Species Status Assessment Report for Eight Virginia Cave Beetles (Genus *Pseudanophthalmus*): Little Kennedy cave beetle (*P. cordicollis)*, Holsinger's cave beetle (*P. holsingeri)*, Hubbard's cave beetle (*P. hubbardi*), Hubricht's cave beetle (*P. hubrichti*), Shenandoah cave beetle (*P. limicola*), Hupp's Hill cave beetle (*P. parvicollis*), Overlooked cave beetle (*P. praetermissus*), and Silken cave beetle (*P. sericus*)

Version 1.0

Photo of *Pseudanophthalmus* cordicollis.
Photo credit: Tom Malabad, Virginia Department of Conservation and Recreation Natural Heritage Program

January 2023

U.S. Fish and Wildlife Service
Northeast Region
Hadley, MA

ACKNOWLEDGEMENTS

This document was prepared by the U.S. Fish and Wildlife Service's Eight Cave Beetles Species Status Assessment Team. We would also like to recognize and thank the following individuals who provided substantive information and/or insights for our SSA: Dan Fitzgerald, Christine Dumoulin, and David Smith of USGS; Wil Orndorff, Tom Malabad, and Katarina Kosic Ficco of VADCR Natural Heritage Karst Program.

Additionally, valuable input into the analysis and reviews of a draft of this document were provided by Kirk Ziegler (Sewanee: University of the South), Jeff Hajenga (WV Division of Natural Resources), and Wil Orndorff (VA Department of Conservation and Recreation). We appreciate their input and comments, which resulted in a more robust status assessment and final report.

Suggested reference:

U.S. Fish and Wildlife Service. 2023. Species Status Assessment Report for Eight Virginia Cave Beetles (Genus *Psuedanophthalmus*): Little Kennedy cave beetle (*P. cordicollis*), Holsinger's cave beetle (*P. holsingeri*), Hubbard's cave beetle (*P. hubbardi*), Hubricht's cave beetle (*P. hubrichti*), Shenandoah cave beetle (*P. limicola*), Hupp's Hill cave beetle (*P. parvicollis*), Overlooked cave beetle (*P. praetermissus*), and Silken cave beetle (*P. sericus*), Version 1.0. January 2023. Hadley, MA.

VERSION UPDATES

EXECUTIVE SUMMARY

In 2010 the Center for Biological Diversity (CBD) petitioned the U.S. Fish and Wildlife Service (the Service or USFWS) to list 404 aquatic, riparian, and wetland species from the Southeastern United States under the Endangered Species Act (ESA or the Act). On September 27, 2011, the Service published a 90-day finding that the petition provided substantial information indicating 374 of those species may warrant listing, including 17 species of cave beetles in the genus *Pseudanophthalmus* (76 FR 59835). Fifteen of these occur in Virginia within the unique geology of the Appalachian Valley and Ridge (AVR) geomorphic province. The Service decided to assess two additional Virginia cave beetle species identified by the Service and partners as species of concern as discretionary actions (Holsinger's cave beetle and Hupp's Hill cave beetle). In a letter dated September 12, 2022, the petitioner withdrew their petition for nine of the Virginia cave beetle species citing new information indicating the species no longer merit consideration for listing (CBD 2022, entire). The remaining six petitioned species and two discretionary reviews, for a total of eight species, are included in this SSA.

Table A. Virginia cave beetles addressed in this SSA and withdrawn from assessment.

Common Name(s)	Scientific Name	Assessed	Withdrawn
Avernus cave beetle	*Pseudanophthalmus avernus*		X
Crossroad's cave beetle	*Pseudanophthalmus intersectus*		X
Cudjo's cave beetle, Cumberland Gap cave beetle	*Pseudanophthalmus hirsutus*		X
Holsinger's cave beetle	*Pseudanophthalmus holsingeri*	X	
Hubbard's cave beetle	*Pseudanophthalmus hubbardi*	X	
Hubricht's cave beetle	*Pseudanophthalmus hubrichti*	X	
Hupp's Hill cave beetle, thin-necked cave beetle	*Pseudanophthalmus parvicollis*	X	
Little Kennedy cave beetle	*Pseudanophthalmus cordicollis*	X	
Maiden spring cave beetle	*Pseudanophthalmus virginicus*		X
Narrows cave beetle, New River Valley cave beetle	*Pseudanophthalmus egberti*		X
Natural Bridge cave beetle	*Pseudanophthalmus pontis*		X
Overlooked cave beetle	*Pseudanophthalmus praetermissus*	X	
St. Paul cave beetle	*Pseudanophthalmus sanctipauli*		X
Shenandoah cave beetle, Maddens cave beetle	*Pseudanophthalmus limicola*	X	
Silken cave beetle	*Pseudanophthalmus sericus*	X	
South Branch Valley cave beetle	*Pseudanophthalmus potomaca*		X
Thomas' cave beetle	*Pseudanophthalmus thomasi*		X

Using the SSA framework established by the Service (Figure 1.1; USFWS 2016 p.6), we consider what a species needs to maintain viability over time by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (Smith *et al*. 2018, entire). The Service is required to use the best scientific and commercial data available to inform our decision-making.

Very little species-specific information is currently available that describes individual needs for these eight cave beetle species; specific life history and ecological parameters for *Pseudanophthalmus* cave beetles in Virginia have not been studied, nor have habitat requirements or individual responses to threats or changes in habitat parameters. As a result, we rely on more general life history information derived from the genus or family level that we can reliably assume to be held in common among the eight species based on the input of experts on carabid beetles (those within the family *Carabidae*).

The eight cave beetle species assessed herein are troglobites, meaning they are obligate cave dwellers and complete all phases of their life cycle within caves. Caves tend to have fairly stable environments (constant temperature, humidity, etc.) when compared to surface environments but they are not entirely static; seasonal fluctuations in parameters like airflow and water levels provide temporal variability in food introduction rates and may act as cues for reproduction in cave species. Cave beetles in the genus *Pseudanophthalmus* range throughout the karst systems from southern Indiana to northern Georgia and Alabama, and from western Kentucky to northern Virginia (see figure 2.1). *Pseudanophthalmus* species occur primarily in two geomorphic provinces that underlie this geographic range: the Interior Lowland Plateau (ILP) and the AVR. As described below, the two systems result in different implications for the speciation and subsequent ecology of *Pseudanophthalmus* beetles in the two regions. All eight cave beetle species in this assessment occur within areas of karst topography in the AVR.

To define analysis units, in the absence of genetic or population information we rely on element occurrences (EOs) as delineated by the Virginia Department of Conservation and Recreation (VADCR) Natural Heritage Program (NHP) and consider them to be the most appropriate representation of discrete analysis units for each species. VADCR also delineates conservation sites which are areas surrounding a particular cave or karst feature within which activities have the potential to affect the cave environment. We use cave conservation sites delineated by VADCR as the spatial units of analysis of impacts to each species.

To evaluate current condition for each species we rely on ease of detection (in the absence of abundance or density information) to partially inform resilience, but we put that into the context of confidence in the results based on the amount of effort (number of cave visits) for each species. Where effort is low (less than five cave visits), we have low confidence in conclusions regarding ease of detection. Although Holsinger's cave beetle, silken cave beetle, and Hubricht's cave beetle are found at only one or two caves, they were all "readily observed" over the course of cave visits between 2014 and 2021. In cases of readily observed species, resilience is unknown because we do not know how ease of detection relates to absolute abundance or density. Hubbard's cave beetle, overlooked cave beetle, and Shenandoah cave beetle exhibit no or low redundancy and low ease of detection; however, the number of cave visits supports low confidence in the ease of detection inference for these three species, and as such their resilience is unknown. The remaining species, Hupp's Hill cave beetle, was rarely observed in one cave and is likely extirpated from another, consistent with elevated risk and moderate confidence that resilience is low.

We also consider redundancy as defined by the number of analysis units, as well as their geographic spread. All but one of the assessed species has low or no redundancy. Little Kennedy cave beetle is the exception; this species occurs in eight caves, which are grouped into five analysis units, spread across an area of 89.3 km^2 (34.48 mi^2).

To develop future scenarios for the evaluation of species viability, we were able to carry forward only those threats in which we have enough confidence that their magnitude of impact would be likely to cause harm at the analysis unit level. Due to the lack of information on species response to changes in habitat condition at smaller magnitudes, there is significant uncertainty as to the type and magnitude of changes in habitat conditions that would elicit a response from the species at the individual level. We are confident that changes to the physical structure of an occupied cave, and changes to the water table and the functioning of the rest of the hydrological system within a cave are impacts that are likely to be detrimental at the level of the analysis unit for each species. We identified sources of those impacts to include commercial cave operations, quarries/mining, and large-scale urbanization/development (residential and/or commercial).

We discuss quarrying and commercial cave operations qualitatively for individual species where each is relevant, but we have no meaningful standardized way of predicting or quantifying their future impacts as the future intentions of private landowners is unpredictable. The metric we use for future projections of impacts from urbanization/development is projected changes in impervious surface within conservation sites. Following the classification system described in Theobald *et al*. 2009, p. 364), we classify the impact of impervious surface within conservation sites as follows: Unstressed (0–0.9 percent), Lightly stressed (1–4.9 percent), Stressed (5–9.9 percent), Impacted (10–24.9 percent), Damaged (>25 percent). We also use projected changes in human populations at the county level as an indicator of road usage and future development potential. We looked at projections of these metrics for the years 2020, 2040, and 2070 to determine the change in these parameters from current out to two timesteps in our future conditions. We evaluated two future time steps to balance the (assumed) short generation time of the species with the availability of future threat projections.

Under the classification described above for impervious surfaces, the Luray-Ruff conservation site, which drains into the cave inhabited by Hubbard's cave beetle, is currently lightly stressed, and is projected to become stressed by 2070 in the A1 scenario. This is the only species that is projected to experience any level of increase in stress from impervious surfaces in the future. Despite this increase, we have no evidence to suggest the future resilience of the species would change significantly from its current status by 2040 or 2070.

The Hupp's Hill cave beetle is the only species that is projected to experience an increase in human population within its county of occurrence (Frederick County). Despite this increase, the percentage of impervious surface within the conservation sites for the species is not projected to increase by 2040 or 2070. In addition, Ogden's Cave's inclusion in a Natural Area Preserve indicates the state has a vested interest in the management and mitigation of impacts to not only the cave itself, but the surrounding sensitive habitats that include springs, wetlands, and Buffalo Marsh Run. We do not expect resilience to change significantly relative to its current status by 2040 or 2070.

For all eight species, we do not expect any changes in redundancy or representation as a result of future threats by 2040 or 2070. Additional surveys may result in new occurrence locations which would confer additional redundancy. Despite our expectation that viability is unlikely to change significantly for any of the eight species in the assessment, most will remain vulnerable to stochastic and catastrophic events given their low redundancy and restricted geographic ranges.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 Introduction

1.1 Background

In 2010 CBD petitioned the Service to list 404 aquatic, riparian, and wetland species from the Southeastern United States under the ESA. On September 27, 2011, the Service published a 90-day finding that the petition provided substantial information indicating 374 of those species may warrant listing, including 17 species of cave beetles in the genus *Pseudanophthalmus* (76 FR 59835). Fifteen of these occur in Virginia within the unique geology of the AVR geomorphic province. The Service decided to assess two additional Virginia cave beetle species identified by the Service and partners as species of concern as discretionary actions (Holsinger's cave beetle and Hupp's Hill cave beetle). In a letter dated September 12, 2022, the petitioner withdrew their petition for nine of the Virginia cave beetle species citing new information indicating the species no longer merit consideration for listing (CBD 2022, entire). The remaining six petitioned species and two discretionary reviews, for a total of eight species, are included in this SSA.

Table 1.1: Cave beetles Withdrawn vs. Assessed in this Document

Common Name(s)	Scientific Name	Assessed	Withdrawn
Avernus cave beetle	*Pseudanophthalmus avernus*		X
Crossroad's cave beetle	*Pseudanophthalmus intersectus*		X
Cudjo's cave beetle, Cumberland Gap cave beetle	*Pseudanophthalmus hirsutus*		X
Holsinger's cave beetle	*Pseudanophthalmus holsingeri*	X	
Hubbard's cave beetle	*Pseudanophthalmus hubbardi*	X	
Hubricht's cave beetle	*Pseudanophthalmus hubrichti*	X	
Hupp's Hill cave beetle, thin-necked cave beetle	*Pseudanophthalmus parvicollis*	X	
Little Kennedy cave beetle	*Pseudanophthalmus cordicollis*	X	
Maiden spring cave beetle	*Pseudanophthalmus virginicus*		X
Narrows cave beetle, New River Valley cave beetle	*Pseudanophthalmus egberti*		X
Natural Bridge cave beetle	*Pseudanophthalmus pontis*		X
Overlooked cave beetle	*Pseudanophthalmus praetermissus*	X	
St. Paul cave beetle	*Pseudanophthalmus sanctipauli*		X
Shenandoah cave beetle, Maddens cave beetle	*Pseudanophthalmus limicola*	X	
Silken cave beetle	*Pseudanophthalmus sericus*	X	
South Branch Valley cave beetle	*Pseudanophthalmus potomaca*		X
Thomas' cave beetle	*Pseudanophthalmus thomasi*		X

1.2 Purpose

This report summarizes the results of an SSA conducted by the Service for eight species of cave beetles in Virginia. An SSA is intended to be a concise review of the species' biology and factors influencing the species, an evaluation of their biological status, and an assessment of the resources and conditions needed to maintain long-term viability. Importantly, the SSA does not result in a decision on whether to apply ESA regulatory protections, but rather, provides the best scientific data available for comparison to standards and policy to guide those ESA decisions. Initially, this SSA report will inform our determination of whether we have sufficient information to indicate that any of the eight cave beetle species meet the statutory definition of either Threatened or Endangered and as such would warrant Federal protection under the ESA. If listing is warranted, the SSA report will serve as the basis of subsequent associated actions and planning documents, including proposed and final listing/critical habitat rules, recovery planning documents, conservation actions, and ESA consultations. The intent is to update this SSA report as pertinent new information becomes available so it may serve as a living document for these and future regulatory/conservation actions.

1.3 Analytical Framework

Using the SSA framework established by the Service (Figure 1.1; USFWS 2016, p.6), we consider what a species needs to maintain viability over time by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (Smith *et al*. 2018, entire). For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in natural ecosystems within a biologically meaningful timeframe: in this case, 20 years and 50 years into the future. We chose two time steps for analysis to balance the (assumed) relatively short generation time for these species with the longer-term information available on identified potential stressors and their expected trends over time.

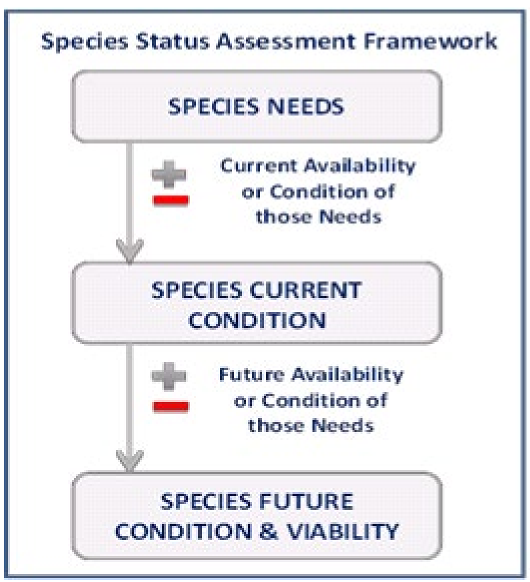

Figure 1.1: Species Status Assessment Framework

Resiliency, Redundancy, and Representation are defined as follows:

Resiliency means having sufficiently large populations for the species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example population size, if that information exists. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of human activities.

Redundancy means having a sufficient number of populations for the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk and can be measured through the duplication and distribution of populations across the range of the species. Generally, the greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.

Representation means having the breadth of genetic makeup of the species to adapt to changing environmental conditions. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of 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 within the geographical range.

The decision whether to list a species is based *not* on a prediction of the most likely future for the species, but rather on an assessment of the species' risk of extinction. Therefore, to inform this assessment of extinction risk, we describe what we know of the species' current biological status and assess how this status may change in the future under a range of scenarios to account for the uncertainty of the species' future. To the best of our ability, we evaluate the current biological status of each species by assessing the primary factors negatively and positively affecting the species to describe its current condition in terms of resiliency, redundancy, and representation (together, the 3Rs). We then evaluate the future biological status by describing a range of plausible future scenarios representing a range of conditions for the primary factors affecting the species and forecasting the most likely future condition of the species for each scenario in terms of the 3Rs. As a matter of practicality, the full range of potential future scenarios and the range of potential future conditions for each scenario are too large to individually describe and analyze. These scenarios do not include all possible futures, but rather include specific plausible scenarios that represent examples from the continuous spectrum of possible futures.

1.4 Best Available Information

The Service is required to use the best scientific and commercial data available to inform our decision making. To determine species viability, an SSA analysis typically starts with and builds upon a foundation of biological information beginning at the level of the needs of an individual, then increases in scope to describe needs at the population and, finally, species levels. Very little species-specific information is currently available that describes individual needs for these eight cave beetle species; specific life history and ecological parameters for *Pseudanophthalmus* cave beetles in Virginia have not been studied, nor have habitat requirements or individual responses to threats or changes in habitat parameters. As a result, we rely on more general life history information derived from the genus or family level that we can reliably assume to be held in common among the eight species based on the input of experts on carabid beetles. As such, this SSA begins with general information about cave beetle life history and ecology common to all eight species, which represents the best available information on individual needs, followed by a general description of the range and factors that may influence viability at the genus level in Virginia. After that, we include sections assessing the status of each individual species including species-specific discussions of range, ease of detection, and habitat information, and influencing factors that may be relevant at the population or species level.

2 Cave Beetle Biogeography, Biology, and Habitat

The eight cave beetle species assessed herein are troglobites, meaning they are obligate cave dwellers and complete all phases of their life cycle within caves. Because caves differ from surface environments in several significant ways, this section begins with an introduction to cave ecology and biology to provide important context for the rest of the analysis. The following subsections summarize the best available information on cave beetle taxonomy, life history, and ecology assumed to be held in common among the eight cave beetle species. As noted above, species- and genus-specific information on these topics is limited; either many life history and ecology traits are common across the species or we can reasonably assume them to be similar to surface-dwelling carabid beetles in the absence of species- or genus-specific information.

2.1 General Cave Biology/Ecology

Caves are difficult to define but a useful definition provided by Culver and Pipan (2019, p. 4) is a natural opening in solid rock with areas of complete darkness and larger than a few millimeters (mm) in diameter. Caves typically form in karst landscapes, that are defined as areas in which dissolution by weak acids is the primary agent shaping the landscape, as opposed to erosion, volcanoes, and earthquakes (Culver and Pipan 2019, p. 4–5). Most solution caves form in carbonate (limestone or dolostone) bedrock.

Caves tend to have fairly stable environments (constant temperature, humidity, etc.) when compared to surface environments but they are not entirely static; seasonal fluctuations in parameters like airflow and water levels provide temporal variability in food introduction rates and may act as cues for reproduction in cave species (Hawes 1939, entire). Caves and other subsurface environments are devoid of light, except for areas near openings. This has two major implications for organisms that live there. First, eyes become useless, and organisms must adapt or evolve the ability to find mates and food and avoid competition and predators without sight. Second, the absence of light means the absence of photosynthesis and therefore primary producers that commonly make up the foundation of the resource chain in surface environments (e.g., algae, plants, and some bacteria). Most cave and other subsurface communities must therefore rely on food that is transported in from the surface environment. Primary mechanisms for the introduction of organic matter, nutrients, and energy into caves include water percolating from the surface, flowing water from sinking streams, wind, and gravity (i.e., leaves blowing into entrances or animals falling into entrances or sinkholes and dying), and active movement of animals in and out of caves (Culver and Pipan 2019, p. 25). While percolating groundwater tends to be the most consistent source of organic carbon, all these sources exhibit considerable variation both spatially and temporally in any given cave.

2.2 Range and Distribution

Cave beetles in the genus *Pseudanophthalmus* range throughout the karst systems from southern Indiana to northern Georgia and Alabama, and from western Kentucky to northern Virginia (see Figure 2.1). *Pseudanophthalmus* species occur primarily in two geomorphic provinces that underlie this geographic range: the ILP and the AVR. As described below, the two systems result in different implications for the speciation and subsequent ecology of *Pseudanophthalmus* beetles in the two regions. While the individual geographic range differs for each species assessed herein and is described in each species account below, collectively the eight species of cave beetle within this SSA occur in Virginia throughout the AVR's geologically unique limestone formations. Uplift, erosion, and dissolution of the faulted and folded strata of the AVR have produced isolated belts of karst topography with numerous caves, where carbonate bedrock is exposed in the valleys and flanks of ridges capped with non-cave forming rocks. In the ILP to the west, caves and karst have developed in more laterally extensive, flat-lying carbonate rocks of similar age to those in the AVR. These differences in subterranean geology result in different implications for the dispersal, isolation, and subsequent speciation of cave-dwelling species, including cave beetles. The lower connectivity of caves due to geological barriers in the AVR has resulted in higher species density, lower dispersal, uncommon incidences of sympatry (co-occurrence of more than one species in cave), smaller modal size, and lower species diversity within individual caves in cave beetles in the AVR relative to species in Mississippian plateaus to the west (Barr 1967, p. 479–486). This is notable because while the biology/ecology of cave beetles in Virginia is largely unstudied, there have been some studies on *Pseudanophthalmus* ecology/niche partitioning, etc. in large expansive cave systems like Mammoth Cave in KY in the ILP karst region (Kane and Poulson 1976, entire; Kane and Ryan 1983, entire; Griffith and Poulson 1993, entire). However, the higher dispersal ability and higher rates of sympatry in those habitats make it difficult to reliably apply that information to species in the much more fragmented and isolated AVR karst habitats.

