolluscaBase 2021).

Habitat: The recharge area was previously delineated using a USGS quadrangle map and polar planimeter at 5,773 acres (2,336 hectares). The recharge area was recently estimated at 7,055.38 acres (2,855.21 hectares) using digital spatial analyses. As the transition from hand to digital estimates are varying, the Ozark Underground Laboratory and Tumbling Creek Cave Foundation are working to verify the official acreage of the recharge area. In 2018, the Tumbling Creek Cave Foundation acquired the 640-acre (258.99 hectare) Meyers tract with the help of grant money obtained through a partnership with the USFWS Recovery Lands Acquisition program, Missouri Department of Conservation, the Conservation Fund, and John and Dorothy Stade. Combined with prior property acquisitions, of the total recharge area, 60.2% is considered protected and appropriately managed for the benefit of the cavesnail (Figure 5 and Figure 6). The recharge area contains approximately 185.29 acres (74.98 hectares) of riparian corridors, nearly 129.05 acres

(52.22 hectares) of which are protected, while approximately 56.24 acres (22.76 hectares) are considered unprotected (Figure 7). However, arson set wildfires damaged many acres of established riparian corridor in 2018. Much of the area is regenerating, but requires frequent maintenance to ensure good quality habitat. With 60.2% of surface area habitat and 69.6% of riparian corridors considered protected, Criterion 2 is still in progress.

Within the cave, habitat conditions for the cavesnail within Tumbling Creek Cave have apparently remained stable or improved (USFWS 2014). Due to the numerous recovery actions undertaken on surface areas within the recharge of Tumbling Creek Cave, sediment levels have been reduced and dissolved oxygen levels remain stable (USFWS 2014). Cave owners Tom and Cathy Aley have both noted apparent improvements in turbidity due to numerous above ground conservation actions undertaken and it is hoped that newly installed turbidity equipment will confirm those observations (Tom Aley and Cathy Aley *pers comm.* 2022).