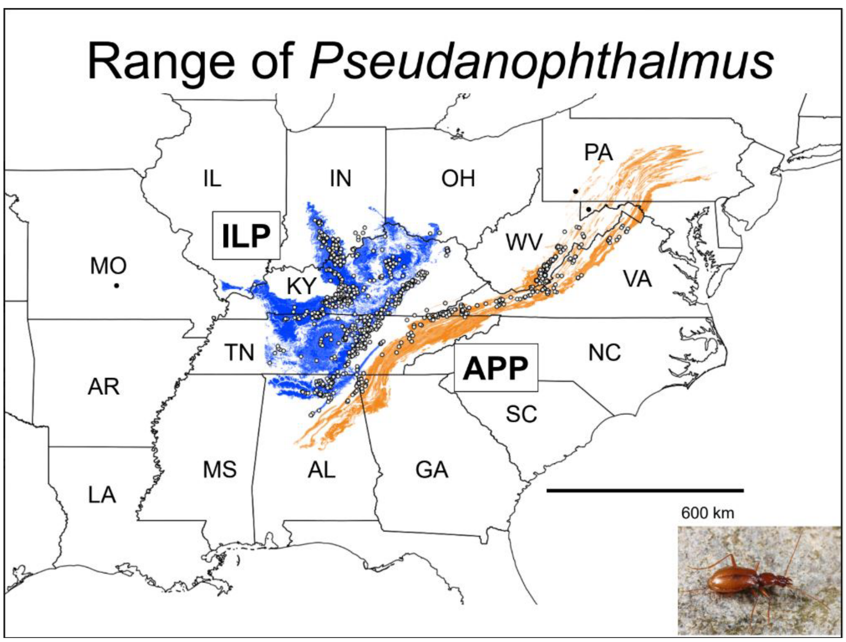

Figure 2.1: Range map for the genus Pseudanophthalmus (from Ober 2019)

2.3 Biology and Life History

2.3.1 Taxonomy

Cave beetles are insects in the Carabidae Family (ground beetles) under the Order Coleoptera. More specifically, they fall under the subfamily Trechinae which includes numerous genera containing troglobitic species, including *Pseudanophthalmus*. This group of cave beetles has an ancient taxonomic lineage and a unique evolution. The prevailing theory is that formerly widespread epigean (surface-dwelling) ancestors adapted or were forced to inhabit caves, and the epigean populations were ultimately driven to extinction by climatic changes. Subsequently, the populations that took refuge in caves evolved over time into different species due to their inability to disperse and intermingle (Barr and Holsinger 1985, p. 318).

Within the genus, there are 145+ species with approximately 80 species currently undescribed (Ober 2019, slide 6). Currently, there are at least 31 described *Pseudanophthalmus* species in Virginia (Holsinger *et al*. 2013, p. 33; Malabad *et al*. 2021, p. 93), although more survey work has resulted in nearly a thousand additional specimens collected since 2012, representing as many as 17 new undescribed species, possibly more (Malabad *et al*. 2021, p. 93). Species are differentiated primarily based on several morphological characteristics, the most informative of which are the shape, size, and features of the male reproductive appendage or aedeagus. Two prominent experts in the field of study of troglobitic species, Barr and Krekeler, debated approaches to troglobite taxonomy; Krekeler (1958, entire) first found it appropriate to rely on the criterion of extrinsic reproductive isolation as the determining factor of species vs. subspecies. In response, Barr (1959, entire) questioned this approach and asserted that morphological characteristics were the most reliable way to distinguish species from one another. After considering Barr's rationale, Krekeler (1959, entire) acknowledged that the assumption that populations are entirely isolated from one another is difficult to support given the intricate nature of the cracks and crevices of cave systems, and that in most cases, using morphological indicators is the more reliable method to differentiate between species. Nixon (2020; p. ix) used molecular genetics to re-examine morphological species delineations in the *pubescens* species group of *Pseudanophthalmus* (which occurs in the ILP karst region) and found that morphology alone is not always a reliable method of delineating species. However, in the absence of molecular genetics for the eight species assessed herein, we rely on established taxonomy as the best data available.

The eight species assessed herein were described by a number of taxonomists over several decades as follows: *P. hubbardi*: Barber 1928; *P. limicola* and *P. parvicollis*: Jeannel 1931; *P. hubrichti*: Valentine 1948; *P. holsingeri*: Barr 1965; *P. cordicollis*, *P. praetermissus*, and *P. sericus*: Barr 1981. Morphologically related species taxa tend to occur in adjacent limestone valleys, with some exceptions, and have thus been gathered into species groups based on similar morphology. One theory is that species within the same species group likely originated from a common epigean ancestor that colonized caves across a particular range, and then diverged into many new troglobitic species in isolation over time. There are cases where species from different species groups overlap or co-occur such as *P. praetermissus* (in the *hypolithos* species group), which is thought to co-occur with *P. seclusus*, which is in the *jonesi* species group. In this example, it is likely that two separate ancestral species of carabid beetles adapted to life underground in the same place, the relative timing of which can't be determined.

2.3.2 Morphological Description

Cave beetles are eyeless, wingless beetles generally reddish/brown in color. Cave-obligate creatures are often completely devoid of pigment with a white appearance since they live in complete darkness and the typical evolutionary reasons for pigment (e.g., camouflage) are unnecessary. Cave beetle color is a by-product of the sclerotization (exoskeleton hardening) process and serves no function for these species. *Pseudanophthalmus* beetles are typically 3-7 mm in size but some of the larger species are 8-9 mm. In the AVR where the eight species occur, the modal size is significantly smaller (by a few mm) than that of the ILP species (Barr 1967, p. 485). As noted above, preserved male specimens are required to make a positive identification at the species level since such confirmation is based primarily on morphological differences of the aedeagus which requires dissection and observation under a microscope (Figure 2.2).

Figure 2.2: Example of cave beetle and male aedeagus viewed under a microscope

2.3.3 Reproduction, Growth, and Longevity

Because we have no information regarding the reproductive cycle of *Pseudanophthalmus* beetles directly, we assume that life history information for other surface-dwelling carabid beetles is a reasonable surrogate. Carabid beetles typically have four life stages: egg, pupae, larvae, and adult. After internal fertilization, females lay one egg at a time, multiple times during breeding season, most likely in moist, silty areas. Carabid beetles generally have three larval instars and then pupate to adults (Lovei and Sunderland 1996, p. 234). Larvae are undescribed for the entire *Pseudanophthalmus* genus. It is unclear how long cave beetles remain in the larval stage but close relatives that are surface-dwelling have a life cycle of approximately 1 year (Lovei and Sunderland 1996, p. 234). Several U.S. Department of Agriculture (USDA) conservation assessment reports for cave beetle species report that nothing is known of the life history of *Pseudanophthalmus* beetles however they contain a personal communication from Thomas Barr in which he indicated that "in most of the troglobitic carabid beetles of eastern North America egg laying is timed for the fall, because food is generally more prevalent then. Larvae appear in the winter, pupae in the late winter and early spring, then tenerals [freshly molted adults that are not yet sclerotized] start appearing in June and July. The beetles are almost all fully sclerotized by fall. Although this is a typical life history, the availability of food can change the cycle" (Lewis 2001a, b, and c, p. 4; Lewis 2002, p. 5). Kane and Ryan (1983, entire) reveal noteworthy differences both between species that are sympatric at their study sites, as well as between populations of the same species in terms of egg production; one species in their study showed clear seasonality in egg production with a sharp peak of gravid females in the fall, whereas the other two species did not display any clear seasonal pattern in egg production. For one species in the study that showed no seasonality, there was significant variation in the percentage of females carrying eggs between sample sites over the majority of sampling dates. These results confirm that closely related species and even different populations of the same species can exhibit significantly different reproductive characteristics. In the absence of this information specific to the eight species in this assessment, we cannot reliably assume what these life history details may be for any population of any species based on proxy information.

2.3.4 Feeding

Cave beetles are generally predatory and carnivorous, most likely feeding on mites, springtails, and opportunistic items, including beetle eggs and larvae. Several USDA reports on cave beetle species report that "The primary food source of *Pseudanophthalmus* is enchytraeid and tubificid worms found associated with cave mudbanks" (Lewis 2001a, b, and c, p. 4; Lewis 2002, p. 5). Two species of cave beetle in Kentucky have been documented with different and specific prey preferences including cave cricket eggs and nymphs (*Neaphaenops tellkampfii*) and Collembola (*Pseudanophthalmus menetriesii*) (Kane and Poulson 1976, entire). However, these species occur in the ILP and are widespread and sympatric with other species, which has likely led to niche partitioning, versus the largely allopatric (occurring as the only cave beetle species within a cave) species in this assessment (with some exceptions) that may be more generalist predators. While it is not clear exactly what each species eats, experts are confident that they forage at a higher trophic level than some other cave invertebrates; they have not been observed associated with mammal scat like some other troglobites that feed on the associated bacterial and fungal growth.

3 Physical and Biological Needs of Cave Beetles

3.1 Individual Needs

Pseudanophthalmus cave beetles typically inhabit riparian mudbanks and other moist areas within limestone caves (Lewis 2001a, p. 5). Individual species that co-occur within the ILP karst region exhibit different preferences for microhabitat characteristics (e.g., mesic vs. riparian vs. upper passages of the cave) based on niche partitioning and preferred prey items (Kane and Ryan 1983, p. 46–47); however no systematic investigations have been conducted for the eight species in this assessment to determine whether they exhibit such preferences, which can have significant implications for several life history parameters including reproduction and population density fluctuations. Sediment deposits on which cave beetles are found in Virginia often exhibit bioturbation, or evidence of the sediment having been processed through the digestive tract of other animals like millipedes, centipedes, and earthworms. Other notable habitat features where *Pseudanophthalmus* have been collected in Virginia include mud cracks, fine silt, woody debris, cobbles, and rocks. It is difficult to interpret these microhabitat features in terms of individual needs because we know so little about the life history of these species. It is common for other carabid beetles to prefer areas where they may seek shelter (hence the mudcracks, rocks, cobbles, and woody debris) and it is likely, again based on other carabid beetles, that females lay eggs in moist silty areas. The combination of moisture and organic material also likely presents the right circumstances for their prey items to be available. The individual needs that seem clear are that karst environments with water or moisture are necessary for beetles to be present (Figure 3.1); they have not been observed outside of caves or in completely dry caves.

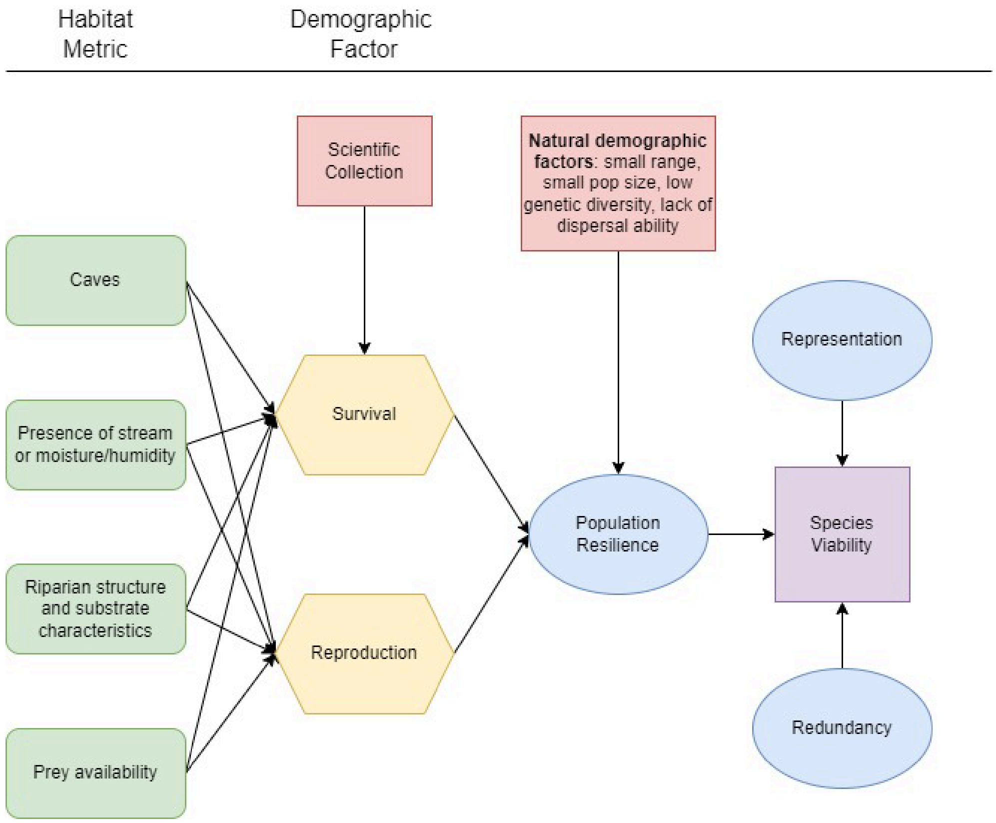

Figure 3.1: Cave Beetle Individual Needs Conceptual Model

3.2 Population/Species Needs

We do not know the specific needs, population sizes, or population trends of the eight cave beetle species. We presume, based on general conservation biology principles, that the viability of the eight cave beetle species would be best supported by multiple, self-sustaining populations distributed throughout the geographical extent of their range (redundancy, resiliency, and representation respectively). However, several of the eight species are currently considered single site endemics based on the best data available, which is common among cave-associated species within the AVR karst area; more than half of described *Pseudanophthalmus* species are currently known to inhabit only single caves (Barr 1960b, p. 3). Single site endemic species lack redundancy as a contributing factor to their overall viability.

4 Factors Influencing Viability

In this section, we evaluate the past, current, and future influences that are affecting or could be affecting the current and future condition of *Pseudanophthalmus* cave beetles in Virginia. These influences are summarized in a conceptual model (Figure 4.1) and discussed in more detail in the subsections below. Factors that influence viability consist of those things that influence the resources that individuals need or those that influence demographic factors directly. In this section, we describe the suite of potential influencing factors that may affect cave environments where these species occur in Virginia. This list was generated via workshop-style discussion with species experts, and subsequent research to inform a comprehensive understanding of potential influences to cave beetle populations where they occur. We have focused primarily on types of land use that have the potential to impact the cave environments where these species are known to occur. All factors described in this section do not apply equally to each of the eight cave beetle species; rather, influencing factors that apply to each individual species are described in the individual species assessments in Section 6 below. In addition, the petition to list these eight species listed threats for each species individually, which are addressed in each individual species assessment.

4.1 Threats

Quarrying: Quarrying is a type of open-pit mining where stone, minerals, or other materials are extracted from the ground. Limestone deposits are typically quarried to supply materials for the building and construction industry. The three primary ways that quarrying may affect cave environments are physical alterations to the cave's structure, changes to the cave's established hydrological system, and impacts to water quality. Physical alterations from blasting can range from loosened rocks, dust build-up, blocked fissures, and cracks to blocked entrances, new entrances, or complete destruction if quarrying activities were to intersect the cave itself (British Geological Survey (BGS) NERC 2022, unpaginated; Langer 2001, p. 13). Every cave is largely unique but even small physical alterations have the potential to change long-established stable habitat parameters including temperature, air flow, water flow, light, and humidity, which can all in turn affect the biological community (Langer 2001, p. 13). Groundwater flows through a network of underground conduits and caves in karst systems. When quarries intercept these flow systems, water often floods quarrying operations and gets diverted by pumping which results in cutting off the original flow and potentially causing springs to diminish or dry up (BGS NERC 2022, unpaginated) resulting in devastating impacts to the biological community dependent upon them. Flow can be altered as a result of some of the physical alterations to caves like new cracks that divert a stream from its established flow path. Quarrying also has the potential to affect water quality by introducing pollutants into the groundwater system, and to remove vegetation and soil overlying the system that serves as a zone of filtration and water purification for surface water that percolates into the cave environment (Hobbs and Gunn 1998, p. 147).

Development/Urbanization: As human populations increase and developments expand into previously rural areas, there can be a variety of significant impacts to the natural environment. Impermeable surfaces (pavement for example) can lead to changes in hydrology of surface water and increased runoff with contaminants that enters groundwater systems. Development is often associated with changes to the water table as drinking water is either sourced from groundwater aquifers or surface water recharge gets routed to subterranean aquifers for storage and extraction. In karst systems, changes to surface and groundwater hydrology can result in significant impacts to the biological communities that depend on long-established and fairly stable habitat conditions within caves. Development also typically coincides with road construction which can have physical impacts to cave systems from blasting, and also brings traffic into previously inaccessible areas increasing the proximity of cave environments to potential spills, run-off, trash, and other contaminants that may wash in from new surface roads and run-off patterns.

Commercial cave tour operations: The effects of commercial cave tour operations within a cave can be numerous and depend on the frequency and size of cave tours, the extent of modifications like light and stairway/walkway installation, and the proportion of the cave that is accessed by tour groups. In general, they may include changes to air circulation, humidity, CO^2 concentration, temperature, organic matter input, chemical pollutants, and noise (causes and effects of these alterations are synthesized by Constantin *et al.* 2021, p. 3). The installation of lights can create a growing environment for fungi and algae that would not typically be able to survive inside caves, which can in turn lead to nonnative species inhabiting those microenvironments and other downstream effects. The construction of new or additional entrances for ease of access for large groups can affect humidity, temperature and other abiotic parameters within the cave. Visitors introduce trash, and lint, dust, and spores from their clothing can deteriorate speleothems (mineral formations or deposits found in caves) and further promote the growth of fungi and algae. To manage fungi and algae that develop, cave operators often deploy biocides that have their own implications for native cave fauna, many of which are not well studied or understood. Several of the eight cave beetle species occur in caves with either active or inactive commercial tour operations. The specific implications are discussed in the individual species assessments below.

Other recreational visitation: Caves without commercial cave tour operations are often visited by recreational cavers, property owners, or others that happen upon the entrances and are curious to explore. These types of visitations range in frequency and magnitude but can result in impacts to the cave environment including compaction of riparian sediment and the introduction of pollutants, trash, or other contaminants. Irresponsible explorers may accidentally or purposefully break formations or do other physical damage as well. We found no information indicating recreational use is an active threat to the habitat of any of the eight cave beetle species and therefore have not carried it forward in our analysis of species viability.

Other land uses: Timbering and agriculture both have the potential to alter hydrology and introduce sediment and pollutants into cave systems. Timbering or logging in areas with karst geology can result in the introduction of sediments into cave systems, and in extreme cases, the erosion and removal of the epikarst layer that serves to filter surface water before it enters the cave system. Timbering activities do not appear to be a significant threat to the eight cave beetle species in this assessment. Several of the cave beetle species occur within National Forests where logging does occur; however, the U.S. Forest Service is required by the 2012 Planning Rule to develop and implement forest management plans to protect and restore National Forests and Grasslands for the benefit of communities, natural resources, and the environment (77 FR 21162–21260). These plans typically include measures to avoid and/or minimize impacts to aquatic environments. One of the primary mechanisms for logging activities to impact cave environments is sedimentation washing in via sinking streams so measures to reduce sedimentation in aquatic environments near caves have the added effect of reducing impacts to the cave environment. In addition, the U.S. Forest Service manages caves and karst resources in keeping with the 1988 Federal Cave Resources Protection Act (the purposes of which are to (1) secure, protect, and preserve significant caves on Federal lands for the perpetual use, enjoyment, and benefit of all people; and (2) to foster increased cooperation and exchange of information between governmental authorities and those who utilize caves located on Federal lands for scientific, education, or recreational purposes) and in accordance with the multiple use mission of the U.S. Forest Service.

Agriculture is a common land use throughout the collective ranges of the eight cave beetle species in rural parts of Virginia. However, agricultural lands in the region are primarily hay/pasture vs. row cropping, and row cropping tends to involve more manipulation of surface hydrology and chemical applications. VADCR biologists have noted that agriculture within the ranges of the eight cave beetles appears to be a compatible land use with species persistence (USFWS-VADCR 10/25/2021 pers. comm.).

Climate change: The impacts of climate change on cave environments are not well studied. There is a small body of research on the drivers of thermal tolerance for subterranean beetles and the ability of poor dispersal species to cope with climate-related changes in their largely stable environments. Caves and cave species have persisted through many large-scale landscape changes throughout geologic history but current rates of climatic changes are unprecedented. Sanchez-Fernandez *et al*. (2016, p. 4) focus on a well-defined clade of troglobitic beetles of the tribe Leptodirini (Coleoptera, Leiodidae) living in the North-eastern Iberian Peninsula and show that “the use of thermal niches estimated from last glacial maximum (LGM) climatic conditions failed to predict the response to past climate changes, as only 4 percent of the populations of the LGM were expected to maintain suitable conditions through the Holocene which obviously was not the case. It is thus clear that based only on current conditions it is not possible to predict the fate of this clade of subterranean species in front of predicted global change.” Additionally, a number of studies suggest that subterranean beetles lack thermal adjustment to their local conditions, that their upper thermal tolerance is larger than the range of thermal conditions experienced throughout their evolutionary history (Sanchez-Fernandez *et al.* 2016, p. 5; Rizzo *et al*. 2015, p. 1) and that the maintenance of physiological tolerance to high temperature up to some point (around 20ºC in most studies) might not pose an excessive energetic cost for these species (Colado *et al*. 2022, p. 7). The implications of these findings are that, at least in the cases of the studied lineages of subterranean beetle species, if exposed to climatic conditions and rates of change unprecedented in their evolutionary history, in most cases temperatures will still be within their fundamental niche and may not result in excessive energetic costs. However, there are a variety of variables that make it difficult to apply these results to the eight species in this assessment, given we do not have information on their specific thermal tolerances.

Another potential effect of future climatic changes is changes in precipitation leading to changes in drought and flooding frequency and intensity. Droughts and floods both have the potential to affect cave environments and their associated fauna that are most often dependent on humidity, moisture, and organic inputs all associated with water in caves. Barr (1967, p. 476) provides the following summary of relevant literature on flooding in caves:

> "Hawes (1939) has discussed some of the ecological consequences of winter flooding in the caves of Herzegovina. Both aquatic and riparian troglobites may be swept about by the mechanical action of flood waters. Barr and Peck (1965) noted a much longer survival time in a riparian species of cave beetle when the riparian species and another species characteristically found in drier, upper cave galleries were immersed in water. Many species of *Pseudanophthalmus* and Ameroduvalius (troglobitic Carabidae) typically feed on minute tubificid annelids in the damp silt along cave streams. Their toleration of immersion is an apparent adaptation to sudden inundation. Poulson (1964) reviewed some of the effects of flooding on aquatic cavernicoles, suggesting (as did Hawes, 1939) that spring floods may trigger their reproductive cycles."

Runoff was used as a proxy for streamflow in a climate analysis for three stonefly species with ranges that overlap with several of the eight cave beetle species (Lyons *et al*. 2023) using the downscaled MACAv2 data for runoff projections, simulated using the Monthly Water Balance Model (MWBM). The MACAv2-MWBM data indicates that it is unclear whether runoff within the ranges of all the stonefly species will increase or decrease under two emissions scenarios and at two timesteps (2040 to 2069 and 2070 to 2099), ranging from a -23.3 percent decrease to a 20.6 percent increase by 2040 to 2069, and a -15.5 percent decrease to a 30.7 percent increase by 2070 to 2099. These changes in runoff are less certain and have more spread in the data at higher elevations (Lyons *et al*. 2023). This level of uncertainty in not only the magnitude, but the direction of projected precipitation changes precludes any projections on how cave hydrology may be affected by climate related changes in the future.

Given the apparent adaptations to flooding within their habitats, and the uncertainty regarding future projections of precipitation in the region, the implications of potential changes in flooding frequency and intensity and/or drought for cave beetles are unclear.

Other considerations: The anthropogenic activities outlined above can have varying magnitudes of impact depending on specific aspects of the cave habitat; those with cave streams may be impacted by activities throughout the stream's watershed on the surface, whereas caves that rely on moisture/organic inputs from epikarstic drips or seepage may experience influences from a smaller and more immediate footprint above and around the cave.

Naturally occurring demographic factors like rarity, endemism, small ranges, small population size, low genetic diversity, and specific habitat requirements are additional sources of vulnerability for a species making them susceptible to stochastic or catastrophic events, whether natural or human-caused. Cave beetles, like other troglobites, are inherently limited in terms of available habitat because they have evolved to complete their entire life cycle within caves. Several species are known from only one cave and do not have means to disperse to new sites.

Since speciation happens rapidly on a geological timescale for isolated species such as troglobites (Barr 1985, p. 319), it is not uncommon for many species to have small, confined ranges and small populations. In the absence of anthropogenic disturbance, these small populations may persist undisturbed for a long time in their naturally rare state. However, some human activities, like those described above, have the potential to have catastrophic effects on these small populations that may otherwise go undisturbed for long periods of time.

Although rare, there are cases of sympatry, or co-occurrence with other cave beetle species, among the eight species in this assessment. In these cases, competition may be a factor that influences viability for one or more species. Studies of other species of *Pseudanophthalmus* beetles in the ILP karst region indicate niche partitioning via food and microhabitat preferences in sympatric species; however, there are significant ecological distinctions between species from the ILP and AVR karst regions (as discussed previously) making it difficult to apply those results to the eight species in this assessment. We have no information on the specific food or microhabitat preferences or other life history characteristics and how they may differ between sympatric species in the AVR karst region and can therefore not reliably state what role, if any, competition may have on the viability of any of the sympatric species in this assessment.

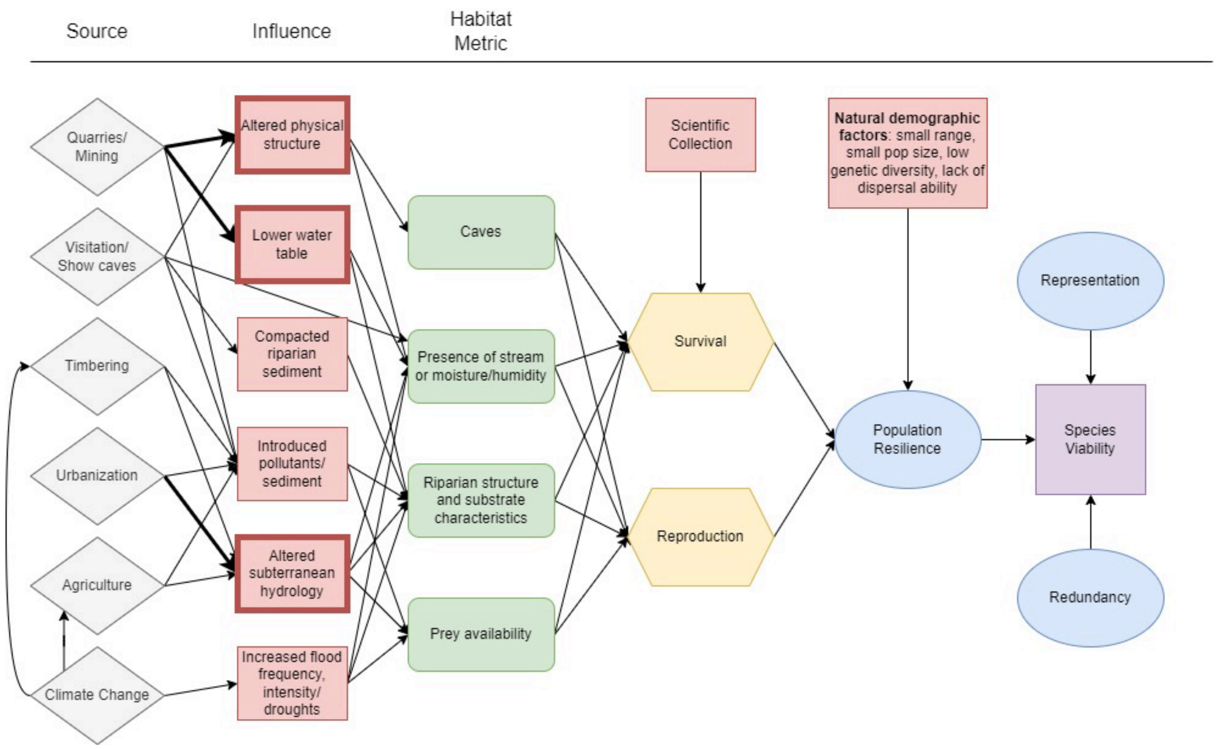

Figure 4.1: Conceptual Model Influence Diagram for Cave Beetles in Virginia

Figure 4.1 is an influence diagram that summarizes all identified potential threats for *Pseudanophthalmus* cave beetles in Virginia. While we evaluated the magnitude and significance of each of these potential influences for each species, it is unclear whether certain environmental changes, like changes in water quality for example, may have an impact on individuals, and if so, what magnitude of change would rise to the level of a response, or what that response may be.

As such, we have focused our assessments on influencing factors that we have confidence may rise to the level of negative effects on analysis units, while including additional discussion of other impacts for which there is high uncertainty in terms of their potential to affect viability.

There is support in scientific literature that physical alterations to cave structure and changes to established hydrologic patterns within caves can have significant impacts to the cave environment and associated biological communities. As summarized by Simoes *et al*. (2015, p. 104):

> "The number, width, position and distribution of the entrances in relation to the extension of the caves can increase or reduce the environmental stability of the cavity and consequently provoke changes in their biological community structures. Besides influencing environmental stability, these metrics can limit or increase the availability of food resources and likewise influence the number of species colonizing the environment (Ferreira 2004, Souza-Silva *et al*. 2012a). Hydrological changes can be another factor that influences the cave fauna. Cave streams and perennial pools can act increasing the humidity and importing organic matter, being determinant for the food resources availability (Souza-Silva *et al*. 2012 and 2012a)."

As such we have identified alterations to the physical structure of caves and changes to the water table and/or hydrology of cave systems as the primary factors to assess for their potential to impact the viability of cave beetle species. Because most cave beetle species are riparian-associated, we make the conservative assumption that compromised water quality may result in indirect impacts to cave beetle species and have therefore included some discussion of future changes to water quality in our assessment. From our list of potential influences, we identified the causes associated with these factors to include quarrying, commercial operations inside the cave, and urbanization/development.

4.2 Conservation Efforts

We discuss conservation efforts for each individual species below because there are instances of protective factors that are specific to individual species. However, protective legislation exists at the state level for caves and karst in Virginia that applies to all eight species assessed herein. The Cave Protection Act was enacted in 1966 to protect the cave and karst resources of the Commonwealth of Virginia. In 1978, the Virginia legislature formed the Virginia Cave Commission, and in 1979 enacted a new comprehensive Virginia Cave Protection Act that defined the role of the Commission. The 1979 Virginia Cave Protection Act had two basic objectives: protecting Virginia cave resources from vandalism and degradation and protecting the cave owner's interest in his property (Lera 2016, p. 2). The 1979 Virginia Cave Protection Act prohibited disturbing or harming any cave organism, dumping of garbage, sewage, dead farm animals, and toxic wastes into caves and sinkholes without written permission from the landowner, and made it illegal to sell, or export for sale, speleothems. It also protected archeological resources by requiring a permit from the Virginia Historic Landmarks Commission and written permission from the cave owner, before excavating, removing, or disturbing any fossils, historic artifacts, or prehistoric animals. It also made it illegal to break, force open, tamper with or deface any gates, locks, signage, and other barriers installed by cave owners for cave access control. The cave owner was also exempted from liability for any injury sustained in the owner's cave if the owner had not charged an admission fee (Lera 2016, p. 3).

In 1980 the Virginia Cave Commission (now known as the Virginia Cave Board) was made a permanent State agency as part of the Department of Conservation and Economic Development. However, since no funding was provided, interested cavers formed the Virginia Cave Conservancy to provide a means of funding to support cave acquisition, management, and research, as well as to assist organizations such as the Virginia Cave Commission (Lera 2016, p. 3). The Virginia Cave Board is tasked with the following responsibilities:

1. Protect the rare, unique, and irreplaceable minerals and archaeological resources found in caves
2. Protect and maintain cave life
3. Protect the natural groundwater flow in caves from water pollution
4. Protect the integrity of caves that have unique characteristics or are exemplary natural community types
5. Make recommendations to interested state agencies concerning any proposed rule, regulation or administrative policy that directly affects the use and conservation of caves in this Commonwealth
6. Study any matters of special concern relating to caves and karst.

The Virginia Cave Board remains active throughout Virginia and engages in project reviews, development of cave and karst management plans, cave related outreach and awareness activities, enforcement cases, archaeological and natural resource protection efforts, property acquisition, and many other activities. They maintain a list of caves designated as "Significant" and 17 of the 20 caves collectively occupied by the eight species in this assessment have been designated as "Significant." "Significant" caves as designated by the Virginia Cave Board under the Cave Protection Act are treated as element occurrences by the VADCR NHP, and each significant cave lies within a conservation site. Any projects passing through the VADCR Office of Environmental Project Review are screened to see if they intersect conservation sites. When conservation sites are intersected, VADCR NHP staff inform the project proponent and provide guidance on protection of the associated resources that may be affected by their project, including "Significant" caves and species within. Although no legal status accompanies this designation, VADCR NHP reports success in avoiding impacts to element occurrences via this review and communication process. In addition, "Significant" caves are given priority for implementation of conservation efforts such as easements, cost-share programs, and fee simple acquisition for long-term protection.

Dumping of garbage, sewage, dead farm animals, and toxic wastes is also illegal under other more general provisions of state law in Virginia. Other forms of protective measures for individual species include occurrence on public lands like within a National Forest or a state-managed Natural Area Preserve. These factors are included in individual species sections as appropriate.

5 Assessment Methods

5.1 Introduction

In Section 6 below we provide an assessment of current and future condition for each of the eight cave beetle species individually and independently. Each assessment relies on the information presented above that we assume to be held in common across the eight species, as well as species-specific survey results and modifications or explanations that are included in each assessment accordingly.

5.2 Key Assumptions/Uncertainties

Life history: in the absence of species-specific information on life history traits for the eight species being assessed, we assume basic information on reproduction for surface-dwelling carabid beetles to apply to cave beetles, and acknowledge that more detailed life history information is not available. We cannot reliably assume more specific information based on proxy species given the demonstrated variability both between closely related species and populations within the same species.

Range: Karst experts at VADCR delineated ranges for the eight cave beetle species individually using a consistent approach. They included the extent of contiguous karst surrounding known cave locations for each species, with the assumption that caves within contiguous belts of karst may be interconnected via subterranean pathways not discernable by researchers. The borders of the ranges were determined by several factors including physical features likely to be barriers to further dispersal (non-karst geology, large water bodies, etc.) and the nearest observations of a different species, assuming that for the most part the species are allopatric and do not co-occur. In some cases, species ranges include non-karst areas between known species locations and these cases are noted in the species sections. The species ranges represent the best data available on potential suitable habitat, but in many cases, range maps would likely change with additional survey effort over time (Malabad *et al*. 2021, entire).

Abundance: Cave beetles are cryptic species that can be hard to locate within their habitats. Most caves likely undergo seasonal fluctuations in moisture that may influence the distribution of cave fauna within the system. Kane and Ryan (1983, p. 49) saw clear seasonal patterns in density of cave beetles at five study sites and attributed the fluctuations to the movement of populations out of the near-entrance study areas in winter months when temperature and humidity decreased. We do not fully understand the seasonal cycles of the cave environments where these species occur and sampling has not occurred with enough frequency to determine what times of year the density in accessible areas (detectability) may be highest. In addition, the nature of caves and karst systems is that there is presumed to be a large portion of area that is accessible to cave beetles, but not to humans including cracks and crevices that may extend long distances and connect to unknown caves. As such, it is not possible to reliably assess abundance for any of these species. Even if a species has not been observed after numerous surveys at a given site, experts are unwilling to surmise that it has been extirpated from that site if their observations reveal that suitable habitat still exists within the cave.

Species Response: In the absence of information on how cave beetles may respond to specific influences like changes in water quality/quantity, we focus our assessment on influencing factors that are likely to present the biggest challenges to the physical habitat for cave beetles, specifically the physical structure of caves and the presence of water or moisture. While we discuss the potential for impacts to environmental parameters like water quality, we are unable to draw any conclusions in terms of how those changes may affect analysis units of cave beetles without reliable information on the species response to or reliance on those elements of their habitat.

5.3 Defining Analysis Units

The VADCR NHP keeps element occurrence (EO) records for all species observations in Virginia. For cave beetles, EOs often consist of a single cave site, but when caves are known or likely to be connected in some way allowing for potential dispersal between sites for cave-obligate species, sites are grouped together into a single EO. The spatial area delineated for each cave beetle EO is essentially the footprint of the cave (or caves) where the species has been recorded. Often the exact extent of caves, even those that are mapped, is unknown because passages are too small for people to enter so VADCR adds a small buffer, usually less than 100 meters, to the mapped area to capture a portion of unmapped area. Where caves have not been mapped, the shape of the EO is based on the best available information which may include written descriptions that estimate length and depth, as well as general trend of passages, or VADCR's first-hand exploration of the cave. VADCR also uses key features to help define the shape of the cave if it is not mapped including entrance location, resurgence of a spring, local geology that may confine the location, etc. (T. Malabad, VADCR, email to K. Maison, Service, 4/5/2022). Given the lack of information regarding population structure or connectivity for all eight species assessed herein, we rely on EOs as delineated by VADCR and consider them to be the most appropriate representation of discrete analysis units for each species.

VADCR also delineates conservation sites that are associated with EOs and represent the area surrounding the EO within which activities or events have the potential to impact the habitat or species associated with each EO. Conservation sites are assigned a biodiversity significance rank from B1 (extremely significant) to B5 (of general significance) based on the suite of biological resources that are encompassed within each site. The cave footprints/species EOs are used as anchors to delineate cave conservation sites, and then geology, topography, and drainage characteristics are considered, along with dye tracing results where available (T. Malabad, VADCR, email to K. Maison, Service, 4/5/2022). In caves with streams that originate from the surface, conservation sites typically include the surface watershed for the stream because impacts to the stream itself from surface activities would likely be carried into the cave environment. Caves that do not have streams but have moisture that is sourced from groundwater seepage from the epikarst (the carbonate bedrock between the surface and the cave, which forms the cave ceiling) typically have smaller conservation sites because influences from the more immediate area surrounding the cave have the highest likelihood of impacting the cave environment. We use cave conservation sites delineated by VADCR as the spatial units of analysis of impacts to each species. For future condition sections, we use Integrated Climate and Land-Use Scenarios

(ICLUS) models to predict changes in the amount of impermeable surface within each conservation site.

5.4 Defining The three Rs

Resilience

As described above, resilience refers to a population's or species' ability to withstand stochastic events and is typically a function of intrinsic growth rate and abundance. Abundance and population growth rates are unknown for all eight species in this assessment, and no trend data are available to serve as a proxy measure. Absolute abundance and density are unknown due to the uncertain detectability and low inventory efforts given the large number of species and limited resources available to complete surveys. However, we compiled and evaluated the available information on effort and collection success to infer resilience based on ease of detection and existing threats. Confidence in inference on ease of detection depended on survey effort as indicated by visits per cave. More detail on the methods and results can be found in the Appendix, but we provide a summary in this section.

Using the VADCR recorded observations for all 17 cave beetle species included in their survey report (Table 5.1; Figure 5.1; Malabad *et al*. 2021, entire), we estimated ease of detection based on a combination of survey effort and recorded detections. Despite the fact that not all surveys were carried out with the same methodology (some were visual surveys, some included the overnight use of bait stations and pitfall traps, and others were incidental to bat surveys), we treat them as equal in terms of effort for the purpose of this analysis because there is no meaningful way to distinguish between survey types, nor would doing so add value to the results. We made three key assumptions for this assessment: (1) VADCR scientists knew how to best sample the area effectively; (2) density within the sampled area is indicative, or representative of density elsewhere within the suitable habitat in the cave; and (3) detectability is constant throughout the year (i.e., we did not factor in the possibility of seasonal fluctuations in detectability). Because there is no estimate of detectability, the relationship between visual counts and absolute abundance or density is unknown. As such, we discuss only ease of detection for each species.

Table 5.1: Summary of observations from the VA state report (Malabad et al. 2021): known number of localities (caves), median counts from visual searches per cave visit, and the total number of cave visits.

Status	Species	Number of caves	Median count per visit	Total visits
Assessed	*Overlooked cave beetle*	1	0.7	6
Assessed	*Little Kennedy cave beetle*	7	0.8	22
Assessed	*Shenandoah cave beetle*	2	0.5	7
Assessed	*Hupp's Hill cave beetle*	2	0.1	14
Assessed	*Holsinger's cave beetle*	1	4.0	3
Assessed	*Hubbard's cave beetle*	1	0.3	3
Assessed	*Hubricht's cave beetle*	2	0.8	10
Assessed	*Silken cave beetle*	1	7.5	2
Withdrawn	*Maiden spring cave beetle*	2	4.3	3
Withdrawn	*Avernus cave beetle*	1	3.0	2

Withdrawn	*New River Valley cave beetle*	4	2.1	8
Withdrawn	*Cumberland gap cave beetle*	3	0.0	5
Withdrawn	*Crossroads cave beetle*	3	0.7	6
Withdrawn	*Natural Bridge cave beetle*	3	1.0	5
Withdrawn	*South Branch Valley cave beetle*	3	2.0	3
Withdrawn	*St. Paul cave beetle*	4	3.0	5
Withdrawn	*Thomas' cave beetle*	3	3.0	6

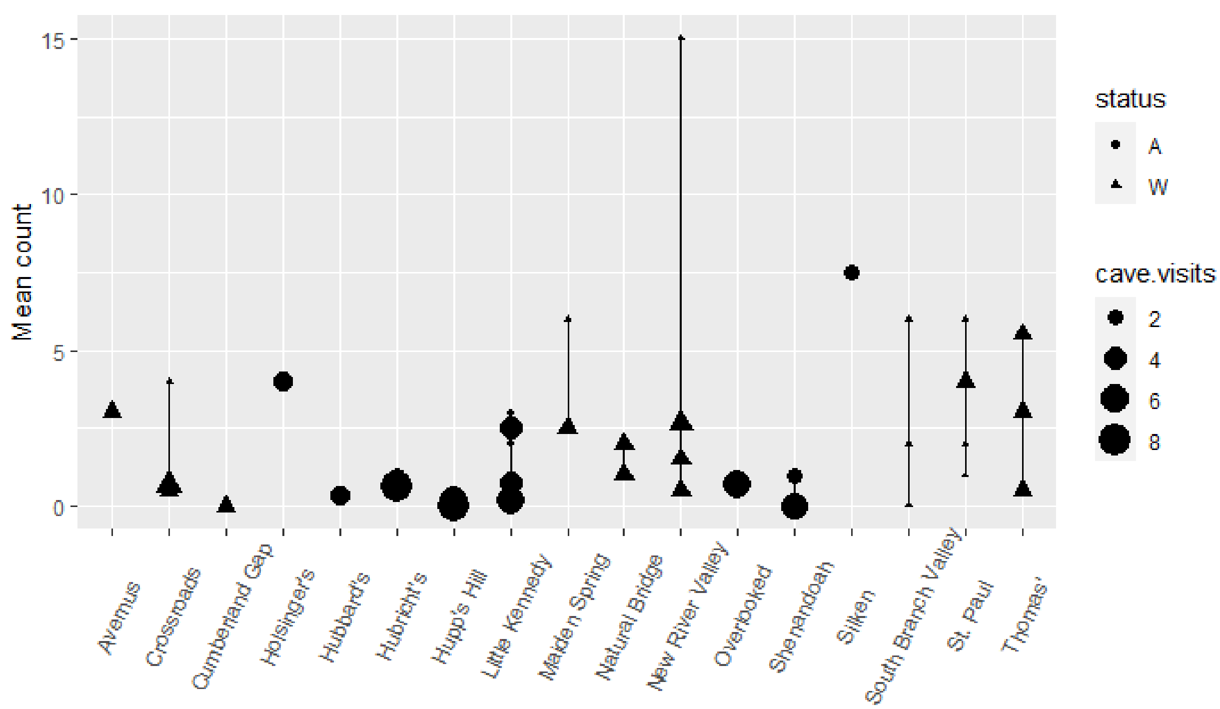

Figure 5.1: Summary of observations from the VA state report (VA DCR 2021): mean count per visit from visual searches at each known locality (cave). Symbol size is proportional to the number of visits at each cave. Symbol shape indicates whether the species are assessed or have been withdrawn by the petitioner.

Ease of detection varied widely among species. We categorized species based on detection rates as follows: caves with less than one individual observed per two visits on average (mean count per visit <0.5) were <u>rarely observed</u> inferring low density. Species with one individual observed per two visits (mean counts between 0.5 and 1) were <u>infrequently observed</u> inferring moderate density. Species with a mean of at least one individual observed per visit (mean count per visit $\geq$1) were <u>readily observed</u> consistent with high density.

While "readily observed" is a straightforward assignment regardless of the number of cave visits, the number of visits contributed to our confidence in cases of or "rarely observed" or "infrequently observed" species, and in cases of repeated zero counts. We used the statistical model for observations of rare species presented by Green and Young (1993, entire) to evaluate the relationship between survey effort (number of visits) and strength of inference (see

Appendix). Logically, as the number of surveys resulting in no detection increases, the maximum probable density decreases because a surveyor likely would have detected the species if densities were higher. As such, our confidence in the true absence or low density of the species at a given site increases with the number of cave visits that result in zero observations. When cave visits were four or less, the probable density includes anything from extirpation to higher than 50 percent of the assessed species (Appendix Figure A-1); this magnitude of uncertainty prevents defensible conclusions about ease of detection (from which we infer probable density) or even presence. In contrast, as the number of visits increases, the confidence increases that the site either supports very low density or the species has been extirpated from the site. Therefore, in cases of repeated zero counts, "rarely observed," or "infrequently observed" at a given cave location with four or fewer cave visits, we have low confidence in the ease of detection conclusion. In those same cases with five or more cave visits, we have moderate confidence in the ease of detection conclusion. There are no cases in which we have high confidence in true absence (extirpation), "rarely observed," or "infrequently observed" ease of detection for a species at a location, unless this information is supported by an observed lack of suitable habitat as assessed and confirmed by VADCR karst experts.

We also used the Poisson distribution (Green and Young 1993, entire) to evaluate the statistical power to detect the presence of a cave beetle species as another way to characterize the strength of VADCR data (Appendix Figure A-1). The power analysis is relevant to the assessment because absence of detection is not indicative of species absence unless the number of visits is sufficiently high. Confidence in the conclusions from the VADCR data rests on the scientists' expertise to sample effectively, the assumption that the survey areas are representative of all suitable habitat areas within a given cave, and the survey effort as indicated by number of visits per cave. The power analysis indicates that at least five visits are required to have a high (>0.8) probability of detecting presence at a locality (Appendix Figure A-1) and ensure the sparseness criteria is met (i.e., the maximum detection falls below 1 per 2 visits, Figure A-2). These results are put into context for each species current condition in the individual species assessments.