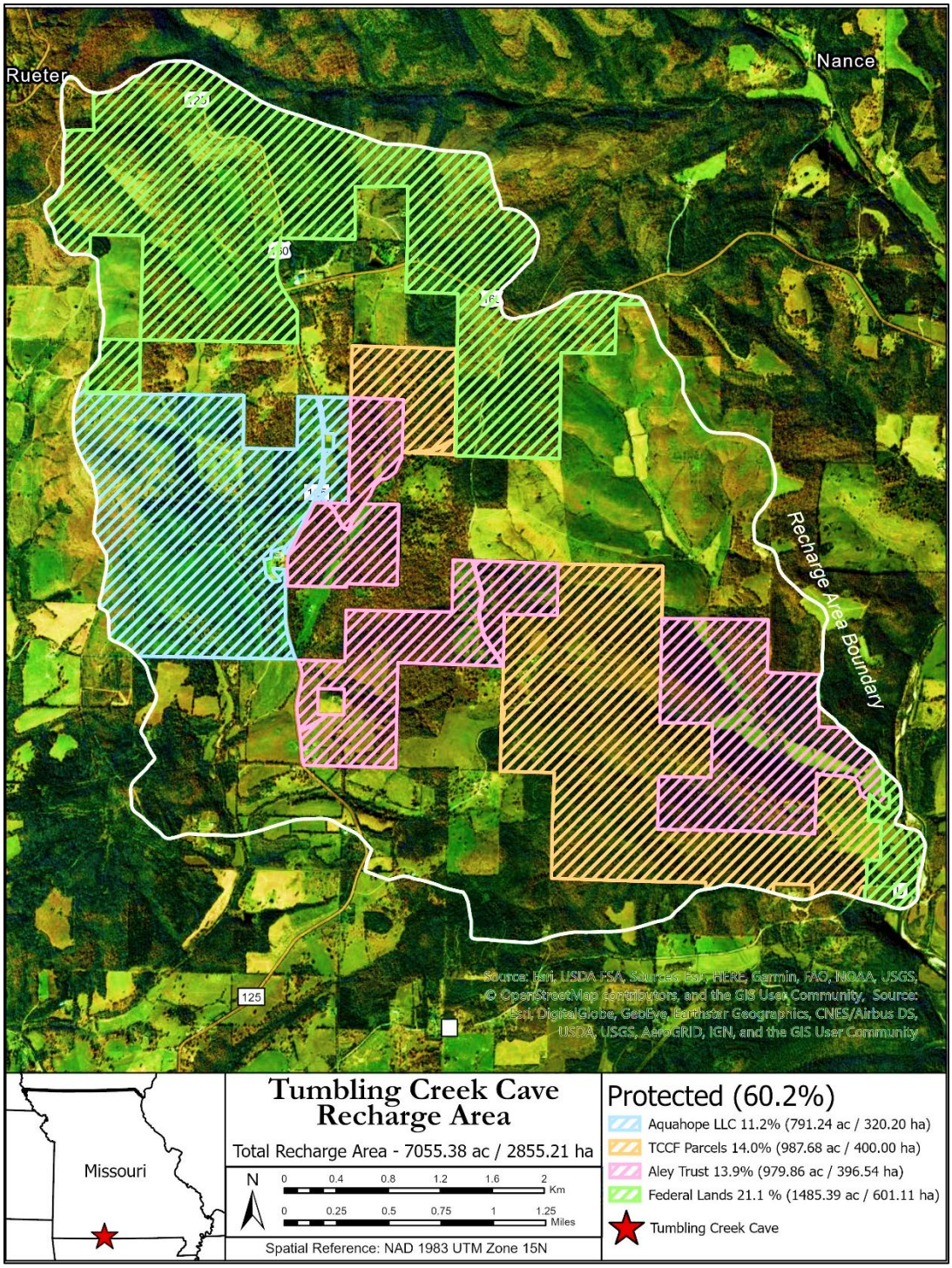

Figure 5: Protection status of properties that exist within the Tumbling Creek Cave Recharge Area. Locations of properties that are considered protected and managed to improve conditions within Tumbling Creek within the recharge area and in relation to Tumbling Creek Cave.