Thus, based on these analyses we would look for at least five cave visits and rare or infrequent observations before concluding (with moderate confidence) that the cave or analysis unit supports a low ease of detection. Conversely, if beetles were readily observable, we would be confident that the cave or analysis unit does not support a low ease of detection. We make the assumption that low ease of detection ("rarely" or "infrequently" observed; mean detection rate <1) is related to low resilience, but in cases of "readily observed" (i.e., mean detection rate ≥1), resilience cannot be inferred and is considered unknown. This is because the relationship between detectability and absolute abundance or density is unknown.

Redundancy

For all eight species, redundancy is measured by the number of analysis units that exist and their geographic distribution based on the best data available.

Representation

No genetic information is available for the eight cave beetle species to inform a robust assessment of representation. One widely accepted theory has been that evolution in caves typically leads to low genetic diversity and small population size (Poulson & White 1969, p. 977). On the other hand, surprisingly high genetic diversity, indicating higher than expected effective population sizes, was found in two species of cave-dwelling invertebrates in the southern Cumberland Plateau, and was positively correlated with cave length (Balogh *et al*. 2020, p. 6). Representation may also be informed by the occurrence of species in varied habitat types; among the eight species in this assessment, four are currently considered to be single site endemics, and for the others we have no information indicating there are differences in habitat between caves where they occur that would rise to the level of bestowing a measurable increase in adaptive capacity, i.e., representation, for the species. However, there are several studies that widely support high genetic differentiation between caves for the same species, regardless of their proximity to one another (Balogh *et al*. 2020, p. 5; Bradic *et al*. 2012, p. 6; Kamimura *et al*. 2019, p. 53). In summary, we assume high genetic differentiation between cave sites for individual species, but we cannot assume low genetic diversity within individual caves in all cases. As such, representation is unknown for each species in this assessment.

<u>Overall Viability</u>

It is important to note that in most cases, karst areas between known localities have not been adequately sampled and the true extent of each species range is a major source of uncertainty, impacting estimates of the number of populations, the potential for genetic connectivity between localities, and our understanding of both current representation and redundancy for these species.

In general, the cave beetles are endemic troglobite species possessing a small range size with dispersal limitations. Habitat requirements of narrow endemics cause vulnerability to acute or chronic influences, natural or manmade, that affect their continued existence (Strayer 2013, p. 176). Troglobites live in food-poor environments leading to sparse populations, which contributes to their vulnerability to habitat shifts from climate change (Manes *et al*. 2021, p. 9).

Specifically, cave beetle species that have (1) low or moderate redundancy as evidenced by presence at one or two localities and (2) low resilience associated with low ease of detection as evidenced by <1 individual per two visits, objectively have an elevated risk of extinction. Presence of mines or quarries, high percentage (>5 percent; ICLUS documentation) of impervious surface, or de-humidification of the cave elevate the risk of extirpation further. Demographic criteria combined with an assessment of threats provides a basis for objectively assessing condition.

5.5 Future Scenarios

To develop future scenarios for the evaluation of species viability, we were only able to carry forward those threats in which we have enough confidence that their magnitude of impact would be likely to cause harm at the analysis unit level. Due to the lack of information on species response to changes in habitat condition at smaller magnitudes, there is significant uncertainty as to the type and magnitude of changes in habitat conditions that would elicit a response from the species at the individual level. We are confident that changes to the physical structure of an occupied cave, and changes to the water table and the functioning of the rest of the hydrological system within a cave are impacts that are likely to be detrimental at the level of the analysis unit for each species. We identified sources of those impacts to include commercial cave tour operations, quarries/mining, and large-scale urbanization/development (residential and/or commercial). These sources also have the potential to impact water quality within cave systems so despite the uncertainty associated with the species' response to changes in water quality, we make a conservative assumption that as riparian-associated species they may experience negative effects as a result of compromised water quality and have included that aspect of potential futures in our discussions.

We discuss quarrying and commercial cave operations qualitatively for individual species where each is relevant, but we have no meaningful standardized way of predicting or quantifying their future impacts as the future intentions of private landowners are unpredictable. The metric we use for future projections of impacts from urbanization/development is projected changes in impervious surfaces. We also use projected changes in county (human) populations as an indicator of road usage and future development potential. We looked at projections of these metrics for the years 2020, 2040, and 2070 to determine the change in these parameters from current out to two timesteps in our future conditions. We evaluated two future time steps to balance the (assumed) short generation time of the species with the availability of future threat projections.

Impervious surface projections

The extent of impervious surface in a watershed affects the integrity of the freshwater ecosystems within it (Theobald *et al.* 2009, p. 364). Because the assessed species are associated with moisture (e.g., drip pools, riparian areas), they may be impacted by the same issues that affect surface waters. We use ICLUS projections to quantify impervious surface within the conservation sites (i.e., the surface area draining into a cave with a known occurrence of an assessed species) determined by the VADCR.

We resampled the ICLUS impervious surface projections to match the spatial grain of the conservation site shapefiles provided by VADCR, extracted the ICLUS data coinciding with those shapes, and calculated the mean impervious surface over each conservation site. We followed this process for the A1 and B1 scenarios, for the years 2020, 2040, and 2070. We chose the A1 and B1 scenarios for their contrasting economic conditions (described in ICLUS documentation, EPA 2009, pp. 2-1 to 2-7), and the three time horizons to represent current and future conditions.

Following the classifications provided in Theobald *et al*. (2009, p. 364), we classify the impact of impervious surface on conservation sites as follows: Unstressed (0-0.9 percent), Lightly stressed (1-4.9 percent), Stressed (5-9.9 percent), Impacted (10-24.9 percent), and Damaged (>25 percent).

County population projections

We used projected changes in human populations at the county level as a proxy for future road usage and development potential. The ICLUS dataset contains county population projections for the same SRES scenarios and years as projected impervious surface.

Future projections and implications for species viability are provided in the individual species assessments below.

6 Species Accounts

6.1 *Pseudanophthalmus parvicollis* (Hupp's Hill Cave Beetle) Species Status Assessment

6.1.1 Taxonomy

Pseudanophthalmus parvicollis, commonly known as Hupp's Hill cave beetle or thin-necked cave beetle, was first described by Jeannel in 1931 as a subspecies of *P. hubbardi*. Subsequently, Barr (1965, p. 55) elevated its taxonomic status to a full species. It is a member of the hubbardi species group.

6.1.2 Current Condition

Habitat/Range

Since its discovery and description, Hupp's Hill cave beetle has been recorded from two cave locations within one contiguous belt of limestone spanning Shenandoah and Frederick Counties. The belt of limestone runs northeast under Cedar Creek. At Battlefield Crystal Caverns, Hupp's Hill cave beetle was first collected in 1928 and the most recent observation of the species at this site is listed in the EO record as "pre-1981" despite eight visits to the cave between 2016 and 2021 by VADCR. The species is assumed to have been extirpated from Battlefield Crystal Caverns in Shenandoah County in the southwestern portion of its range on the southwestern side of Cedar Creek (Malabad *et al*. 2021, p. 59). The peninsular extension of limestone where Battlefield Crystal Caverns occurs is bound to the southeast by U.S. Route 11 and associated commercial development and to the northwest by limestone quarrying that intersects the water table.

At the second location, Ogden's Cave, a single specimen of Hupp's Hill cave beetle was first collected in 2005, prior to which the species was thought to be extinct by VADCR biologists. Another single specimen was collected at this location in 2014. There were five additional cave visits between 2016 and 2018 that yielded no collections. Ogden's Cave is northwest of Cedar Creek in Frederick County and is located in the 131-acre VADCR-managed Ogden's Cave Natural Area Preserve (NAP). Nutrients that sustain the cave's ecosystem and inhabitants are provided by a subterranean branch of Buffalo Marsh Run, which flows overland nearby, and from water that percolates from the surface and accumulates in drip pools throughout the cave. Additional nutrients are delivered by animals that come and go from the cave, like bats and crickets, and contribute waste products and occasionally corpses as additional sources of nutrients for cave invertebrates (VADCR 2022, unpaginated). The NAP is closed to general visitation to protect the natural community within the cave. This location is also in close proximity to quarrying activity along the southern boundary of the associated conservation site (See figure 6.1).

Currently, the known species range as delineated by VADCR consists of 25.37 square kilometers (km^2) (9.80 square miles [mi^2]) (Figure 6.1).

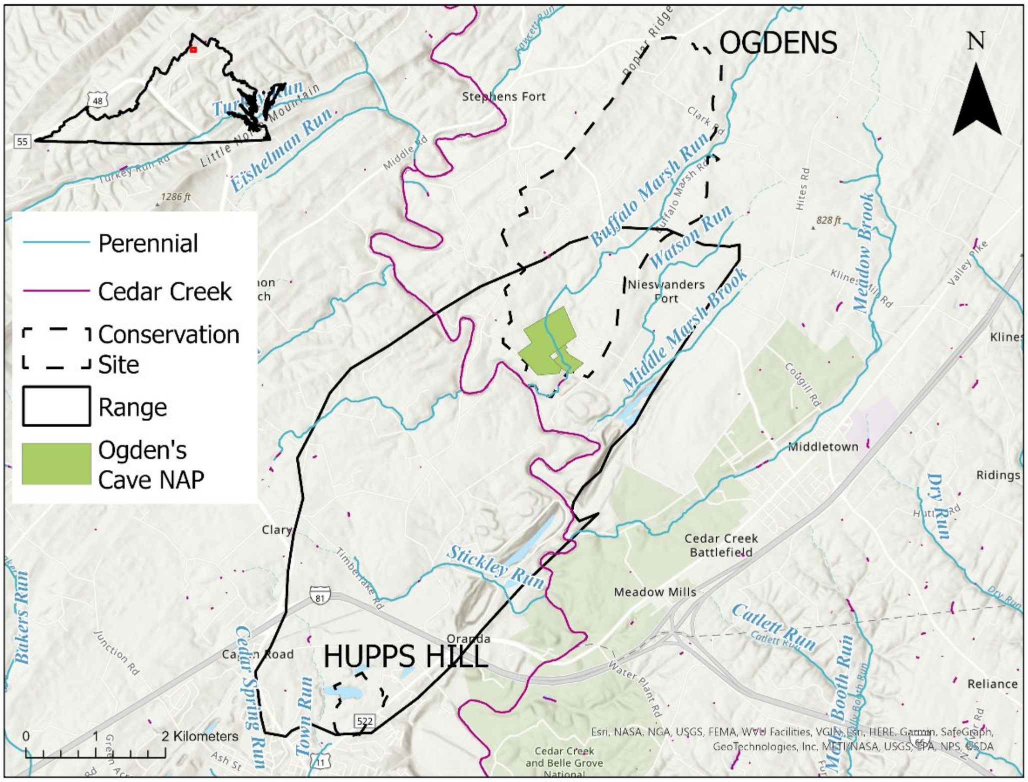

Figure 6.1: Hupp's Hill Cave Beetle Range and Conservation Sites

Additional information on habitat condition within the caves is provided by VADCR as brief site descriptions associated with their survey visits. The first visit to Ogden's Cave in October 2014 resulted in the collection of one beetle from the surface of a small pool surrounded by an area of bedrock overlain with pockets of small cobbles covered with mud. Some active drips are in the area and the substrate is damp to wet in the vicinity. Other observations on subsequent visits include organic debris like small sticks, leaves, and nuts (observed on a different visit and at a different location from where the single specimen was collected). Battlefield Crystal Caverns has a building over the entrance with ventilation fans that run continuously pulling moisture out of the cave. The building was originally constructed to support a commercial tour operation inside the cave. After the closure of the commercial tour operation in 2010, the building has remained in use as either a residence, office, or storage facility and the fans still operate to reduce mold inside the building (email from T. Malabad, VADCR to K. Maison, Service, 11/4/2022). VADCR notes that it is likely that these fans have dried the accessible portion of the cave out to the point that it no longer has suitable habitat for Hupp's Hill cave beetle (Malabad *et al*. 2021, p. 59).

Hupp's Hill cave beetle may be extant at other caves that have not been surveyed to the northwest of its current location. Cedar Creek currently represents a modern barrier to dispersal in a southeasterly direction as it has eroded through the karst layers down to bedrock, so there is no karst underneath it through which cave beetles could potentially disperse via fissures, etc. The spatial distribution of the Hupp's Hill cave beetle on either side of Cedar Creek is likely explained by the fact that these are ancient lineages and their spatial patterns often pre-date modern surface topography, i.e., they occupied these same caves before Cedar Creek eroded through the karst layer to bedrock and became a barrier between occurrences. VADCR suggests future surveys and conservation should focus on areas northwest of quarrying on both sides of Cedar Creek.

Analysis Units

The two locations for the Hupp's Hill cave beetle are within one contiguous belt of limestone but are treated as two separate EOs. We adopt these two EOs as our analysis units. VADCR has established conservation sites associated with these EOs that delineate the area of influence surrounding each cave. The species is presumed to be extirpated from Battlefield Crystal Caverns (discussed in more detail below) leaving a single confirmed location at Ogden's Cave. However, we have completed threats analyses for the two conservation sites that include both analysis units. We use the Ogden's (8.55 km^2, 3.30 mi^2) and Hupp's Hill (0.46 km^2, 0.18 mi^2) conservation sites as our spatial units to evaluate threats that may be impacting the species and its habitat currently and in the future (Figure 6.1).

Ease of Detection

In the absence of information on absolute abundance or density, we focus on ease of detection for the Hupp's Hill cave beetle. At Battlefield Crystal Caverns, no individuals were observed in eight cave visits. As noted in the methods section above, in cases of repeated zero counts, we look for more than four cave visits before concluding that the cave or analysis unit supports a low ease of detection with moderate confidence, which is the case for Battlefield Crystal Caverns. Coupled with the assessment of VADCR biologists that this cave no longer contains suitable habitat for the species, we have moderate confidence in the conclusion that the Hupp's Hill cave beetle is extirpated from this site.

At Ogden's Cave, one individual was collected over six cave visits from 2014-2018 for a mean detection rate of 0.17. This falls into the "rarely observed" category and we have moderate confidence in this conclusion given the number of cave visits.

Influences

As noted above, the peninsular extension of limestone where Battlefield Crystal Caverns occurs is bound to the southeast by U.S. Route 11 and associated commercial development and to the northwest by limestone quarrying that intersects the water table. Battlefield Crystal Caverns is no longer connected to the rest of the karst belt due to quarrying activity. There was a commercial operation inside the cave with ventilation fans continuously pulling moisture out; commercial operations ceased when the business closed in 2010, however the building over the entrance remains in use as a residence/office/storage facility and the ventilation fans continue to run to reduce mold in the building. This site also contains evidence of dried lakes and pools. Humidity may currently be too low to provide suitable habitat for the Hupp's Hill cave beetle. In general, the Shenandoah County portion (southwest of Cedar Creek) of the range is has more potential negative influences than the Frederick County portion (northeast of Cedar Creek), with several quarries, commercial development, industrial development, and Interstate 81 crossing potential habitat (Malabad *et al*. 2021, p. 59).

The Ogden's Cave NAP was established in 2007, after the initial discovery of Hupp's Hill cave beetle at the site. Prior to its establishment, the spring that sinks to form the stream in the cave was in the permitting process for use as a municipal water supply. The property had also been subdivided for a residential development. The establishment of the NAP precluded both actions. Much of the Frederick County portion of the species' range is owned either by the State of Virginia (VADCR) or by the National Park Service at the Cedar Creek and Belle Grove National Historical Park. However, there is significant existing and planned quarrying along the southeastern margin of the species' range in Frederick County, where the belt of limestone has been mined for 100+ years. Ogden's Cave and Buffalo Marsh Run are fed by several springs to the north and the existing quarry activities do not appear to have affected or altered the flow from these springs thus far, even though the quarrying has excavated limestone to further depths than where the springs emerge within the karst layer; the geology of the area suggests that intersecting the conduits that feed Buffalo Marsh Run by quarrying activities is unlikely (USFWS-VADCR 5/5/2022 pers. comm.).

Conservation Efforts

Hupp's Hill cave beetle is currently listed by the Virginia Department of Agriculture and Consumer Services as an endangered species under the Virginia Endangered Plant and Insect Species Act. Prohibited acts for threatened and endangered species under the Virginia Endangered Plant and Insect Species Act include "to dig, take, cut, process, or otherwise collect, remove, transport, possess, sell, offer for sale, or give away any species native to or occurring in the wild in the Commonwealth that are listed in this chapter or the regulations adopted hereunder as threatened or endangered, other than from such person's own land, except in accordance with the provisions of this chapter or the regulations adopted hereunder" (Code of Virginia, Section 3.2–1003).

The Cave Conservation Act enacted in 1966 was established to protect the cave and karst resources of the Commonwealth. In 1978, the Virginia legislature formed the Virginia Cave Commission, and in 1979 enacted a new comprehensive Virginia Cave Protection Act that defined the role of the Commission, which is now known as the Virginia Cave Board. The Virginia Cave Board is an advisory committee and tasked the board with researching and surveying Virginia's caves, creating reports to be used by other agencies, reporting dangers or threats to caves, and increasing public awareness of the importance of caves and cave fauna. In addition, the 1979 Virginia Cave Protection Act spells out penalties for vandalism, pollution, and disturbance of endemic species, and how to go about getting permits to conduct any sort of disturbing action within a cave.

The Virginia Cave Board maintains a list of caves designated as "Significant" and both sites for Hupp's Hill cave beetle are included as "Significant" caves. Significant Caves as designated by the Virginia Cave Board under the Cave Protection Act are treated as element occurrences by the VADCR NHP, and each significant cave lies within a Conservation Site. Any projects passing through the VADCR Office of Environmental Project Review are screened to see if they intersect conservation sites. When conservation sites are intersected, VADCR NHP staff inform the project proponent and provide guidance on protection of the associated resources that may be affected by their project, including "Significant" caves and species within. Although no legal status accompanies this designation, VADCR NHP reports success in avoiding impacts to element occurrences via this review and communication process. In addition, "Significant" caves are given priority for implementation of conservation efforts such as easements, cost-share programs, and fee simple acquisition for long-term protection.

As noted above, Ogden's Cave is within a state-managed NAP. The NAP was established in 2007 at 110 acres. To enhance water quality in Buffalo Marsh Run, nearly 8,000 native trees have been planted in the riparian zone, and 35 acres of upland fields have been restored to native warm-season grasslands within the NAP. The NAP was expanded in 2012 with the purchase of an additional 21 acres of wetlands bringing its current size to 131 acres. As a result of the expansion, an additional 1,350 feet of Buffalo Marsh Run is protected. VADCR maintains riparian buffers along the stream banks to protect water quality (VADCR 2012, unpaginated).

Viability Under Current & Imminent Threats

Currently, Hupp's Hill cave beetle is believed extirpated from one of its two known locations, Battlefield Crystal Caverns, owing to some combination of quarrying activities, commercial cave tour operations, industrial development, and roads. At the second location, Ogden's Cave, low ease of detection suggests low density and thus low resilience, resulting in limited ability to withstand inherent stochasticity and threats. Portions of the conservation site surrounding the Ogden's Cave occurrence are publicly owned and protected, and although quarrying activities have been ongoing in close proximity to the site, much of the remaining habitat appears unaffected by them. Hupp's Hill cave beetle's restricted geographical extent and single extant occurrence render it vulnerable to stochastic and catastrophic events. We lack genetic information to inform genetic diversity and effective population size for this species so its ability to cope with and adapt to changing conditions is unknown. However, under the assumption that different caves are likely to be genetically distinct, extirpation from one site represents a decrease in genetic diversity, and thus representation, for this species. Overall, Hupp's Hill cave beetle's ability to withstand stochasticity and catastrophic events is currently constrained. This synthesis is predicated upon several key assumptions.

1) There are no other occurrences of the species.
2) The Battlefield Crystal Caverns occurrence is extirpated – eight recent survey efforts found no individuals, and there is ongoing degradation of habitat leaving no suitable habitat at the site.

6.1.3 Future Condition

Impervious Surface Projections

Following Theobald *et al*. (2009, p. 364), we classify the impact of impervious surface on conservation sites as follows: Unstressed (0–0.9 percent), Lightly stressed (1–4.9 percent), Stressed (5–9.9 percent), Impacted (10–24.9 percent), and Damaged (>25 percent). Under this classification, the Hupp's Hill cave beetle conservation sites are both currently lightly stressed and projected to remain lightly stressed under both scenarios through 2070 (Table 6.1).

Table 6.1: Percent impervious surface projections for conservation sites containing Hupp's Hill cave beetle.

Area	**Mean percent impervious surface**					
	ICLUS A1			**ICLUS B1**		
Conservation Site	**2020**	**2040**	**2070**	**2020**	**2040**	**2070**
Ogden's	1.50	1.54	1.54	1.20	1.20	1.20

Hupps Hill	4.97	4.97	4.97	4.97	4.97	4.97

County Population

The VACDR report (Malabad *et al*. 2021, entire) indicates that proximity to roads is a threat for several cave beetle species. The mechanisms given include runoff of sediment, hydrocarbons, and deicing agents; trash from the roadway entering the mouth of a cave; and the possibility of spills of hydrocarbons and other hazardous materials. The severity of these threats depends on usage of roads in areas draining into the habitat of the assessed species. We use projected changes in county (human) populations as a proxy for future road usage and development potential. The Frederick County population is projected to increase by up to 38 percent under the A1 scenario by 2070 and 18 percent under the B1 scenario by 2070. We therefore expect an increase in traffic within the Ogden's Cave conservation site, which is in Frederick County (Table 6.2).

Table 6.2: ICLUS county population projections through 2070 under the SRES A1 and B1 scenario for Hupp's Hill cave beetle.

County	**County population**					
	ICLUS A1			**ICLUS B1**		
	2020	**2040**	**2070**	**2020**	**2040**	**2070**
Shenandoah	33,382	22,882	8,607	37,647	33,652	26,112
Frederick	87,838	108,517	121,480	81,008	91,141	95,234

Land Ownership

As noted above, land within the Frederick County portion of the species range is owned either by the state of Virginia or by the NPS. However, there is significant existing and planned quarrying along the southeastern margin of the species' range in Frederick County.

Viability Under Future Threats

We do not expect Hupp's Hill cave beetle's abundance or spatial extent to change relative to their current status through 2070, and thus, nor will the species' viability. The rationale for our conclusion rests primarily on two facets. First, despite the projected increase in road density in Frederick County, the percentage of impervious surface within the conservation sites remains unchanged (lightly stressed) through 2070. Secondly, although quarrying activities are likely to continue just outside the southern edge of the Ogden's conservation site, we have no information to indicate they are likely to expand, and the state's vested interest in the management and mitigation of impacts to the NAP will likely prevent any future degradation to the cave and the surrounding sensitive habitats including springs, wetlands, and Buffalo Marsh Run. Thus, we believe the species' abundance and spatial extent will not change from its current condition. Under future conditions, Hupp's Hill cave beetle will remain vulnerable to stochastic and catastrophic events and will have limited ability to adapt to shifting and novel conditions.

6.2 *Pseudanophthalmus hubbardi* (Hubbard's cave beetle) Species Status Assessment

6.2.1 Taxonomy

Pseudanophthalmus hubbardi, commonly known as Hubbard's cave beetle, was first described as a new species by Barber in 1928 based on collections from its only known location, Luray Caverns in Page County, VA. It is a member of the hubbardi species group.

6.2.2 Current Condition

Habitat/Range

Hubbard's cave beetle has historically been collected from only one location and as such is currently considered a single site endemic. The only confirmed location for this species is Luray Caverns in Page County, VA. The first discovery and collection of the species in Luray Caverns was in 1884, when a single specimen was collected. An unknown number of specimens were collected again in 1980 and the most recent collection of a live specimen of Hubbard's cave beetle was in 1996, when D. A. Hubbard collected "both male and female specimens, with and without bait, near Broaddus Lake in Luray Caverns in February 1996" (Holsinger *et al*. 2013, p. 36). No additional live specimens were collected in four site visits to the known location between 2016 and 2021, which included deployment of pitfall traps and bait stations. One dead beetle was found in a drip pool in 2021 and several exoskeletons later confirmed to be Hubbard's cave beetle were also collected, however it is unclear how long dead beetles and exoskeletons may persist in a cave environment; some exoskeletons were observed partially calcified into flowstone indicating they are likely to be quite old and others were found on the tops of various surfaces and inside drip pools (Malabad *et al*. 2021, p. 39). Despite not collecting any live specimens of Hubbard's cave beetle during survey efforts from 2016-2021, VADCR biologists still consider the species likely to be extant and recommend additional surveys efforts to confirm the species at Luray Caverns and potentially other unsurveyed caves within the contiguous belt of limestone (Malabad *et al*. 2021, p. 40).

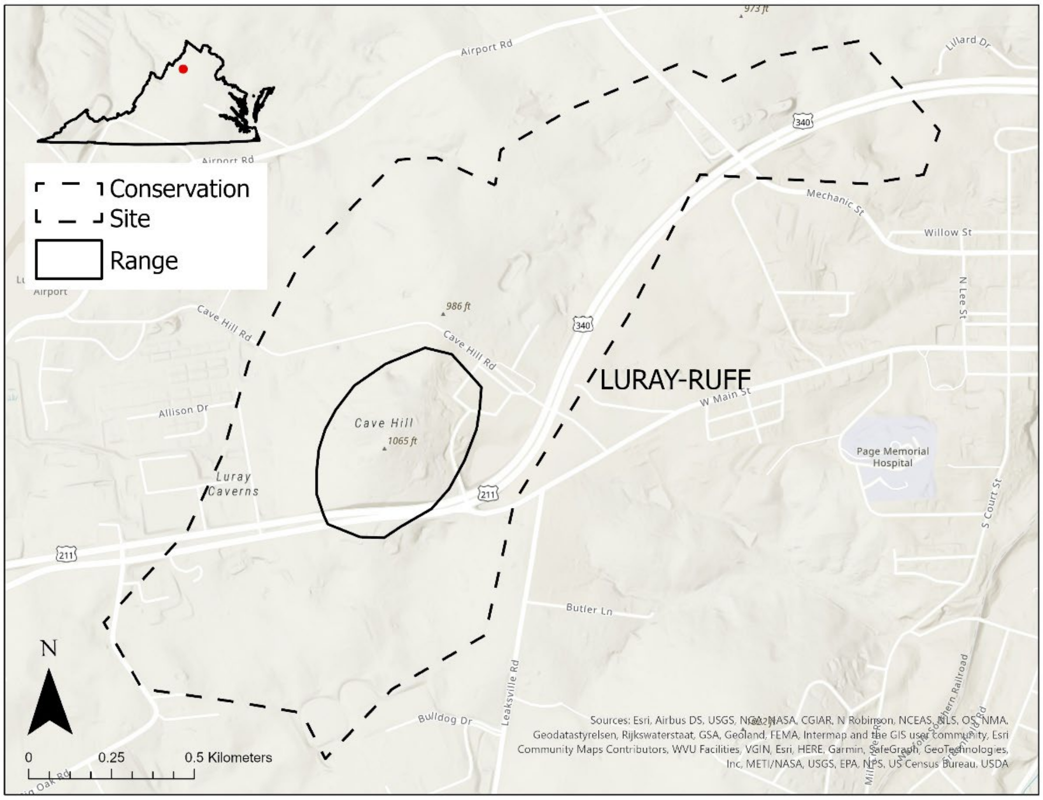

Figure 6.2: Hubbard's Cave Beetle Range and Conservation Site

Based on the information currently available, Hubbard's cave beetle is considered to be a single site endemic with a range of 0.2 km^2 (0.08 mi^2) (Figure 6.2). Luray Caverns lies within a contiguous limestone exposure stretching 482.8 km (186.41 mi). The only available information on habitat condition within the cave is provided by VADCR as brief site descriptions associated with their survey visits. Surveys focused in an area of the cave known as Broaddus Lake, where Hubbard's cave beetle specimens had been collected in 1996. This section of cave is not in the commercialized portion (which is described in more detail below) and contains a large lake and pool complex with active formations and abundant mud banks and drip pools which constitute suitable habitat for cave beetles. VADCR biologists also indicated that many portions of the cave that are not commercialized or used as heavily by the commercial operation still have what appears to be suitable habitat for cave beetles (Malabad *et al*. 2021, p. 41).

The majority of land within the species range and the Luray-Ruff conservation site is owned by the Luray Caverns Corporation. Within the conservation site, there are several additional privately owned parcels on the southern end of the site.

Analysis Units

Given the current understanding of this species as a single site endemic, we consider it to consist of a single analysis unit at the only known location in Luray Caverns in Page County, VA. VADCR has established a conservation site associated with this EO that delineates the area of influence surrounding the cave. We use the Luray-Ruff conservation site (2.02 km^2 or 0.78 mi^2) as our spatial unit to evaluate threats that may be impacting the species and its habitat currently and in the future (Figure 6.2).

Ease of Detection

Information on how many individuals were collected in historical collection events is not available. During 2016-2021 survey efforts, VADCR did not detect any live beetles in four cave visits. As noted in the methods section above, in cases of repeated zero counts, we look for more than four cave visits before concluding that the cave or analysis unit supports a low ease of detection. In this case, four cave visits gives us low confidence in making any conclusions regarding ease of detection or probable density and more effort is required to make supportable conclusions for this species.

Malabad *et al*. (2021, p. 41) notes that site occupancy, as measured by sampling success for cave beetles in the Shenandoah Valley is generally lower than in other regions of Virginia's karst, and VADCR's failure to verify live Hubbard's cave beetle at Luray Caverns may simply reflect this. Additional cave visits are needed to improve our confidence in demographic conclusions regarding this species.

Influences

The petition to list Hubbard's cave beetle listed the commercial tour operation, and "general threats to cave beetles" including toxic chemical spills, pollution, trash dumping, vandalism, disruption of nutrient input, alteration of entrances, or creation of new entrances as existing threats as threats to the species, as well as a lack of existing regulatory mechanisms to protect the species. The most immediate influence on Hubbard's cave beetle habitat is the commercial operation of Luray Caverns, one of the most popular and heavily visited show caves in the U.S. Luray Caverns was discovered in 1878 and opened to the public for candle-lit tours at the end of that same year. Electric lights were installed for tours by 1881, and Hubbard's cave beetle was discovered within the cave in 1884, after several years of commercial operation.

The effects of operating a commercial cave tour company can be numerous and depend on the frequency and size of cave tours, the extent of modifications like light and stairway/walkway installation, the proportion of the cave that is made accessible to tour groups, and other factors. In general, effects may include changes to air circulation, humidity, CO^2 concentration, and temperature, organic matter input, chemical pollutants, and noise (causes and effects of these alterations are synthesized by Constantin *et al*. 2021, p. 3). The installation of lights can create a growing environment for fungi and algae that would not typically be able to survive inside caves, which can in turn lead to other non-native species inhabiting those microenvironments and other downstream effects. The construction of new or additional entrances for ease of access for large groups can affect humidity, temperature, and other abiotic parameters within the cave. Visitors introduce trash, and lint, dust, and spores from their clothing can deteriorate speleothems and further promote the growth of fungi and algae. To manage fungi and algae that develop, cave operators often deploy biocides which have their own implications for native cave fauna, and many of which are not well studied or understood.

Even with heavy commercial usage for 100+ years, many portions of Luray Caverns still appear to have suitable beetle habitat (Malabad *et al*. 2021, p. 41). It is unclear to what extent the many commercial modifications that have been made may be impacting the species. According to VADCR (Malabad *et al*. 2021, p. 41), site occupancy, as measured by sampling success for cave beetles in the Shenandoah Valley is generally lower than in other regions of Virginia's karst, and VADCR's failure to verify live Hubbard's cave beetle at Luray Caverns from 2016-2021 may simply reflect this. Many portions of the cave that are not commercialized or used as heavily by the commercial operation still have what appears to be suitable habitat for cave beetles. Collections in 1996 after many years of commercialization support that this beetle may still be extant in Luray Caverns (Malabad *et al*. 2021, p. 41).

Other than the potential effects of the commercial tour operation discussed above, we found no information to indicate that toxic chemical spills, pollution, trash dumping, vandalism, disruption of nutrient input, alteration of entrances, or creation of new entrances are likely to be influencing viability for the species currently or in the future.

Conservation Efforts

The Cave Conservation Act enacted in 1966 and was established to protect the cave and karst resources of the Commonwealth. In 1978, the Virginia legislature formed the Virginia Cave Commission, and in 1979 enacted a new comprehensive Virginia Cave Protection Act that defined the role of the Commission, which is now known as the Virginia Cave Board. The Virginia Cave Board is an advisory committee and tasked the board with researching and surveying Virginia's caves, creating reports to be used by other agencies, reporting dangers or threats to caves, and increasing public awareness of the importance of caves and cave fauna. In addition, the 1979 Virginia Cave Protection Act spells out penalties for vandalism, pollution, and disturbance of endemic species, and how to go about getting permits to conduct any sort of disturbing action within a cave.

The Virginia Cave Board also maintains a list of caves designated as "Significant" and Luray Caverns is included as a "Significant" cave. "Significant" caves as designated by the Virginia Cave Board under the Cave Protection Act are treated as element occurrences by the VADCR NHP, and each significant cave lies within a Conservation Site. Any projects passing through the VADCR Office of Environmental Project Review are screened to see if they intersect conservation sites. When conservation sites are intersected, VADCR NHP staff inform the project proponent and provide guidance on protection of the associated resources that may be affected by their project, including "Significant" caves and species within. Although no legal status accompanies this designation, VADCR NHP reports success in avoiding impacts to element occurrences via this review and communication process. In addition, "Significant" caves are given priority for implementation of conservation efforts such as easements, cost-share programs, and fee simple acquisition for long-term protection.

Viability Under Current and Imminent Threats

The only known location for Hubbard's cave beetle is a heavily used commercial cave; however, the species is thought to persist at the site despite 100+ years of commercial use and the magnitude and mechanisms for negative impacts from commercial tour operations are unclear. Hubbard's cave beetle's restricted geographical extent and single occurrence render it vulnerable to stochastic and catastrophic events. We lack genetic information to inform the species' ability to adapt to changing conditions. As a single site endemic, the species does not have the genetic advantage of multiple sites that are likely to be genetically distinct, however Balogh *et al*. (2020, p. 6) found a correlation between cave length and genetic diversity in cave invertebrates and Luray Caverns is one of the largest cave systems in the Eastern U.S. The commercial tour route is 2.4 km and there are additional portions of the cave system that are not used commercially. Without genetic sampling for this analysis unit, we have no information on the genetic diversity of Hubbard's cave beetle. Overall, Hubbard's cave beetle's ability to withstand stochasticity, and catastrophic events is currently constrained by its single occurrence location, and its ability to adapt to changing conditions is unknown. This synthesis is predicated upon several key assumptions.

1) The species is extant in Luray Caverns.
2) There are no other occurrences of the species.

6.2.3 Future Condition

Key assumptions

Despite the lack of observations or collections in four cave visits between 2016 and 2021, we assume the species is extant given its cryptic nature, low survey effort, and professional opinions of VADCR karst biologists.

Impervious Surface Projections

Following Theobald *et al*. (2009), we classify the impact of impervious surface conservation sites as follows: Unstressed (0–0.9 percent), Lightly stressed (1–4.9 percent), Stressed (5–9.9 percent), Impacted (10–24.9 percent), and Damaged (>25 percent). Under this classification, the Luray-Ruff conservation site, which drains into the cave inhabited by Hubbard's cave beetle, is currently lightly stressed, and is projected to become stressed by 2070 in the A1 scenario (Table 6.3).

Table 6.3: Percent impervious surface projections for conservation site and range of Hubbard's cave beetle.

Area	**Mean percent impervious surface**					
	ICLUS A1			**ICLUS B1**		
Conservation Site	**2020**	**2040**	**2070**	**2020**	**2040**	**2070**
Luray-Ruff	4.93	4.93	5.49	4.93	4.93	4.93

County Population

The VACDR report (Malabad *et al*. 2021, entire) indicates that proximity to roads is a threat for several cave beetle species. The mechanisms given include runoff of sediment, hydrocarbons, and deicing agents; trash from the roadway entering the mouth of a cave; and the possibility of spills of hydrocarbons and other hazardous materials. The severity of these threats depends on usage of roads in areas draining into the habitat of the assessed species. We use projected changes in county (human) populations as a proxy for future road usage and development potential. The population of Page County, VA is projected to decline through 2070, which indicates road usage is likely to decline by proxy (Table 6.4).

Table 6.4: ICLUS county population projections through 2070 under the SRES A1 and B1 scenario for Hubbard's cave beetle.

County	**County population**					
	ICLUS A1			**ICLUS B1**		
	2020	**2040**	**2070**	**2020**	**2040**	**2070**
Page	17,973	8,929	1,961	22,054	18,210	11,760

Land Ownership

The entire range and conservation site for Hubbard's cave beetle are privately owned. Most of both spatial areas are owned by the Luray Caverns Corporation. We have no information on their future plans for the property but assume the commercial operation will continue and is unlikely to change significantly in scope within the foreseeable future. The operation of Luray Caverns as a commercial show cave open to the public pre-dates the discovery of Hubbard's cave beetle within the cave.

Viability Under Future Threats

We do not expect Hubbard's cave beetle's abundance or spatial extent to change relative to their current status through 2070, and thus, nor will the species' viability. The rationale for our conclusion rests primarily on two facets. First, despite the potential for the conservation site to go from "lightly stressed" to "stressed" in terms of impervious surface cover by 2070 under the A1 scenario, there is a projected decline in the human population in Page County, indicating less road usage. Secondly, although we expect the commercial tour operations to continue in Luray Caverns, we have no information to indicate they are likely to expand. Thus, we believe the species' viability and spatial extent will not change. Under future conditions, Hubbard's cave beetle will remain vulnerable to stochastic and catastrophic events, and its ability to adapt to changing conditions remains unknown.

6.3 *Pseudanophthalmus praetermissus* (overlooked cave beetle) Species Status Assessment

6.3.1 Taxonomy

Pseudanophthalmus praetermissus, commonly known as the overlooked cave beetle, was first described as a new species by Barr in 1981 based on collections from Kerns Cave No. 1 in Scott County, VA in 1969 and 1979. It is a member of the hypolithos species group.

6.3.2 Current Condition

Habitat/Range

The overlooked cave beetle has historically only been collected from one location and as such is currently considered a single site endemic. The species was described based on collections on two separate occasions (1969 and 1979) from Kerns Cave No. 1 in Scott County, VA. In the original species collections, two males of the overlooked cave beetle and one specimen of *P. seclusus* were collected from Kerns Cave No. 1 on each of the two visits in 1969 and 1979 for a total of four individuals collected (Barr 1981, p. 88). VADCR visited Kerns Cave No. 1 four times between 2015 and 2020 and did not collect additional specimens of overlooked cave beetle but collected a total of 26 *P. seclusus* individuals (Malabad *et al*. 2021, p. 73). Several other caves within the same contiguous belt of rock were surveyed during the 2015-2020 VADCR survey efforts and overlooked cave beetle was not documented, although *P. seclusus* specimens were collected, from other nearby caves. Despite not collecting any specimens of the overlooked cave beetle during 2015-2020 survey efforts, VADCR biologists consider the species likely to be extant and recommend additional surveys to confirm the species at the known location and potentially other unsurveyed caves within the contiguous belt of limestone (Malabad *et al*. 2021, p. 74–75). The species found to co-occur within Kerns Cave No. 1, *P. seclusus*, has been confirmed in at least seven other caves in the area, indicating the overlooked cave beetle's range may be within the range of another species, something which is rare among *Pseudanophthalmus* species within Virginia that tend to be allopatric vs. *Pseudanophthalmus* species in the ILP.

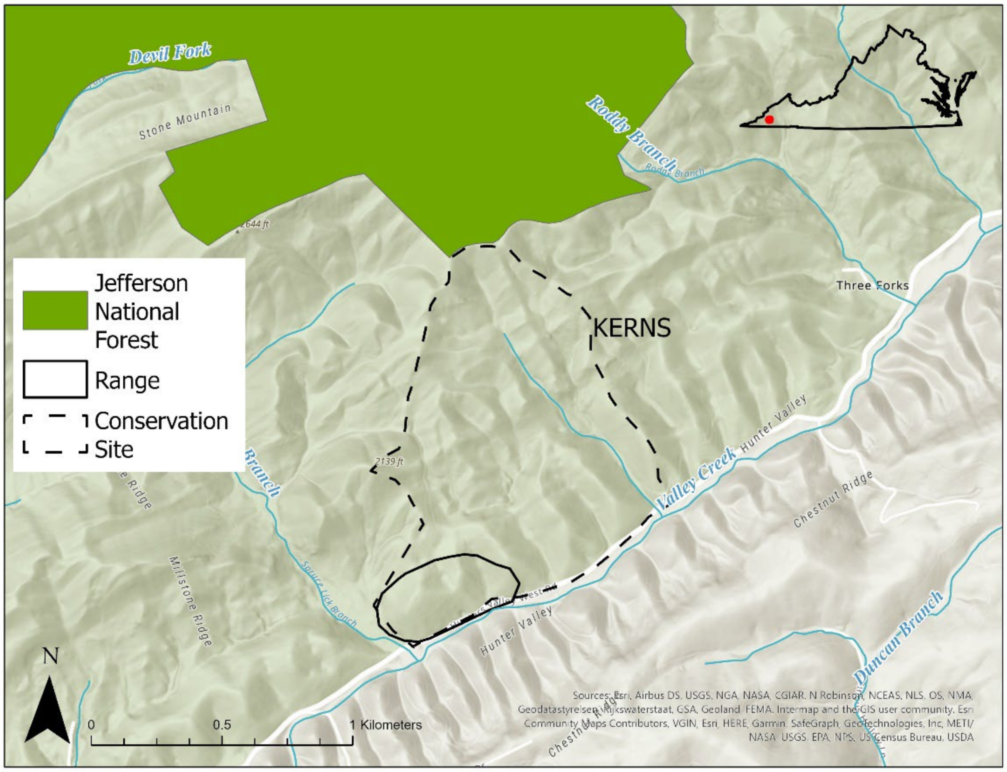

Figure 6.3: Overlooked Cave Beetle Range and Conservation Site

Based on the information currently available, the overlooked cave beetle is considered a single site endemic with a range of 0.12 km2 (0.05 mi2) (Figure 6.3). Kerns cave No. 1 is on private property. The only available information on habitat condition within the cave is provided by VADCR as brief site descriptions associated with their survey visits (2015–2020). The site showed significant fluctuations in stream flow and levels over the course of their study. In September 2015, the stream channel was dry. Moist mud banks and rich organic material were present along almost the entire length of the stream passage. A year later in early October 2016, the cave was wetter, but the stream was still not flowing. The final two visits were both in spring; in March 2017, the stream was flowing and there were signs of recent flooding within the cave. During the final visit in March 2020, the cave was wet and showed signs of recent flooding. These anecdotal observations suggest the possibility that spring floods bringing more moisture into the accessible section of the cave may increase the availability of suitable habitat for beetles in that section. Land surrounding the cave is entirely privately owned in forested residential parcels. The upper slopes of the watershed that drain toward the cave are largely in U.S. Forest Service (National Forest) or private ownership, with predominantly forested land use.

Analysis Units

Given the current understanding of this species as a single site endemic, we consider it to consist of a single analysis unit at the only historically known location of Kerns Cave No. 1 in Scott County, VA. VADCR has established a conservation site associated with this EO that delineates the area of influence surrounding the cave. We use the Kerns conservation site (1.03 km^2 or 0.40 mi^2) as the spatial unit for our current and future threats analyses (Figure 6.3).

Ease of Detection

In the original species collections, two males of the overlooked cave beetle and one specimen of *P. seclusus* were collected from Kerns Cave No. 1 on each of the two visits in 1969 and 1979 for a total of four individuals collected (Barr 1981, p. 88). VADCR visited Kerns Cave No. 1 four times between 2015 and 2020 and did not collect additional specimens of overlooked cave beetle but collected a total of 26 *P. seclusus* individuals. As noted in the methods section above, in cases of repeated zero counts, we look for more than four cave visits before concluding that the cave or analysis unit supports a low ease of detection. In this case, four cave visits gives us low confidence in making any conclusions regarding ease of detection or probable density and more effort is required to make supportable demographic conclusions for this species.

Biologists with VADCR believe the species is likely extant and that more survey effort covering different seasons and a wider variety of habitat conditions within the cave may yield additional specimens. In addition, they note that contiguous limestone habitat with numerous caves exists for over 40 mi (64.37 km) to both the northeast and southwest, affording ample opportunity for range extension and for sampling efforts to better define the full range of the overlooked cave beetle (Malabad *et al*. 2021, p. 75).

Influences

The petition to list overlooked cave beetle cited recreational spelunking, and pollution from mountaintop removal coal mining as threatening the species' habitat. There are no active mining operations within the range or associated conservation site for overlooked cave beetle. We found no information indicating recreational use of the cave is occurring. The upper slopes of the watershed for Kerns Cave No. 1 within the conservation site are in private ownership with forested land use. VADCR notes that numerous rural residences along Hunter's Valley West Road, which runs along the southern edge of the range and conservation site, use on-site waste disposal systems, and the lower resurgence entrance to Kerns Cave No. 1 is immediately adjacent to the road, both of which have the potential to negatively impact the species (Malabad *et al*. 2021, p. 75) although the specific magnitude and mechanisms of effects are not clear.