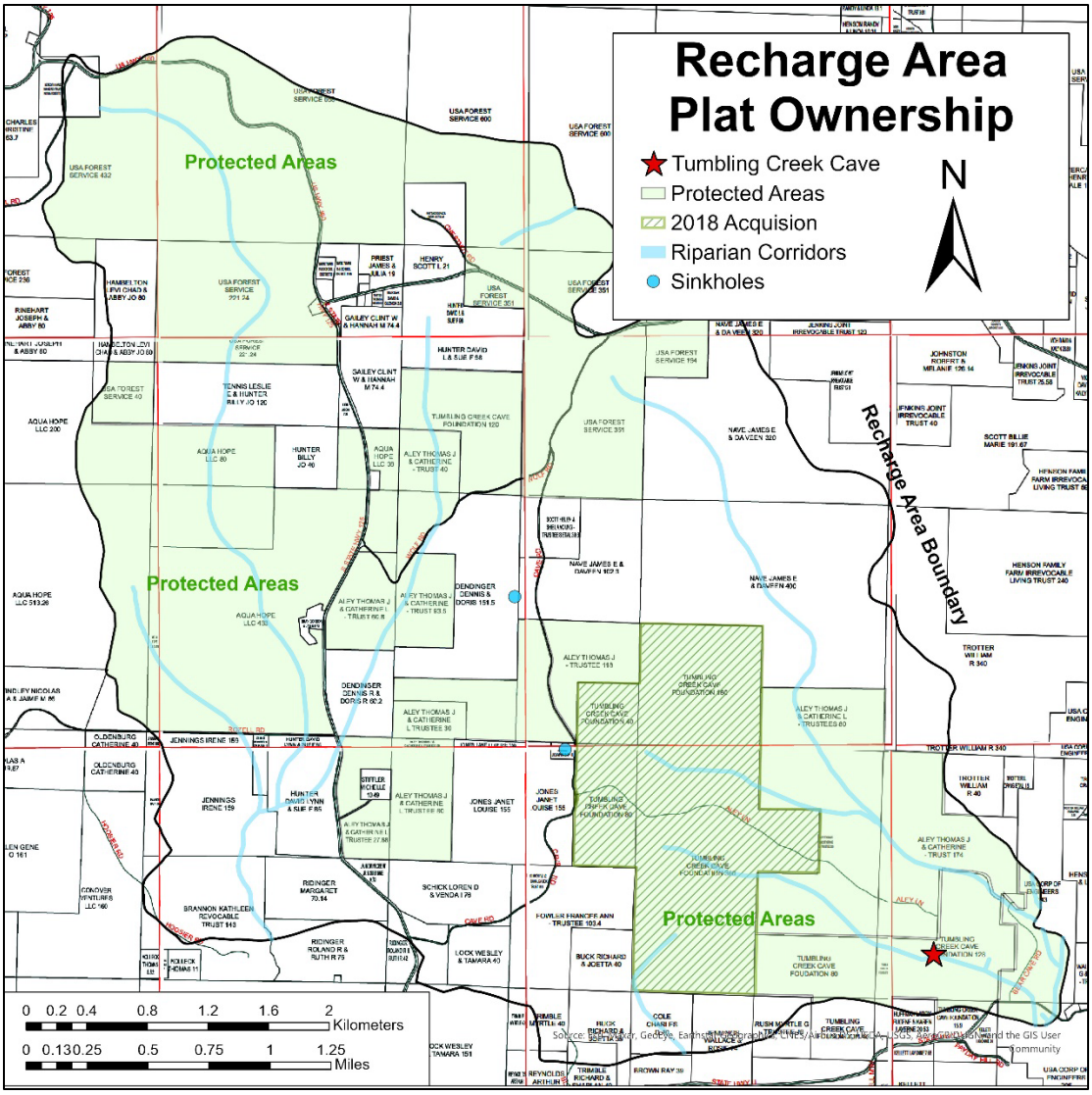

Figure 6: Plat Ownership within the Recharge Area of Tumbling Creek Cave. Future property acquisitions should prioritize protections of riparian corridors to continue to progress recovery criterion 2.