The overlooked cave beetle has been recorded as sympatric with *P. seclusus*. Studies of other species of *Pseudanophthalmus* beetles in the ILP indicate niche partitioning via food and microhabitat preferences in sympatric species, however there are significant ecological distinctions between species from the ILP and AVR karst regions as discussed previously making it difficult to apply those results to the overlooked cave beetle. We have no information on the specific food or microhabitat preferences or other life history characteristics and how they may differ between the overlooked cave beetle and *P. seclusus* and can therefore not reliably state what role, if any, competition may have on the viability of the overlooked cave beetle.

Conservation Efforts

The Cave Conservation Act enacted in 1966 and was established to protect the cave and karst resources of the Commonwealth. In 1978, the Virginia legislature formed the Virginia Cave Commission, and in 1979 enacted a new comprehensive Virginia Cave Protection Act that defined the role of the Commission, which is now known as the Virginia Cave Board. The Virginia Cave Board is an advisory committee and tasked the board with researching and surveying Virginia's caves, creating reports to be used by other agencies, reporting dangers or threats to caves, and increasing public awareness of the importance of caves and cave fauna. In addition, the 1979 Virginia Cave Protection Act spells out penalties for vandalism, pollution, and disturbance of endemic species, and how to go about getting permits to conduct any sort of disturbing action within a cave.

The Virginia Cave Board maintains a list of caves designated as "Significant" and Kerns Cave No. 1 is included as a "Significant" cave. "Significant" caves as designated by the Virginia Cave Board under the Cave Protection Act are treated as element occurrences by the VADCR NHP, and each significant cave lies within a Conservation Site. Any projects passing through the VADCR Office of Environmental Project Review are screened to see if they intersect conservation sites. When conservation sites are intersected, VADCR NHP staff inform the project proponent and provide guidance on protection of the associated resources that may be affected by their project, including "Significant" caves and species within. Although no legal status accompanies this designation, VADCR NHP reports success in avoiding impacts to element occurrences via this review and communication process. In addition, "Significant" caves are given priority for implementation of conservation efforts such as easements, cost-share programs, and fee simple acquisition for long-term protection.

Viability Under Current and Imminent Threats

Given the low inventory effort, we have low confidence in the low ease of detection for overlooked cave beetle. A sympatric species, *P. seclusus*, was readily observed in the only known location for overlooked cave beetle and several other nearby caves. Overlooked cave beetle's restricted geographical extent and single occurrence render it vulnerable to stochastic and catastrophic events. We lack genetic information to inform the species ability to adapt to changing conditions. As a single site endemic, the species does not have the genetic advantage of multiple sites that are likely to be genetically distinct. Overall, overlooked cave beetle's ability to withstand stochasticity and catastrophic events is currently constrained due to its single occurrence location, and its ability to adapt to changing conditions is unknown. This synthesis is predicated upon several key assumptions.

1) The species is extant in Kern's Cave No. 1.
2) There are no other occurrences of the species.

6.3.3 Future Condition

Key assumptions

Despite the lack of observations or collections in four cave visits between 2015 and 2020, we assume the species is extant in at least one known location given their cryptic nature, low survey effort, and professional opinions of VADCR karst biologists.

Impervious Surface Projections

Following Theobald *et al*. (2009), we classify the impact of impervious surface on conservation sites as follows: Unstressed (0–0.9 percent), Lightly stressed (1–4.9 percent), Stressed (5–9.9 percent), Impacted (10–24.9 percent), and Damaged (>25 percent). Under this classification, the overlooked cave beetle conservation site is currently unstressed and projected to remain unstressed under both scenarios through 2070 (Table 6.5).

Table 6.5: Percent impervious surface projections for conservation site and range of overlooked cave beetle.

Area	Mean percent impervious surface					
	ICLUS A1			ICLUS B1		
Conservation Site	2020	2040	2070	2020	2040	2070
Kerns	0.63	0.63	0.63	0.63	0.63	0.63

County Population

The VACDR report (Malabad *et al*. 2021, entire) indicates that proximity to roads is a threat for several cave beetle species. The mechanisms given include runoff of sediment, hydrocarbons, and deicing agents; trash from the roadway entering the mouth of a cave; and the possibility of spills of hydrocarbons and other hazardous materials. The severity of these threats depends on usage of roads in areas draining into the habitat of the assessed species. We use projected changes in county (human) populations as a proxy for future road usage and development potential. The population of Scott County, VA is projected to decline through 2070, which indicates road usage is likely to decline by proxy (Table 6.6).

Table 6.6: ICLUS county population projections through 2070 under the SRES A1 and B1 scenario for overlooked cave beetle.

County	County population					
	ICLUS A1			ICLUS B1		
	2020	2040	2070	2020	2040	2070
Scott	12,918	4,003	1,890	19,022	13,519	7,207

Land Ownership

Land surrounding the cave is entirely privately owned in forested residential parcels. The upper slopes of the watershed that drain toward the cave are either part of Jefferson National Forest (although U.S. Forest Service lands are outside of the boundaries of the conservation site, and therefore are unlikely to affect the cave) or in private ownership with predominantly forested land use (see figure 6.3). It is challenging to predict future changes in land use on private lands; however, the impervious surface projections are intended to capture expected changes in development within our spatial analysis units.

Viability Under Future Conditions

We do not expect overlooked cave beetle's abundance or spatial extent to change relative to their current status through 2070, and thus, nor will the species' viability. The rationale for our conclusion rests primarily on two facets. First, the conservation site for Kern's Cave No. 1 is projected to remain "unstressed" through 2070. Secondly, there is a projected decline in the human population of Scott County through 2070 which will result in lower road usage. Thus, we believe the species' viability and spatial extent will not change. Under future conditions, overlooked cave beetle will remain vulnerable to stochastic and catastrophic events and ability to adapt to changing conditions remains unknown.

6.4 *Pseudanophthalmus limicola* (Shenandoah cave beetle) Species Status Assessment

6.4.1 Taxonomy

Pseudanophthalmus limicola, commonly known as the Shenandoah or Madden's cave beetle, was first described by Jeannel in 1931 based on the collection from the type locality of Madden's Cave in Shenandoah County, VA. It is a member of the hubbardi species group.

6.4.2 Current Condition

Habitat/Range

Shenandoah cave beetle has historically been collected from four caves: Shenandoah Caverns, Shenandoah Wild Cave, and Madden's Cave in Shenandoah County, VA and Bakers Cave in Rockingham County, VA. The species was first collected from Shenandoah Caverns in 1962, in unknown quantity. No surveys have been carried out since 1962 at this location. The species was first collected at Shenandoah Wild Cave in 1962 (in unknown quantity) which represents the most recent observation at this site despite five visits between 2015 and 2021 by VADCR (Malabad *et al*. 2021, p. 53–54). The species was first collected from Madden's Cave (in unknown quantity) prior to its description in 1931 and no known surveys have been conducted at Madden's Cave since. The species was first collected from Bakers Cave in 1994 with two individuals collected, and confirmed extant in Bakers Cave with the collection of two individuals in 2016. In summary, during survey efforts between 2015 and 2021, VADCR biologists were able to survey only two of the four caves; Madden's Cave could not be located, and Shenandoah Caverns is a commercial operation that could not be accessed for sampling. At least six additional known caves and several previously unknown caves within the reported vicinity of Madden's Cave were also visited in search of cave beetle specimens, but none were observed or collected. Currently, the known species range as delineated by VADCR consists of 33.89 km^2 (13.08 mi^2). However, this range lies within a 300-mile-long exposure of Cambrio-Ordovician limestone and VADCR biologists indicate it is likely that the Shenandoah cave beetle's range is larger than what current sampling efforts suggest (Malabad *et al*. 2021, p. 54).

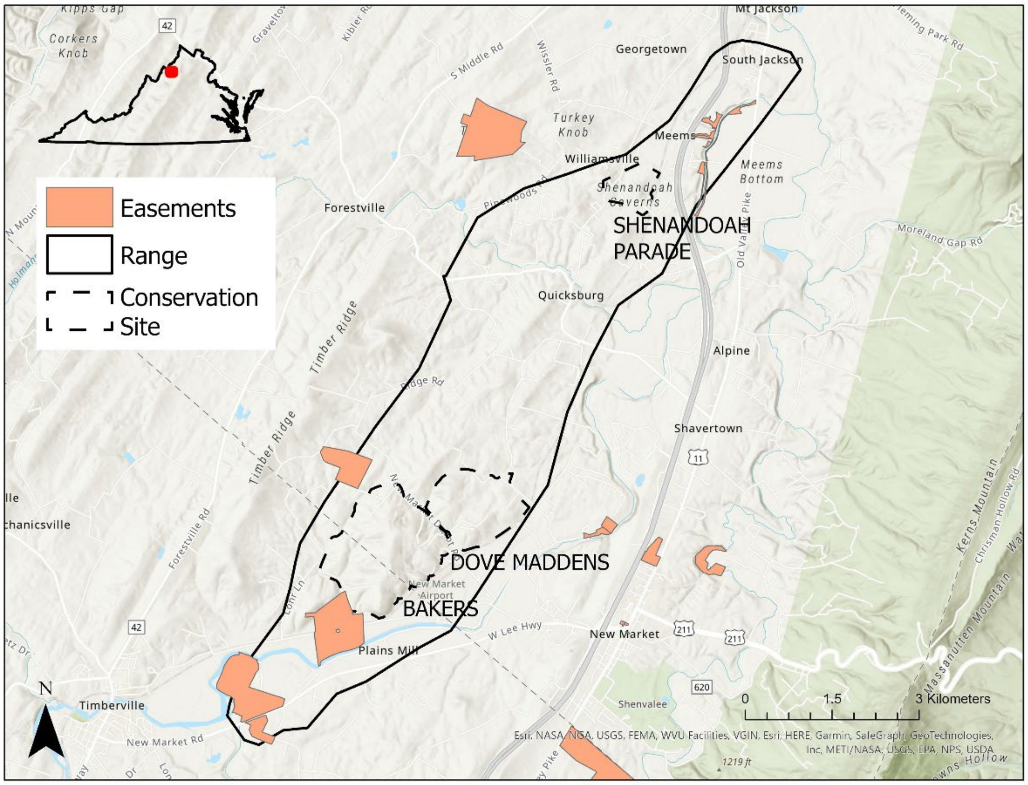

Figure 6.4: Shenandoah Cave Beetle Range and Conservation Sites

The only available information on habitat condition within the caves is provided by VADCR as brief site descriptions associated with their survey visits (2015-2021). They were only able to visit two of the four known caves for this species. Bakers Cave was visited twice in December 2016 and had damp, but not muddy substrate and evidence of several sources of organic material inputs including a dead animal carcass, root wad, and a fissure in the ceiling through which organic debris like leaf, twig and nut fragments had entered the cave. The two beetles collected from this location were both collected from under rocks on top of damp substrate near root wads. Shenandoah Wild Cave was visited three times in summer months (once in August 2015 and twice in July 2021) and twice in the winter (December 2016). During the winter visits, several areas of muddy substrate and mud banks are described along with active drip features, indicating suitable habitat was present in the cave. Habitat features were not described for the summer visits. Land use within the species range is largely agricultural. The conservation sites are smaller areas within the species range and they encompass most of the forested area that is within the range (Figure 6.4).

Analysis Units

We rely on EOs and adopt them as appropriate analysis units for this species. We consider the Shenandoah cave beetle to consist of three analysis units. Shenandoah Wild Cave and Shenandoah Caverns are grouped into a single EO due to the high likelihood of connectivity of these two caves which would enable dispersal between them. The Madden's Cave EO is considered an analysis unit despite the fact that its location is not reliable as VADCR biologists have not been able to locate and sample that cave. The Bakers Cave EO is the third analysis unit.

VADCR has established conservation sites associated with these EOs that delineate the area of influence surrounding each cave. We use three conservation sites (Shenandoah Parade, 0.55 km^2 or 0.21 mi^2; Dove Maddens, 1.64 km^2 or 0.63 mi^2; and Bakers, 3.16 km^2 or 1.22 mi^2) as the spatial units for our current and future threats analyses (Figure 6.4).

Ease of Detection

We have no information on historical abundance in any locations for this species. In 2015-2021 survey efforts, two individuals were collected from Baker's Cave over the course of two visits, and no beetles were collected from Shenandoah Wild Cave in five visits. Based on this information, the species is "readily detected" in Baker's Cave, and we have moderate confidence that it is "rarely detected" in Shenandoah Wild Cave. The two remaining sites were not visited.

Influences

The petition to list Shenandoah cave beetle cited recreational/commercial spelunking, and "general threats to cave beetles" including toxic chemical spills, pollution, trash dumping, vandalism, disruption of nutrient input, alteration of entrances, or creation of new entrances as threats to the species. We found no information to indicate that recreational spelunking, toxic chemical spills, pollution, trash dumping, vandalism, disruption of nutrient input, alteration of entrances, or creation of new entrances are likely to be influencing viability for the species currently or in the future at any of the known sites.

Shenandoah Caverns, one of the sites for the Shenandoah cave beetle, is currently operating as a commercial cave open for public tours. The effects of operating a commercial cave tour company within a cave can be numerous and depend on the frequency and size of cave tours, the extent of modifications like light and stairway/walkway installation, the proportion of the cave that is accessed by tour groups, and other factors. In general, they may include changes to air circulation, humidity, CO^2 concentration, and temperature, organic matter input, chemical pollutants, and noise (causes and effects of these alterations are synthesized by Constantin *et al*. 2021, p. 3). The installation of lights can create a growing environment for fungi and algae that would not typically be able to survive inside caves, which can in turn lead to other non-native species inhabiting those microenvironments and other downstream effects. The construction of new or additional entrances for ease of access for large groups can affect humidity, temperature, and other abiotic conditions within the cave. Visitors introduce trash, and even lint, dust, and spores from their clothing that can deteriorate speleothems and further promote the growth of fungi and algae. To manage fungi and algae that develop, cave operators often deploy biocides which have their own implications for native cave fauna, many of which are not well studied or understood.

It is unclear to what extent the many commercially related modifications that have been made may be impacting the species. Shenandoah Wild Cave is not connected to Shenandoah Caverns through a humanly passable cave passage; however, there are clear atmospheric, hydrologic and sound connections between the two. VADCR was unable to confirm that the species is still present at Shenandoah Caverns or Shenandoah Wild Cave. According to VADCR (Malabad *et al*. 2021, p. 41), site occupancy, as measured by sampling success for cave beetles in the

Shenandoah Valley is generally lower than in other regions of Virginia's karst, and VADCR's failure to verify the Shenandoah cave beetle at these sites may reflect this.

Other potential influences within the range of the species noted by VADCR include confined animal feeding operations (CAFO) (poultry farms) and proximity to the Interstate 81 development corridor. Both factors may result in the introduction of contaminants and other pollutants into the cave system; however, there is high uncertainty regarding the species response to those types of habitat alterations. Animal waste permit data from the Virginia Department of Environmental Quality indicate there are several poultry farms within the southern half of the species range; however, none are within conservation sites for the species, which are the areas within which activities have the potential to influence the known cave locations (see Figure 6.5).

Figure 6.5: CAFOs in the proximity of Shenandoah Cave Beetle Range and Conservation Sites

Conservation Efforts

The Cave Conservation Act enacted in 1966 and was established to protect the cave and karst resources of the Commonwealth. In 1978, the Virginia legislature formed the Virginia Cave Commission, and in 1979 enacted a new comprehensive Virginia Cave Protection Act that defined the role of the Commission, which is now known as the Virginia Cave Board. The Virginia Cave Board is an advisory committee and tasked the board with researching and surveying Virginia's caves, creating reports to be used by other agencies, reporting dangers or threats to caves, and increasing public awareness of the importance of caves and cave fauna. In addition, the 1979 Virginia Cave Protection Act spells out penalties for vandalism, pollution, and disturbance of endemic species, and how to go about getting permits to conduct any sort of disturbing action within a cave.

The Virginia Cave Board maintains a list of caves designated as "Significant" and three of the four caves occupied by this species are included on the list as "Significant" caves (Bakers Cave is not). "Significant" caves as designated by the Virginia Cave Board under the Cave Protection Act are treated as element occurrences by the VADCR NHP, and each significant cave lies within a Conservation Site. Any projects passing through the VADCR Office of Environmental Project Review are screened to see if they intersect conservation sites. When conservation sites are intersected, VADCR NHP staff inform the project proponent and provide guidance on protection of the associated resources that may be affected by their project, including "Significant" caves and species within. Although no legal status accompanies this designation, VADCR NHP reports success in avoiding impacts to element occurrences via this review and communication process. In addition, "Significant" caves are given priority for implementation of conservation efforts such as easements, cost-share programs, and fee simple acquisition for long-term protection.

Small portions of the species' range are under conservation easements managed by the Virginia Outdoors Foundation (VOF) and the Valley Conservation Council (VCC) (Figure 6.4). The VOF implements open-space easements on private lands that are voluntary legal agreements that limit residential, commercial, and industrial development. Specific limitations are tailored to each property individually and depend on the conservation values being protected at a given location (i.e., water quality, wildlife habitat, historic significance, scenic viewsheds, or public access; VOF 2022, unpaginated). We have no information on the specific restrictions associated with the VOF easements within the range of Shenandoah cave beetle. The mission of the VCC is to "protect the natural and cultural resources of the greater Shenandoah Valley region through land conservation, education, and experiences to preserve the life-enriching benefits our land and water provide" (VCC 2022, unpaginated). They work with private landowners to implement easements including open space easements, riparian easements, scenic easements, public recreation easements, and wildlife habitat easements. We have no information on the specifics of the VCC easements within the range of Shenandoah cave beetle.

Viability Under Current Conditions

Among the four known locations for Shenandoah cave beetle, two were visited between 2015 and 2021, and they had different ease of detection results (rare with moderate confidence, and readily observed). Despite some redundancy with three analysis units, Shenandoah cave beetle's restricted geographical extent renders it vulnerable to stochastic and catastrophic events. We lack genetic information for the species to inform an assessment of its ability to adapt to changing conditions. However, under the assumption that different caves are genetically distinct from one another, we assume the species has some genetic diversity with three distinct analysis units. Overall, Shenandoah cave beetle's ability to withstand stochasticity and catastrophic events is currently constrained given its restricted geographical range, and its ability to adapt to changing conditions is currently unknown. This synthesis is predicated upon several key assumptions.

1) There are no other occurrences of the species.
2) The species is extant in Madden's cave, Shenandoah Wild Cave, and Shenandoah Caverns.

6.4.3 Future Condition

Key assumptions

Despite the lack of observations or collections in five visits at one site, inability to locate another site, and inability to access a third site, we assume the species is extant in at least three analysis units based on the professional opinions of VADCR karst biologists.

Impervious Surface Projections

Following Theobald *et al*. (2009), we classify the impact of impervious surface on ranges and conservation sites as follows: Unstressed (0–0.9 percent), Lightly stressed (1–4.9 percent), Stressed (5–9.9 percent), Impacted (10–24.9 percent), and Damaged (>25 percent). Under this classification, the Shenandoah cave beetle conservation sites are all currently lightly stressed and projected to remain lightly stressed under both scenarios through 2070 (Table 6.7).

Table 6.7: Percent impervious surface projections for conservation sites of Shenandoah cave beetle.

Area	**Mean percent impervious surface**					
	ICLUS A1			**ICLUS B1**		
Conservation Site	**2020**	**2040**	**2070**	**2020**	**2040**	**2070**
Shenandoah Parade	3.10	3.10	3.10	3.10	3.10	3.10
Dove Maddens	2.06	2.06	2.06	2.06	2.06	2.06
Bakers	1.08	1.08	1.08	1.08	1.08	1.08

County Population

The VACDR report (Malabad *et al*. 2021, entire) indicates that proximity to roads is a threat for several cave beetle species. The mechanisms given include runoff of sediment, hydrocarbons, and deicing agents; trash from the roadway entering the mouth of a cave; and the possibility of spills of hydrocarbons and other hazardous materials. The severity of these threats depends on usage of roads in areas draining into the habitat of the assessed species. We use projected changes in county (human) populations as a proxy for future road usage and development potential. The populations of both Shenandoah and Rockingham Counties, are projected to decline through 2070, which indicates road usage is likely to decline by proxy (Table 6.8).

Table 6.8: ICLUS county population projections through 2070 under the SRES A1 and B1 scenario for Shenandoah cave beetle.

County	**County population**					
	ICLUS A1			**ICLUS B1**		
	2020	**2040**	**2070**	**2020**	**2040**	**2070**
Rockingham	71,504	62,921	40,514	74,653	73,335	64,383
Shenandoah	33,382	22,882	8,607	37,647	33,652	26,112

Land Ownership

Land within the species' range is largely privately owned and agricultural. Within the conservation sites, there are higher proportions of forested areas. It is challenging to predict future changes in land use on private lands; however, the impervious surface projections are intended to capture expected changes in development within our spatial analysis units.

Viability Under Future Conditions

We do not expect Shenandoah cave beetle's abundance or spatial extent to change relative to their current status through 2070, and thus, nor will the species' viability. The rationale for our conclusion rests primarily on two facets. First, all three conservation sites for the species are projected to remain "lightly stressed" through 2070. Secondly, there is a projected decline in the human populations of both Rockingham and Shenandoah Counties through 2070 which will result in lower road usage. Thus, we believe the species' viability and spatial extent will not change. Under future conditions, Shenandoah cave beetle will remain vulnerable to stochastic and catastrophic events and its ability to adapt to shifting and novel conditions remains unknown.

6.5 *Pseudanophthalmus cordicollis* (Little Kennedy cave beetle) Species Status Assessment

6.5.1 Taxonomy

Pseudanophthalmus cordicollis, commonly known as the Little Kennedy cave beetle, was first described by Barr in 1981 based on collections from the type locality Little Kennedy Cave in Wise County, Vain 1970. It is a member of the jonesi species group.

6.5.2 Current Condition

Habitat/Range

The Little Kennedy cave beetle has been collected from eight caves all within Wise County, VA. Little Kennedy Cave, Omega Cave, and Wildcat Saltpetre Cave were known locations before the 2015-2021 survey efforts by VADCR. Additional Little Kennedy cave beetle specimens were collected from Abe's Abyss, Big Kennedy Cave, Kelly Cave, Parsons Cave, and Wildcat Cavern between 2015 and 2021 (Malabad *et al*. 2021, p. 21–23). The eight caves are grouped into five EOs (described in more detail below). Little Kennedy and Big Kennedy Caves are grouped to form one EO. Little Kennedy cave beetle was first observed in Little Kennedy cave in 1970, observed again in the mid-1990s, and most recently collected in 2017. The species was collected for the first time from Big Kennedy Cave in 2017. The most recent survey at both locations in 2020 did not result in any additional observations of Little Kennedy Cave beetles. Omega and Parsons caves are grouped into one EO. The species was first collected from Omega Cave in 2003, and again in 2016 and 2017. The first and only collection of the species from Parsons Cave was in 2018. Wildcat Cavern and Wildcat Saltpetre cave are grouped into one EO. Records for the Wildcat caves are unclear as the names of the caves have sometimes been confused in field notes. The first collection of the species from Wildcat Saltpetre cave was likely prior to 2004 and may have actually included observations in both caves (T. Malabad, VADCR, email to K. Maison, Service, 11/21/22). There have been no new surveys in Wildcat Saltpetre cave. The most recent (and only confirmed) collection of the species from Wildcat Cavern was in 2016. Kelly Cave represents a distinct EO and the first and only collection of Little Kennedy cave beetle from this site was in 2017. Abe's Abyss represents a distinct EO and the first and only time the species has been collected from this site was in 2021.