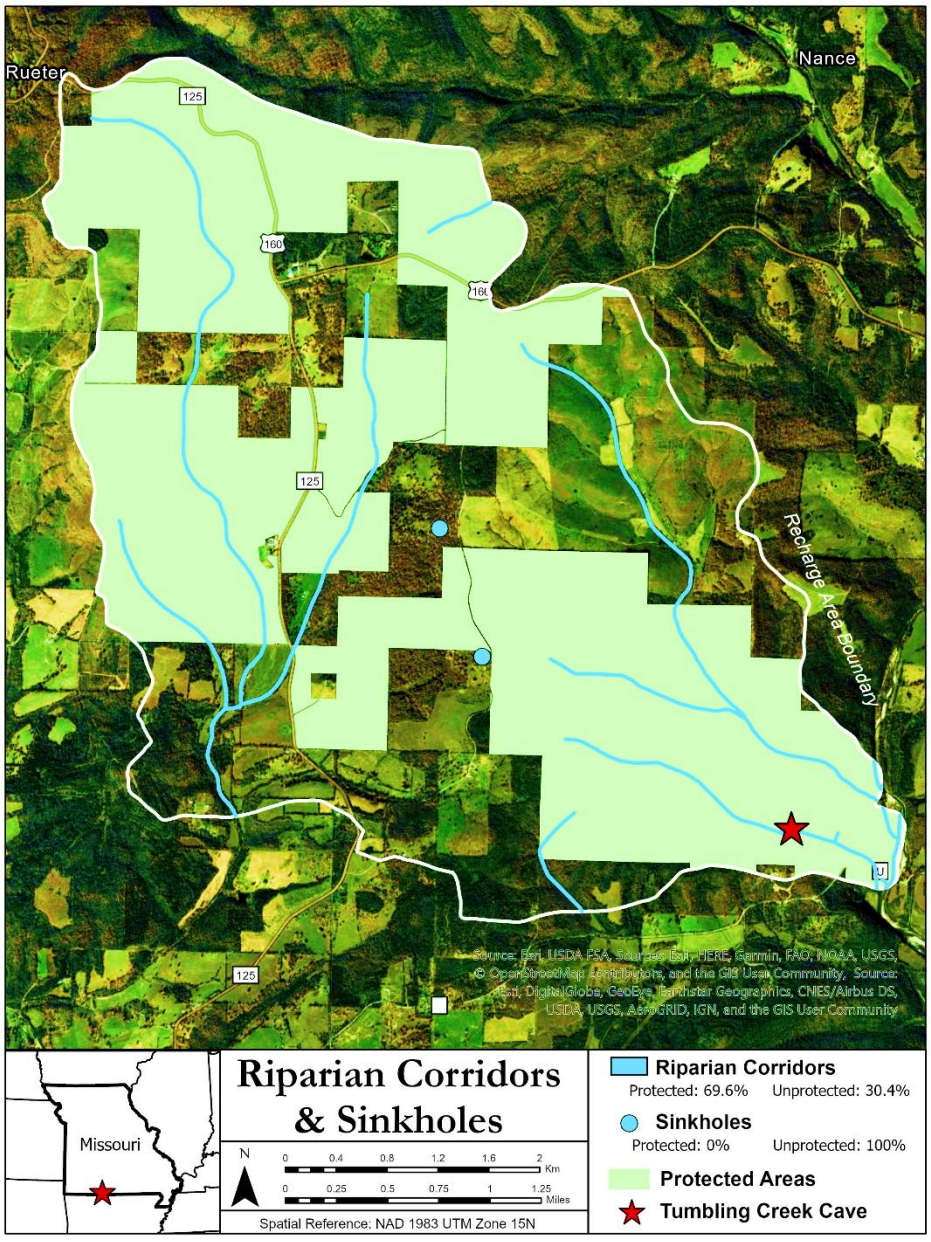

Figure 7: Protection status of riparian corridors and sinkholes that exist within the recharge area of Tumbling Creek Cave

Additional Information:

Threats Analysis (threats, conservation measures, and regulatory mechanisms):

Threats: There is no new information regarding the threats to this species since the previous five-year status review in 2014 (USFWS 2014). Information regarding the species' known threats can be found in the species' recovery plan (USFWS 2003) and in the 2014 status review (USFWS 2014).

Present or threatened destruction, modification or curtailment of its habitat or range: There is no new information regarding the present or threatened destruction, modification or curtailment of the habitat of this species since the previous five-year status review in 2014 (USFWS 2014). Information regarding the species' known threats can be found in the species' recovery plan (USFWS 2003) and in the 2014 status review (USFWS 2014).

Overutilization for commercial, recreational, scientific, or educational purposes: This species is not at risk of threats from commercial, recreational, scientific or educational purposes.

Disease or predation: White-nose syndrome (WNS) is an infectious disease caused by the psychrophilic fungus *Pseudogymnoascus destructans* (Pd). In 2009, WNS was considered an emerging threat for the federally listed gray bat (*Myotis grisescens*) and in 2014, an indirect threat to the Tumbling Creek cave's detritus food chain that could indirectly affect the cavesnail by reducing the amount of guano within the cave system (USFWS 2009; 2014). Bat guano is essential to energy input within the cave and is associated with a potential food source for the Tumbling Creek cavesnail— biofilm, the organic coating and bacterial layer or detritus associated with the underside of rocks or bare rock stream bottom (Aley and Ashley 2003; Krajick 2007). Thus, the loss of bats was considered a potential threat to the cavesnail. However, information gathered since 2009 shows the gray bat population is stable despite the introduction of WNS throughout its range (Janicki et al. 2015) and that the species is potentially resistant to the disease (Frick et al. 2017). There has not been a significant change in gray bat numbers in Tumbling Creek Cave (USFWS, 2021), and we do not consider WNS to be a threat to the food-supply of the cavesnail.

Backwater flooding of Bull Shoals Reservoir is thought to facilitate the movement of invasive Gapped Ringed Crayfish (*Faxonius neglectus chaenodactylus*) from the reservoir into Tumbling Creek Cave (USFWS 2014; Mouser et al. 2019). Crayfish within the cave were found to reproduce more frequently, were larger, and lived longer than crayfish in the surface stream (Mouser et al. 2019). A v-notch weir was installed in 1968 and may have inadvertently prevented upstream migration by this crayfish (see Figure 1 for location within cave). As of December 2021, over 6,000 crayfish have been trapped and removed from Tumbling Creek Cave; however, the population persists (Mouser et al. 2019; Dave Woods *pers comm*. 2022). In 2018, a cement barrier was installed to reduce movement upstream by Gapped Ringed Crayfish; after which few crayfish were found upstream (Mouser et al. 2019). A second barrier was installed in 2021 by the Ozark Underground Laboratory with materials provided by the Service (Woods 2021). The US

Army Corps of Engineers (Corps), who operates Bull Shoals reservoir, has secured a funding package of $50,000 to install additional crayfish exclusion structures on habitat features that are impacted by reservoir operations. These include springs along Big Creek that are connected to the designated critical habitat and the karst window on Tumbling Creek Cave Foundation property. Funds will also be used to excavate and stabilize springs and install crayfish exclusion structures to prevent migration into the critical habitat between the springs and cave.

Inadequacy of existing regulatory mechanisms: Land ownership within the Tumbling Creek Cave recharge area is likely the primary factor that limits the effectiveness of existing regulatory mechanisms. Recovery options are often limited on private lands.

Other natural or manmade factors affecting its continued existence: Climate change was identified as a potential indirect factor affecting the existence of the cavesnail in the 2014 species review. Long-term changes in environmental conditions have had observable impacts on plants, wildlife, ecosystems, and the ecosystem services they provide to society. Many species within the Tumbling Creek Cave may be impacted by climatic change including the endangered gray bat (USFWS 2021). The cavesnail may be directly impacted by the changes to water quality, drought and flooding, and the spread of invasive species. Such changes are projected to continue; and without substantial and sustained reductions in global greenhouse gas emissions, extinctions and transformative impacts on some ecosystems cannot be avoided in the long term. Additionally, the cavesnail may be directly impacted if gray bats within the cave change their usage patterns because of climate change impacts. More frequent and intense extreme weather and climate-related events, as well as changes in average climate conditions, are expected to continue to damage infrastructure, ecosystems, and social systems that provide essential benefits to communities (USGCRP 2018).

Subterranean species are expected to exhibit low tolerance to climatic perturbations due to their evolution in and dependence on a stable environment (Mammola et al. 2019). Caves and other subterranean habitats are semi-closed systems characterized by a remarkable thermal stability, which are expected to be impacted by climate change (Mammola et al. 2019). There is a direct relationship between external and internal temperature, and thus the stability of subterranean climate.

Changes to temperature and precipitation patterns has occurred and will likely continue to occur past the end of the century (Collins et al. 2013; IPCC 2019). Increased frequency of extreme weather events (e.g., flooding and drought) is predicted (Collins et al. 2013; IPCC 2019). Given the small population, and low recent observations, a severe and extended drought could further contribute to a decrease in numbers and speed the species toward extinction (USFWS 2014). Large scale precipitation events that result in major floods remain a threat to some gray bat caves, including Tumbling Creek Cave, and may become a more serious threat in the future due to climate change. The frequency of flood events has increased across the southeastern region and also across most of the Midwestern U.S. over the past two or more decades (Konrad et al. 2013; Neri et al. 2019) Continued increase in flood events may result in the abandonment of suitable and preferred summer gray bat sites, and thus a loss in nutrient input within Tumbling Creek

Cave. Additionally, flooding can increase turbidity and increased silt loads which can negatively affect reproduction and recruitment of cavesnails and other aquatic species (Ashley 2000; Taylor et al. 2000; USFWS 2003). Clay particles were previously reported to cement spaces between gravel and rocks, thus reducing the cavesnail habitat (USFWS 2003).

The Ozark Underground Lab has not conducted any climate change studies in Tumbling Creek Cave; however, they work to increase resilience to climate change by protecting and maintaining intact terrestrial communities on the surface. The degree to which negative effects of climate change will be offset by positive effects on other life history features remains uncertain. Further monitoring and research are needed to better understand the impacts of climate change on the Tumbling Creek cavesnail and its habitat.

Conservation Measures: The Ozark Underground Lab has completed a suite of conservation actions to benefit the cavesnail. For a list of conservation actions prior to 2014, refer to the previous species status review (USFWS 2014). Conservation actions since 2014 include, but are not limited to: land acquisition, crayfish removal, and continued population monitoring. Table 1 contains a list of conservation measures that have occurred between 2014 and 2021.

Table 1: Conservation actions for the Tumbling Creek Cavesnail (2014-2021)

Conservation Measure	Dates	Comments
Antrobia Monitoring	1996 – Present	Information on this included in "Population trends section"
Maintenance of Cave Gate	2003 – Present	Cave gate installed in 2003 but requires periodic inspection and maintenance, debris clearing, and dead or fallen tree removal near cave entrance.
Water Quality Station	2002 – Present	Funded by USFWS, maintained by OUL
Septic Lift Station	Ongoing	Funded by USFWS, maintained by OUL
Crayfish Removal Plan	2011 – Present	Weekly trapping events are conducted to eradicate invasive crayfish in Tumbling Creek Cave funded by MDC and TCCF
Land Acquisition	2018	The Tumbling Creek Cave Foundation acquired the 640-acre Meyers tract with the help of grant money obtained through a partnership with the USFWS Recovery Lands Acquisition program, Missouri Dept. of Conservation, the Conservation Fund, and John and Dorothy Stade
Construction of Crayfish Barriers	2018 & 2021	Recent publication: Mouser et al. (2019) describes impacts of crayfish barrier installation and removal efforts.
Vegetation Study	2021 – Present	OUL contracted ecology and botany expert Mr. Paul Nelson to conduct a 2-year vegetation and natural community analysis of all lands owned by OUL/TCCF. These results will serve as the basis for the development of an above-ground management plan and restoration recommendations to maintain the surface habitat of areas within the cave's recharge zone.