Caves with Little Kennedy cave beetle records are split between two separate belts of limestone. Big Kennedy, Little Kennedy, Omega, and Kelly Caves lie within a single belt of Greenbrier limestone exposed along Cliff and Powell Mountains. Wildcat Cavern, Wildcat Saltpetre Cave, and Abe's Abyss are in a Silurian-aged Hancock Formation in the valley below the Greenbriar belt. A significant talus pile occupies the space between the two limestone exposures, providing a possible migration route for the subterranean species (Malabad *et al*. 2021, p. 23). Currently, the known species' range as delineated by VADCR consists of 89.3 km^2 (34.48 mi^2) (Figure 6.6).

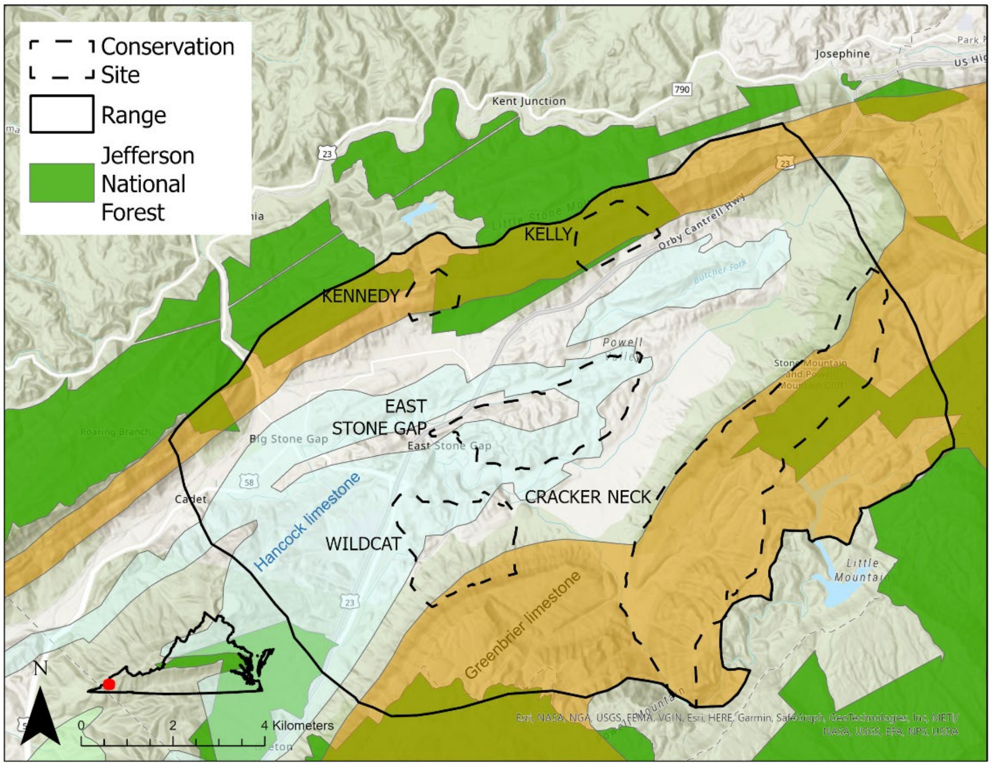

Figure 6.6: Little Kennedy Cave Beetle Range and Conservation Sites

The only available information on habitat condition within the caves is provided by VADCR as brief site descriptions associated with their survey visits (2015-2021). They were able to visit seven of the eight known caves for this species but did not provide specific habitat details for all visits. Habitat features noted include a large pool with mudbanks in Big Kennedy Cave, an active drip and damp sections of the stream and a small stream passage in Kelly Cave, a large flowstone and big pool with wet, decaying logs in Little Kennedy Cave, rimstone dam complexes and flowstone features in Parson's Cave, numerous mud pools, flowstones, and active formations in Omega Cave, and in Wildcat Cavern, a large intermittent stream in times of high water full of large quantities of organic debris from the surface including large logs that completely block the passage further downstream and much smaller material such as leaves and other decaying vegetation. Mud and cobble banks are also abundant in Wildcat Cavern (Malabad *et al*. 2021, p. 21–23).

A proportion of the land within the Greenbriar limestone part of the species' range is in the Jefferson National Forest (see figure 6.6). The portion of the species' range in the Hancock limestone formation consists of privately owned lands with a combination of forested and agricultural land uses.

Analysis Units

Based on VADCR EOs, we consider the Little Kennedy cave beetle to consist of five analysis units: Kelly Cave, Wildcat Cavern and Wildcat Saltpetre Cave, Omega Cave and Parson's Cave, Little Kennedy and Big Kennedy Cave, and Abe's Abyss (Figure 6.6).

VADCR has established conservation sites associated with these EOs that delineate the area of influence surrounding each cave. We used VADCR-established conservation sites as the spatial units of threats analysis for each analysis unit; Wildcat (2.91 km^2, 1.12 mi^2), Kennedy (0.56 km^2, 0.22 mi^2), Cracker Neck (10.49 km^2, 4.05 mi^2), East Stone Gap (3.63 km^2, 1.40 mi^2), and Kelly (1.12 km^2, 0.43 mi^2) conservation sites were analyzed for this species.

Ease of Detection

We have no information on historical abundance in any location for this species. In 2015-2021 survey efforts, 14 individuals were collected from seven caves; results for individual caves and analysis units are in Table 6.9.

Table 6.9: Ease of Detection for Little Kennedy Cave Beetle Analysis Units

Cave (Grouped into EOs)	No. of Visits	Total No. Confirmed Individuals	Average Detection per Visit	Ease of Detection	Confidence
Little Kennedy	3	2	0.67	infrequent	mod
Big Kennedy	3	1	0.33		
Kelly*	4	1	0.25	infrequent	low
Omega*	4	4	1.00	infrequent	mod
Parsons	6	1	0.17		
Abe's Abyss	1	2	2.00	readily	NA
Wildcat Cavern	1	3	3.00	readily	NA
Wildcat Saltpetre	0	N/A	N/A		

*Kelly Cave and Omega Cave have additional collections that are pending ID and were not included in these calculations.

Influences

The petition to list the species cited recreational spelunking, federal oil and gas development, and mountaintop removal coal mining as potential threats to the species. We have no information indicating recreational spelunking occurs within caves occupied by Little Kennedy cave beetle at a magnitude that would influence viability for the species. There are no active coal mining permits within the range or conservation sites for the species. The petition cited the U.S. Forest Service's 2004 Revised Land and Resources Management Plan regarding the potential for federal oil and gas development within the watersheds near Little Kennedy cave beetle locations. However, Little Kennedy cave beetle caves formed in the Greenbrier limestone have forested land use in their watersheds and Kelly and Omega caves have the additional protection of inclusion in U.S. Forest Service Special Biological Areas which would preclude oil and gas development. Special Biological Areas serve "as a network of core areas for conservation of significant elements of biological diversity. The goal of designation and management of these areas is to perpetuate or increase existing individual plant or animal species and communities that are of national, regional, or state significance and identified as threatened, endangered, sensitive, or locally rare" (USFS 2044, p. 3-27). The lower section of Omega Cave is part of the Powell Mountain Karst Preserve, which is owned and administered by the Cave Conservancy of the Virginias. The mission of the Cave Conservancy of the Virginias is to promote and facilitate the conservation, management, knowledge, and acquisition of cave and karst resources in Virginia and West Virginia (CCV 2022). The Kennedy caves on Stone Mountain underlie a forested area that is privately owned and was left untouched during a clear-cut harvest by the landowner (Malabad *et al*. 2021, p. 24). Though this harvest did not demonstrably affect the beetles or habitat in either Kennedy cave, it is unclear what effects future actions by the landowner may have at these locations. Almost half of the conservation site for the Kennedy caves is in Jefferson National Forest.

The sites in the Hancock limestone occur on privately owned lands. Wildcat Saltpetre Cave has a history of fuel oil contamination from a nearby tank yard. Although this issue was resolved, its long-term impact on the cave is unknown. Nearby Wildcat Cavern is described by VADCR (2021) as "highly degraded." Wildcat Creek flows north for over 4.82 km (3 mi) along the east side of U.S. Route 23 before flowing through two 3 m (6 ft) diameter culverts under the railroad and into the entrance of Wildcat Cavern. When the Wildcat Cavern beetle specimens were collected, VADCR staff were able to proceed only about 152 m (499 ft) into the main cave before encountering a plug of trash that filled the passage. Of additional concern are the proximity to both U.S. Route 23 and the railroad and the associated potential for the introduction of contaminants directly into Wildcat Cavern via runoff or a catastrophic spill (Malabad *et al*. 2021, p. 24). Despite these conditions, Wildcat Cavern had the highest rate of detection among the Little Kennedy cave beetle sites that were visited, underscoring the uncertainty associated with the species response to various types of habitat degradation.

Conservation Efforts

The Cave Conservation Act enacted in 1966 and was established to protect the cave and karst resources of the Commonwealth. In 1978, the Virginia legislature formed the Virginia Cave Commission, and in 1979 enacted a new comprehensive Virginia Cave Protection Act that defined the role of the Commission, which is now known as the Virginia Cave Board. The Virginia Cave Board is an advisory committee and tasked the board with researching and surveying Virginia's caves, creating reports to be used by other agencies, reporting dangers or threats to caves, and increasing public awareness of the importance of caves and cave fauna. In addition, the 1979 Virginia Cave Protection Act spells out penalties for vandalism, pollution, and disturbance of endemic species, and how to go about getting permits to conduct any sort of disturbing action within a cave.

The Virginia Cave Board also maintains a list of caves designated as "Significant." Seven of the eight known caves for this species have been given the "Significant" designation by the Board (Abe's Abyss is the exception, with no designation). "Significant" caves as designated by the Virginia Cave Board under the Cave Protection Act are treated as element occurrences by the VADCR NHP, and each significant cave lies within a Conservation Site. Any projects passing through the VADCR Office of Environmental Project Review are screened to see if they intersect conservation sites. When conservation sites are intersected, VADCR NHP staff inform the project proponent and provide guidance on protection of the associated resources that may be affected by their project, including “Significant” caves and species within. Although no legal status accompanies this designation, VADCR NHP reports success in avoiding impacts to element occurrences via this review and communication process. In addition, “Significant” caves are given priority for implementation of conservation efforts such as easements, cost-share programs, and fee simple acquisition for long-term protection.

As noted above, both Kelly and Omega caves have the additional protection of inclusion in U.S. Forest Service Special Biological Areas. The lower section of Omega Cave is part of the Powell Mountain Karst Preserve, which is owned by the Cave Conservancy of the Virginias.

Viability Under Current Conditions

Little Kennedy cave beetle is known from eight locations grouped into five analysis units that span two different-aged limestone deposits. This level of redundancy confers some ability to withstand stochasticity and catastrophic events, however all five analysis units are confined to an area of 89.3 km^2 (34.48 mi^2). In two analysis units, we have moderate confidence that the species is infrequently observed, which may indicate low density and therefore low resilience in those locations. We lack genetic information to inform an assessment of the species’ ability to adapt to changing conditions. However, under the assumption that different analysis units are genetically distinct, the isolation of five different analysis units confers some genetic diversity at the species level. In addition, Balogh *et al*. (2020, p. 6) found a correlation between genetic diversity of cave invertebrate populations and cave length. The Omega cave system is one of the longest cave systems in the eastern U.S. at over 47 km in length, which may indicate the potential for significant genetic diversity at this analysis unit. Overall, Little Kennedy cave beetle’s ability to cope with stochasticity and catastrophic events is higher than that of a single site endemic, but still limited given its restricted geographic range. The species’ ability to adapt to shifting and novel conditions is unknown. This synthesis is predicated upon the assumption that there are no other occurrences of the species.

6.5.3 Future Condition

Impervious Surface Projections

Following Theobald *et al*. 2009), we classify the impact of impervious surface on conservation sites as follows: Unstressed (0–0.9 percent), Lightly stressed (1–4.9 percent), Stressed (5–9.9 percent), Impacted (10–24.9 percent), and Damaged (>25 percent). Under this classification, the Little Kennedy cave beetle conservation sites are all currently lightly stressed and projected to remain lightly stressed under both scenarios through 2070 (Table 6.10).

Table 6.10: Percent impervious surface projections for conservation sites and range of Little Kennedy cave beetle.

Area	**Mean percent impervious surface**					
	ICLUS A1			**ICLUS B1**		
Conservation Site	**2020**	**2040**	**2070**	**2020**	**2040**	**2070**

Kelly	1.30	1.30	1.30	1.40	1.40	1.40
East Stone Gap	3.41	3.41	3.41	3.41	3.41	3.41
Kennedy	3.00	3.00	3.00	3.00	3.00	3.00
Wildcat	3.89	3.89	3.89	3.89	3.89	3.89
Cracker Neck	1.17	1.17	1.17	1.17	1.17	1.17

County Population

The VACDR report (Malabad *et al*. 2021, entire) indicates that proximity to roads is a threat for several cave beetle species. The mechanisms given include runoff of sediment, hydrocarbons, and deicing agents; trash from the roadway entering the mouth of a cave; and the possibility of spills of hydrocarbons and other hazardous materials. The severity of these threats depends on usage of roads in areas draining into the habitat of the assessed species. We use projected changes in county (human) populations as a proxy for future road usage and development potential. The populations of both Wise and Scott Counties, are projected to decline through 2070, which indicates road usage is likely to decline by proxy (Table 6.11).

Table 6.11: ICLUS county population projections through 2070 under the SRES A1 and B1 scenario for Little Kennedy cave beetle.

County	**County population**					
	ICLUS A1			**ICLUS B1**		
	2020	**2040**	**2070**	**2020**	**2040**	**2070**
Wise	29,257	13,991	2,060	38,403	30,890	19,309
Scott	12,918	4,003	1,890	19,022	13,519	7,207

Land Ownership

As noted above, Little Kennedy cave beetle sites formed in the Greenbrier limestone all have forested land use in their watersheds. Both Kelly and Omega caves have the additional protection of inclusion in U.S. Forest Service Special Biological Areas. The lower section of Omega Cave is part of the Powell Mountain Karst Preserve, owned by the Cave Conservancy of the Virginias. The sites in the Hancock limestone occur on privately owned lands. While it is challenging to predict future changes in land use on private lands, the impervious surface projections are intended to capture expected changes in development within our spatial units of analysis.

Viability Under Future Conditions

We do not expect Little Kennedy cave beetle's abundance or spatial extent to change relative to their current status through 2070, and thus, nor will the species' viability. The rationale for our conclusion rests primarily on three facets. First, all five conservation sites for the species are projected to remain "lightly stressed" through 2070. Secondly, there is a projected decline in the human populations of both Wise and Scott counties through 2070 which will result in lower road usage. Thus, we believe the species' viability and spatial extent will not change. Third, occurrence in eight locations grouped into five analysis units confers some ability to withstand stochastic and catastrophic events that may affect one or more of the analysis units. Despite our expectation that viability is unlikely to change significantly, the species will remain vulnerable to stochastic and catastrophic events in at least two analysis units given its possibly low resilience in those units.

6.6 *Pseudanophthalmus holsingeri* (Holsinger's cave beetle) Species Status Assessment

6.6.1 Taxonomy

Pseudanophthalmus holsingeri, commonly known as Holsinger's cave beetle, was first described by Barr in 1965 based on the specimens collected by John Holsinger in August 1962 from the type locality and only known location for this species, Young-Fugate Cave in Lee County, VA. It is a member of the englehardti species group.

6.6.2 Current Condition

Background

Holsinger's cave beetle is being assessed as a discretionary action initiated by the Service. This species, along with all other cave beetles in Virginia, was listed by the Service as a candidate species in the 1980s. It was subsequently removed from the candidate species list in 2005 with the rationale that insufficient information exists on biological vulnerability and threats to support listing, and because the two previous major threats had been eliminated through conservation efforts (70 FR 24885). In subsequent years, State partners at VADCR have conducted additional survey efforts for the species. As a result of working with state partners, the Service included the species in the *National Domestic Listing Workplan FY22-27* (March 2022 version) with a scheduled fiscal year 2023 12-month finding (USFWS 2022, unpaginated).

Habitat/Range

Holsinger's cave beetle has been collected only from Young-Fugate Cave in Lee County, VA. It was first collected in 1962, and the collection totaled eight individuals. In 1965 10-20 beetles were observed (Hobson 2001), one individual was observed in 1999, and 13 individuals were observed 2000. During 2015-2019 survey efforts, VADCR biologists confirmed it remains extant with the collection of 13 individuals and observation of 36 additional beetles (Malabad *et al*. 2021, p. 35). Currently, the known species range as delineated by VADCR consists of the 0.26 km^2 (0.1 mi^2) footprint of a single cave (Young-Fugate Cave) (Figure 6.7). The species' range may extend southwest within the Powell Valley across the border into Tennessee, as well as east/northeast within the Powell Valley in Virginia. However, for now it should be treated as a single site endemic (Malabad *et al*. 2021, p. 37).

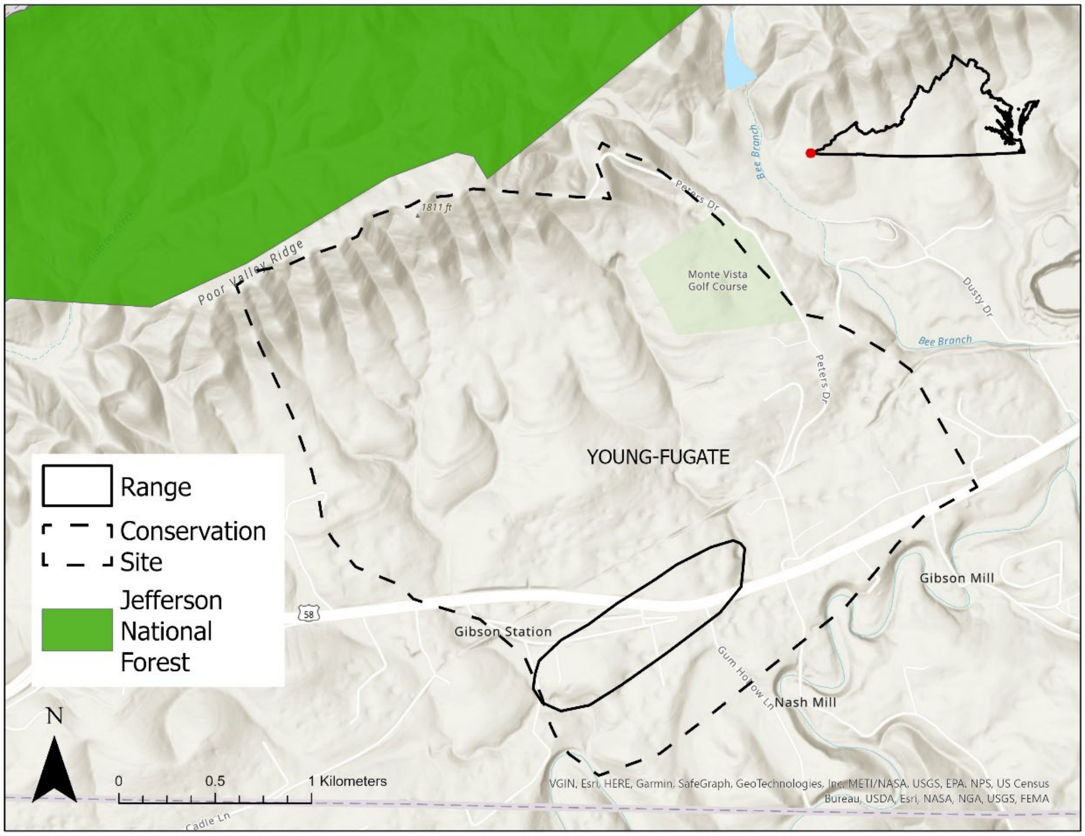

Figure 6.7: Holsinger's Cave Beetle Range and Conservation Site

Hobson (2001, p. 5) describes the stream system with Young-Fugate Cave as dynamic, with notable seasonal shifts in water quantity. Hobson (2001, p. 5) also described notable influxes of nutrients from the cave stream during survey periods, coarse woody debris during periods of high water, and raccoon feces present during all surveys in 2000-2001. VADCR provided brief site descriptions associated with their survey visits (2015-2019). In August 2015, plentiful habitat including mud banks and detritus was observed; however no beetles were observed or collected despite leaving baited traps overnight. In September 2016, bioturbated mud banks considered "really good" habitat were observed; several mud banks and cobbles, and a decaying log were all recorded as places that beetles were either observed or collected (Malabad *et al*. 2021, p. 36). VADCR noted that the lower downstream end of the cave seems to have higher concentrations of cave beetles, but they have been observed throughout the cave (Malabad *et al*. 2021, p. 36). The cave entrance is located on private land, and the landowners strictly prohibit entry into the cave.

Analysis Units

We consider Holsinger's cave beetle to consist of a single analysis unit in Young-Fugate Cave in Lee County, VA.

VADCR has established a conservation site associated with this EO that delineates the area of influence surrounding the cave. We used the VADCR-established conservation site as the spatial unit of threats analysis; for Holsinger's cave beetle, that includes the Young Fugate conservation site (4.58 km^2 or 1.77 mi^2) (Figure 6.7).