Recommendations for future actions

There have been significant accomplishments achieved related to habitat for Tumbling Creek Cavesnail since the species was listed in 2002. Conservation actions to benefit the species include: land acquisition, restoration and maintenance of above ground areas within the cave's recharge area through tree plantings along riparian corridors, establishment of warm season grasses on overgrazed fields and glades, cleanup of trash dumps in sinkholes, replacement of leaking or subpar sewage/septic systems, road surfacing to reduce the transportation of sediment, replacement of stream drain pipes that impeded stream flow, construction of a bat-friendly gate on the natural exit to Tumbling Creek Cave to eliminate illegal entry and disturbance to gray and Indiana bats, the installation of movement barriers to reduce upstream migration of exotic crayfish, and the installation of new equipment in 2013 to monitor turbidity.

During the next five years, it is recommended that the following actions be undertaken for reasons given below:

1. To address criterion 3 of the cavesnail recovery plan, we recommend the continuation of water quality monitoring in the Tumbling Creek Cave with annual compilation of data on levels of any water pollutant that exceeds USEPA recommended water quality, toxicity thresholds, sediment, and suspended organic matter deposition.

2. In 2014, propagation efforts made significant progress using a surrogate aquatic snail; however, these efforts have not continued since. We recommend that these efforts continue to determine if the Tumbling Creek Cavesnail can be propagated successfully. As previously recommended, propagation efforts should be guided by a propagation plan developed and approved by the Tumbling Creek Cavesnail Workgroup and Partnership.

3. Efforts to reduce crayfish predation and migration upstream have been successful with the installation of two barriers; however, the persistence of invasive Gapped Ringed Crayfish (*Faxonius neglectus chaenodactylus*) can continue to impede cavesnail recovery. We recommend that crayfish trapping efforts and barrier construction be continued with studies conducted to investigate invasion pathways. Cavesnail partners should suggest to the Corps that signs be placed at boat ramps of the Bull Shoals reservoir that it is illegal to use or release invasive species of crayfish for fishing. If the invasive Rusty Crayfish (*Orconectes rusticus*), which has spread rapidly across most of the Midwest, is released unintentionally in MO, proactive steps should be initiated to prevent an additional crayfish problem for Tumbling Creek Cave.

4. Cavesnail numbers and the results of ongoing conservation efforts need to be regularly monitored to assess recovery efforts. Annual surveys should be conducted with a determined seasonality requirement to allow for consistency and more comparable surveys between years. Suggested recommendations should be outlined in an adaptive management framework and adjustments made as necessary. Further monitoring on the use of surrogate tiles by cavesnails is needed to determine the applicability of using supplemental substrates as a method to index population numbers of the cavesnail.

5. Consultation should be initiated between the Corps and the Service to assess the potential impact of the operation of Bull Shoals Reservoir on the species and critical habitat. This should focus on backwater flooding and the likely emigration of invasive crayfish into Tumbling Creek via the reservoir and Big Creek. The Corps should develop a conservation program to contribute to the recovery of the Tumbling Creek Cavesnail.

6. Climate change may impact the mean annual surface temperature for a given area and this, in turn, could alter critical cave temperatures. Studies need to be initiated on the potential impacts of climate change on the Tumbling Creek Cavesnail and its habitat. We recommend continued monitoring of temperature regimes throughout Tumbling Creek Cave with the use of HOBO temperature loggers. It is likely that additional units will need to be installed to detect temperature changes throughout the cave. We also recommend that weather stations be established in the cave at appropriate locations to evaluate relative changes between surface and subsurface meteorological conditions. These temperature changes could also change the diversity, distribution, and abundance of bats roosting in Tumbling Creek Cave and thus indirectly restrict the nutrient flow into the stream habitats. Conversely, it has also been suggested that warmer caves may help bats reduce the energy stress during hibernation (Boyles 2009), but with drastic changes in conditions bats may leave Tumbling Creek Cave to find caves with a more optimal microclimate.

7. The development of environmental DNA (eDNA) sampling methodology would allow for sampling of this elusive species in nearby systems not associated with the Tumbling Creek Cave system. We recommend establishing an eDNA monitoring program for nearby karst habitats as this could lead to range expansion of the cavesnail if found. The development of a genetic profile for the cavenail would also allow for determining its phylogenetic relationship among other snail species.

Synthesis

Numerous conservation actions have been conducted to benefit the Tumbling Creek Cavesnail; however, cavesnail numbers have precipitously declined in the transect area (<1,000 in 2019 to 0 in 2021) and remain low in both the transect area and Refugium (21-43 cavesnails 2015-2021). It is unknown how climate change has affected this species and will affect the species in the long-term. The species remains in danger of extinction. None of the recovery criteria have been achieved for downlisting or delisting the Tumbling Creek Cavesnail.

After reviewing the best available scientific information, we conclude that Tumbling Creek Cavesnail is appropriately classified as an endangered species. The evaluation of threats affecting the species under the factors in 4(a)(1) of the Endangered Species Act and analysis of this status of the species is an accurate reflection of the species current status.

RESULTS

U.S. FISH AND WILDLIFE SERVICE
STATUS REVIEW of Tumbling Creek Cavesnail, *Antrobia culveri*

Current Classification: Endangered

Status Recommendation resulting from Status Review:

____ Downlist to Threatened
____ Uplist to Endangered
____ Delist (Indicate reasons for delisting per 50 CFR 424.11):
    ____ The species is extinct
    ____ The species does not meet the definition of an endangered or threatened species
    ____ The listed entity does not meet the statutory definition of a species
__X__ No change needed

Lead Field Supervisor, Fish and Wildlife Service

KAREN HERRINGTON Digitally signed by KAREN HERRINGTON
Date: 2022.02.01 06:24:14 -06'00'

Approve _____ Date _____

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APPENDIX:

Table A1: Yearly and Seasonal Counts of Tumbling Creek Cavesnail Surveys in the Transect Area. Seasons where a survey was not conducted are indicated by a hyphen (-).

Year	Fall	Spring	Summer	Winter
1996	1766	-	-	-
1997	2699	-	-	533
1998	-	1499	916	100
1999	-	-	200	300
2000	300	567	267	-
2001	-	0	0	0
2002	33	0	0	0
2003	0	0	-	-
2004	0	0	-	-
2005	0	0	-	-
2006	0	-	0	-
2007	100	0	-	-
2008	0	0	-	-
2009	-	-	16	0
2010	0	0	-	-
2011	-	-	33	-
2012	-	0	-	-
2013	233	200	-	33
2014	566	0	-	-
2015	833	467	-	300
2016	1266	866	-	-
2017	367	333	-	133
2018	367	267	-	-
2019	100	1066	-	-
2020	33	-	0	-
2021	-	0	-	-

Table A2: Seasonal Refugium Tumbling Creek Cavesnail Counts at Tile Stations at Station 1, Upstream. Seasons where a survey was not conducted are indicated by a hyphen (-).

Year	Fall	Spring	Summer	Winter
2006	2	0	0	-
2007	2	3	-	2
2008	9	8	-	-
2009	17	-	-	9
2010	19	13	-	-
2011	-	23.5	-	16
2012	-	-	-	-
2013	5	19	-	20
2014	-	-	-	-
2015	25	17	-	8
2016	28	25	-	-
2017	24	15	-	11
2018	22.5	-	-	-
2019	30	26	-	-
2020	42	-	12	-
2021	31	-	-	-

Table A3: Seasonal Refugium Tumbling Creek Cavesnail Counts at Tile Stations at Station 2, Downstream. Seasons where a survey was not conducted are indicated by a hyphen (-).

Year	Fall	Spring	Summer	Winter
2006	1	0	0	-
2007	0	1	-	1
2008	2	1	2	-
2009	6	-	1	1
2010	2	1	-	-
2011	-	3.5	-	2
2012	-	-	-	-
2013	2	14	-	7
2014	-	0	-	-
2015	0	8	-	0
2016	4	23	-	-
2017	2	4	-	4
2018	1	-	-	-
2019	1	1	-	-
2020	1	-	6	-
2021	0	-	-	-