Ease of Detection

In the absence of information on absolute abundance or density, we focus on ease of detection for Holsinger's cave beetle. Results from a survey conducted in August 2000 totaled 13 specimens (Hobson 2001, p. 4). This number is comparable to earlier surveys conducted in August of 1962 (n = 8) and 1965 (n = 10-20) (Hobson 2001, p. 4). Conversely, surveys conducted by Barr in November 1962 and March 1964 yielded no beetles, and surveys conducted by Holsinger after 1965 produced only a few or no specimens; high water thwarted survey efforts in November 1999, but one specimen was collected. One or two beetles were seen each time in surveys in April, May, and June 2000 (Hobson 2001, p. 4). In the 2015 to 2021 survey efforts by VADCR, 13 individuals were collected and an additional 36 beetles were observed in Young-Fugate Cave over the course of three visits from 2015 to 2019. Based on these surveys, Holsinger's cave beetle is "readily observed." Of note, however, is that detections were not spread evenly across the three cave visits with 12 of the 13 collections and the additional 36 observations occurring during one visit in mid-September 2016. One additional beetle was collected in July of 2019. Hobson (2001, p. 5) summarized the seasonality of available survey results through 2001 and noted that more beetles tend to be found in late summer (August), indicating potential seasonal population fluctuations. This aligns with Barr's assumption that due to the timing of the reproductive cycle, new adults are recruiting into the population in late summer/early fall (Lewis 2001a, b, and c, p. 4; Lewis 2002, p. 5). Other factors may include more challenging survey conditions (i.e., high water) in the spring and late fall, and more abundant prey items associated with detritus from spring and summer flooding events (Hobson 2001, p. 5). The surveyors note that this cave is regularly monitored for gray bat usage by VADCR-DNH and additional beetles have been observed in this cave without collection outside of the dedicated surveys.

Influences

Young-Fugate Cave runs obliquely beneath U.S. Highway 58, a four-lane road that is the main thoroughfare connecting Tennessee to Virginia, through the Cumberland Gap mountain pass. In 1991, the cave was contaminated by petroleum product leaking from an underground storage tank at a gas station above the cave (Malabad *et al*. 2021, p. 36). The gas station is no longer present and the storage tanks were replaced as noted below under Conservation Efforts. The cave's proximity to U.S. Highway 58 introduces the potential for road-related contaminants to enter the cave without much filtration, as well as the potential catastrophic effects of a major spill nearby. However, we do not have a clear understanding of the species' response to contaminants, or the likelihood of minor or major contamination events at this site. This uncertainty is highlighted by the relatively high density of cave beetles still present in the cave despite prior contamination from leaking petroleum storage tanks.

Conservation Efforts

Holsinger's cave beetle is currently listed by the Virginia Department of Agriculture and Consumer Services as an endangered species under the Virginia Endangered Plant and Insect Species Act. Prohibited acts for threatened and endangered species under the Virginia Endangered Plant and Insect Species Act include "to dig, take, cut, process, or otherwise collect, remove, transport, possess, sell, offer for sale, or give away any species native to or occurring in the wild in the Commonwealth that are listed in this chapter or the regulations adopted hereunder as threatened or endangered, other than from such person's own land, except in accordance with the provisions of this chapter or the regulations adopted hereunder" (Code of Virginia, Section 3.2-1003).

The Cave Conservation Act enacted in 1966 and was established to protect the cave and karst resources of the Commonwealth. In 1978, the Virginia legislature formed the Virginia Cave Commission, and in 1979 enacted a new comprehensive Virginia Cave Protection Act that defined the role of the Commission, which is now known as the Virginia Cave Board. The Virginia Cave Board is an advisory committee and tasked the board with researching and surveying Virginia's caves, creating reports to be used by other agencies, reporting dangers or threats to caves, and increasing public awareness of the importance of caves and cave fauna. In addition, the 1979 Virginia Cave Protection Act spells out penalties for vandalism, pollution, and disturbance of endemic species, and how to go about getting permits to conduct any sort of disturbing action within a cave.

The Virginia Cave Board also maintains a list of caves designated as "Significant." Young-Fugate Cave was designated "Significant" by the Virginia Cave Board in 1980 (Hubbard and Balfour 1993, p.1). "Significant" caves as designated by the Virginia Cave Board under the Cave Protection Act are treated as element occurrences by the VADCR NHP, and each significant cave lies within a Conservation Site. Any projects passing through the VADCR Office of Environmental Project Review are screened to see if they intersect conservation sites. When conservation sites are intersected, VADCR NHP staff inform the project proponent and provide guidance on protection of the associated resources that may be affected by their project, including "Significant" caves and species within. Although no legal status accompanies this designation, VADCR NHP reports success in avoiding impacts to element occurrences via this review and communication process. In addition, "Significant" caves are given priority for implementation of conservation efforts such as easements, cost-share programs, and fee simple acquisition for long-term protection.

Historically, there have been threats to the cave system that have been removed through policy action. In 1991, there was a proposal to realign part of U.S. Route 58, near the Young-Fugate cave, which would have directed runoff into the entrance (Hubbard and Balfour 1993, p.1). Around the same time, there were reports of petroleum leakage and fumes in the cave and sediments originating from underground storage tanks from the nearby gas station. The storage tanks were replaced in 1992, remedying the problem, though previous contamination likely remains in the sediment within the cave.

Despite the protection afforded by the Virginia Cave Protection Act, there have been reports of trash in and around the cave, along with other non-point source pollution (Malabad *et al*. 2021, p. 36).

Viability Under Current Conditions

Holsinger's cave beetle was readily detected at its single known location based on surveys from 2015-2019. Despite contamination and seasonal flooding events over the last five decades, the survey results from 2015-2019 are comparable to those from 2000-2001 and from the 1960s. Survey results over time suggest the population of Holsinger's cave beetle in Young Fugate cave may fluctuate seasonally but has potentially been relatively stable over the long term. The species' restricted geographical extent and single occurrence render it vulnerable to stochastic and catastrophic events. We lack genetic information to inform an assessment of the species' ability to adapt to changing conditions. As a single site endemic, the species does not have the genetic advantage of multiple sites that are likely to be genetically distinct. Overall, Holsinger's cave beetle's ability to withstand stochasticity and catastrophic events is currently constrained due to its single occurrence location, and its ability to adapt to changing conditions is unknown. This synthesis is predicated upon the assumption that there are no other occurrences of the species.

6.6.3 Future Condition

Impervious Surface Projections

Following Theobald *et al*. (2009), we classify the impact of impervious surface on the species' conservation site as follows: Unstressed (0–0.9 percent), Lightly stressed (1–4.9 percent), Stressed (5–9.9 percent), Impacted (10–24.9 percent), and Damaged (>25 percent). Under this classification, the Holsinger's cave beetle conservation site is currently lightly stressed and projected to remain lightly stressed under both scenarios through 2070 (Table 6.12).

Table 6.12: Percent impervious surface projections for conservation site of Holsinger's cave beetle

Area	**Mean percent impervious surface**					
	ICLUS A1			**ICLUS B1**		
Conservation Site	**2020**	**2040**	**2070**	**2020**	**2040**	**2070**
Young-Fugate	1.35	1.35	1.35	1.35	1.35	1.35

County Population

The VADCR report (Malabad *et al*. 2021, entire) indicates that proximity to roads is a threat for several cave beetle species. The mechanisms given include runoff of sediment, hydrocarbons, and deicing agents; trash from the roadway entering the mouth of a cave; and the possibility of spills of hydrocarbons and other hazardous materials. The severity of these threats depends on usage of roads in areas draining into the habitat of the assessed species. We use projected changes in county (human) populations as a proxy for future road usage and development potential. The population of Lee County, VA is projected to decline through 2070, which indicates road usage is likely to decline by proxy (Table 6.13).

Table 6.13: ICLUS county population projections through 2070 under the SRES A1 and B1 scenario for Holsinger's cave beetle.

County	**County population**					
	ICLUS A1			**ICLUS B1**		
	2020	**2040**	**2070**	**2020**	**2040**	**2070**
Lee	13,416	4,378	2,067	20,431	15,035	8,480

Land Ownership

As noted above, the cave entrance is located on privately owned property and the current landowners strictly prohibit entrance into the cave, with the exception of working with VADCR.

It is challenging to predict future conditions on private lands given the potential for ownership to change and for private landowners to change their land management practices; however, impervious surface projections are intended to capture expected changes in terms of development within the spatial extent of the species' conservation site.

Viability Under Future Conditions

We do not expect Holsinger's cave beetle's abundance or spatial extent to change relative to their current status through 2070, and thus, nor will the species' viability. The rationale for our conclusion rests primarily on two facets. First, the conservation site is projected to remain lightly stressed through 2070. Secondly, there is a projected decline in the human population in Lee County, indicating less road usage. Under future conditions, Holsinger's cave beetle will remain vulnerable to stochastic and catastrophic events and its ability to adapt to shifting and novel conditions remains unknown.

6.7 *Pseudanophthalmus hubrichti* (Hubricht's cave beetle) Species Status Assessment

6.7.1 Taxonomy

Pseudanophthalmus hubrichti, commonly known as Hubricht's cave beetle, was first described by Valentine in 1948 based on collections from the type locality, Daugherty Cave, in 1939. It is a member of the hubrichti species group.

6.7.2 Current Condition

Habitat/Range

Hubricht's cave beetle was historically known from only Daugherty Cave in Russell County, VA but was collected from a second location in 2020 also in Russell County, Bundy's Cave No. 2 representing a large range expansion. Currently, the known species range as delineated by VADCR consists of 19.18 km^2 (17.41 mi^2; Figure 6.8). With the discovery of the species at Bundy Cave No. 2, additional caves in the Sinking Creek/Grays Water Cave basin (Russell County, VA) should be considered likely locations for additional populations of Hubricht's cave beetle. Bundy's Cave No. 2 represents a site near the upstream end of the drainage. Daugherty Cave is at the downstream end of the drainage of that basin. Caves in the interior of this drainage have not been inventoried for cave beetles. Sampling at these locations is recommended (Malabad *et al*. 2021, p. 45).

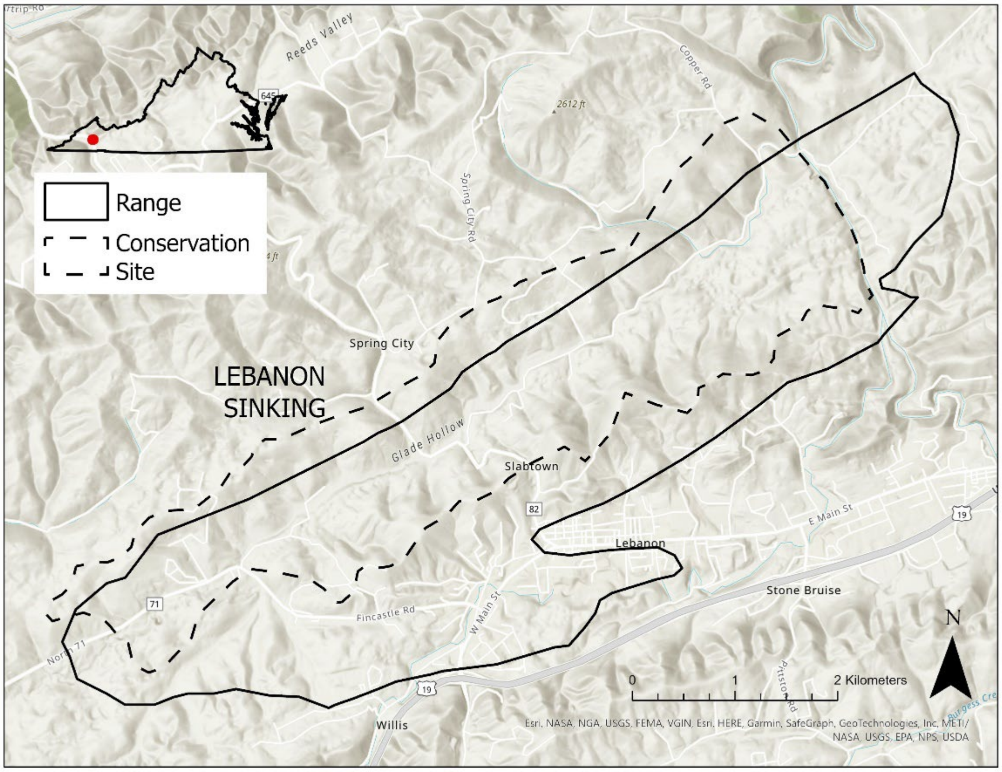

Figure 6.8: Hubricht's Cave Beetle Range and Conservation Site

The only available information on habitat condition within the caves is provided by VADCR as brief site descriptions associated with their survey visits. In Bundy's Cave No. 2, beetles were collected from underneath rocks immediately adjacent to a wet section of the cave containing a drip pool and a muddy floor. In Daugherty Cave, suitable habitat consisting of active drips, mud banks, muddy pools, decayed wood, and cobble piles were observed (Malabad *et al*. 2021, p. 44).

Private ownership with agricultural land use dominates within the range of Hubricht's cave beetle. A large portion of the species' range consists of open pastures used for livestock and hay production. State Routes 71 and 82 also drain into the recharge area for this cave system.

Analysis Units

Based on VADCR-established EOs, we consider Hubricht's cave beetle to consist of two analysis units: Daugherty Cave and Bundy's Cave No. 2 (Figure 6.8). VADCR has established a conservation site associated with these EOs that delineates the area of influence surrounding the caves. We used VADCR-established conservation sites as the spatial unit of threats analysis for each analysis unit. Both EOs for the species are within the same conservation site so we use the Lebanon Sinking conservation site (12.37 km^2 or 4.78 mi^2) as our spatial unit for threats analyses.

Ease of Detection

In the absence of information on absolute abundance or density, we focus on ease of detection for Hubricht's cave beetle. During the collection of type specimens in 1939, three individuals were collected (Valentine 1948, p. 13–14). Five individuals were collected from Daugherty Cave in two visits in 2017 (average detection of 2.5 per visit), and two individuals were collected from Bundy's Cave No. 2 in two visits between 2018 and 2020 (average detection of one per visit). Both analysis units are in the "readily observed" category with an average of one or more individuals detected per visit.

Influences

The petition cited recreational spelunking, mountaintop removal coal mining, and "general threats to cave beetles" including toxic chemical spills, pollution, trash dumping, vandalism, disruption of nutrient input, alteration of entrances, or the creation of new entrances as potential threats to the species. We found no information to indicate that recreational spelunking, toxic chemical spills, pollution, trash dumping, vandalism, disruption of nutrient input, alteration of entrances, or creation of new entrances are likely to be influencing viability for the species currently or in the future. There are no active coal mining permits within the range or conservation site for this species.

As noted above, agricultural land use is the dominant land use within the range of Hubricht's cave beetle. A large portion of the species range consists of open pastures used for livestock and hay production. Low intensity agriculture is considered largely compatible with cave beetle persistence (USFWS-VADCR 10/25/2021 pers. comm.). State Routes 71 and 82 also drain into the recharge area for this cave introducing the potential for road-related contaminants to enter the cave without much filtration, as well as the potential catastrophic effects of a spill. However, we do not have a clear understanding of the species' response to contaminants, or the likelihood of minor or major contamination events at this site.

Conservation Efforts

The Cave Conservation Act enacted in 1966 and was established to protect the cave and karst resources of the Commonwealth. In 1978, the Virginia legislature formed the Virginia Cave Commission, and in 1979 enacted a new comprehensive Virginia Cave Protection Act that defined the role of the Commission, which is now known as the Virginia Cave Board. The Virginia Cave Board is an advisory committee and tasked the board with researching and surveying Virginia's caves, creating reports to be used by other agencies, reporting dangers or threats to caves, and increasing public awareness of the importance of caves and cave fauna. In addition, the 1979 Virginia Cave Protection Act spells out penalties for vandalism, pollution, and disturbance of endemic species, and how to go about getting permits to conduct any sort of disturbing action within a cave.

The Virginia Cave Board maintains a list of caves designated as "Significant." Daugherty's Cave is included as a "Significant" cave, while Bundy's Cave No. 2 has no designation. "Significant" caves as designated by the Virginia Cave Board under the Cave Protection Act are treated as element occurrences by the VADCR NHP, and each significant cave lies within a Conservation Site. Any projects passing through the VADCR Office of Environmental Project Review are screened to see if they intersect conservation sites. When conservation sites are intersected, VADCR NHP staff inform the project proponent and provide guidance on protection of the associated resources that may be affected by their project, including "Significant" caves and species within. Although no legal status accompanies this designation, VADCR NHP reports success in avoiding impacts to element occurrences via this review and communication process. In addition, "Significant" caves are given priority for implementation of conservation efforts such as easements, cost-share programs, and fee simple acquisition for long-term protection.

Viability Under Current Conditions

Hubricht's cave beetle was readily detected at both analysis units based on surveys from 2017-2020. The species' restricted geographical extent renders it vulnerable to stochastic and catastrophic events. There are no apparent immediate threats to the species beyond the speculative potential for contaminants from nearby roadways. We lack genetic information to inform an assessment of the species' ability to adapt to changing conditions. Under the assumption that different caves are genetically distinct, having two occurrence locations confers limited genetic diversity to the species. Overall, Hubricht's cave beetle's ability to withstand stochasticity and catastrophic events is currently constrained due to its restricted geographic range, and its ability to adapt to changing conditions is unknown. This synthesis is predicated upon the assumption that there are no other occurrences of the species.

6.7.3 Future Condition

Impervious Surface Projections

Following Theobald *et al*. (2009), we classify the impact of impervious surface on the species' conservation site as follows: Unstressed (0–0.9 percent), Lightly stressed (1–4.9 percent), Stressed (5–9.9 percent), Impacted (10–24.9 percent), and Damaged (>25 percent). Under this classification, the Hubricht's cave beetle conservation site is currently lightly stressed and projected to remain lightly stressed under both scenarios through 2070 (Table 6.14).

Table 6.14: Percent impervious surface projections for conservation site of Hubricht's cave beetle.

Area	**Mean percent impervious surface**					
	ICLUS A1			**ICLUS B1**		
Conservation Site	**2020**	**2040**	**2070**	**2020**	**2040**	**2070**
Lebanon Sinking	1.64	1.64	1.69	1.64	1.64	1.64

County Population

The VACDR report (Malabad *et al*. 2021, entire) indicates that proximity to roads is a threat for several cave beetle species. The mechanisms given include runoff of sediment, hydrocarbons, and deicing agents; trash from the roadway entering the mouth of a cave; and the possibility of spills of hydrocarbons and other hazardous materials. The severity of these threats depends on usage of roads in areas draining into the habitat of the assessed species. We use projected changes in county (human) populations as a proxy for future road usage and development potential. The population of Russel County, VA is projected to decline through 2070, which indicates road usage is likely to decline by proxy (Table 6.15).

Table 6.15: ICLUS county population projections through 2070 under the SRES A1 and B1 scenario for Hubricht's cave beetle.

County	**County population**					
	ICLUS A1			**ICLUS B1**		
	2020	**2040**	**2070**	**2020**	**2040**	**2070**

Russell	18,746	5,012	1,928	25,551	19,537	11,615

Land Ownership

As noted above, private ownership with agricultural land use dominates within the range of Hubricht's cave beetle. A large portion of the species range consists of open pastures used for livestock and hay production. It is challenging to predict if or how land use on private lands may change in the future; however, impervious surface projections are intended to capture expected changes in development within the conservation site for the species.

Viability Under Future Conditions

We do not expect Hubricht's cave beetle's abundance or spatial extent to change relative to their current status through 2070, and thus, nor will the species' viability. The rationale for our conclusion rests primarily on two facets. First, the conservation site is projected to remain lightly stressed through 2070. Secondly, there is a projected decline in the human population in Russell County, indicating less road usage. Under future conditions, Hubricht's cave beetle will remain vulnerable to stochastic and catastrophic events and will have limited ability to adapt to shifting and novel conditions.

6.8 *Pseudanophthalmus sericus* (silken cave beetle) Species Status Assessment

6.8.1 Taxonomy

Pseudanophthalmus sericus, commonly known as the silken cave beetle, was first described by Barr in 1981 based on collections from the type locality of Lane Cave in Scott County, VA in 1967. It is a member of the hirsutus species group.

6.8.2 Current Condition

Habitat/Range

The silken cave beetle has historically only been collected from Lane Cave in Scott County, VA. VADCR biologists made two visits to Lane Cave (August 2016 and October 2019) and collected or observed a total of 22 beetles. The estimated area of the known range is 0.24 km^2 (0.09 mi^2) (Figure 6.9). The outcrop belt of contiguous limestone within which it exists continues over 80.5 km (50 mi) in each direction (northeast and southwest.) Silken cave beetle exists in a single cave within the range of a more broadly distributed *Pseudanophthalmus*, *P. thomasi*, however there are no records of any *Pseudanophthalmus* species other than silken cave beetle in Lane Cave.

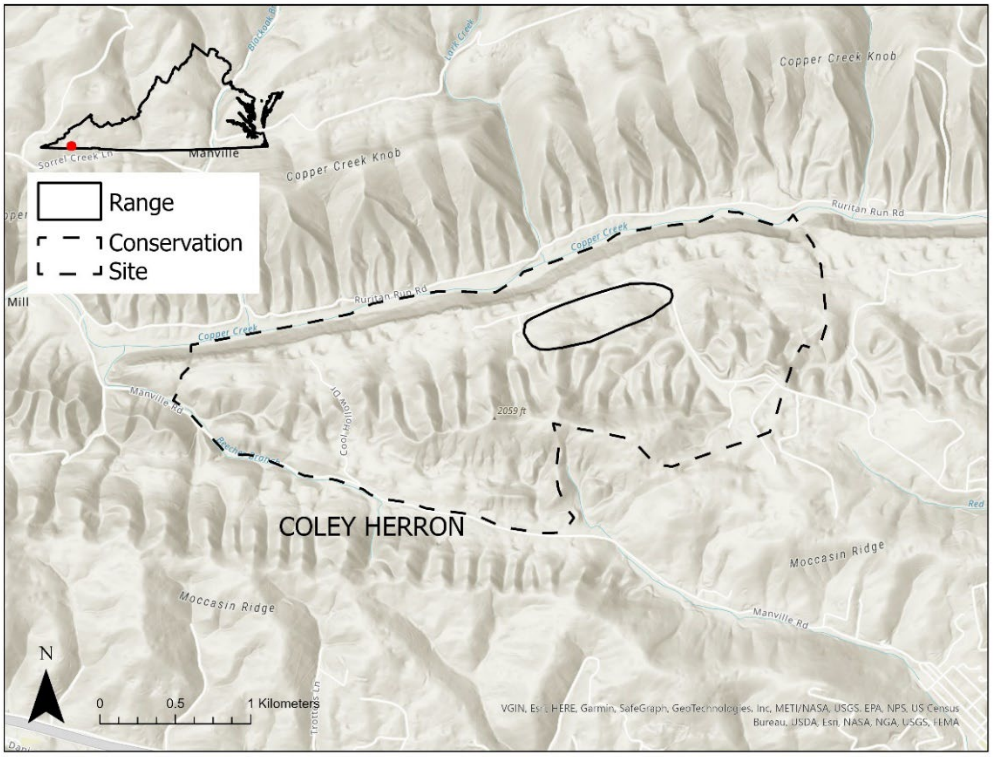

Figure 6.9: Silken Cave Beetle Range and Conservation Site

The only available information on habitat condition within the caves is provided by VADCR as brief site descriptions associated with their survey visits: "The cave has a large stream. The downstream section was searched first. This section of the cave has irregular bioturbation with some sections being completely worked over and others showing little sign of any activity. Large mud banks run along the stream and mud cracks are higher on the banks all the way down to the sump" (Malabad *et al*. 2021, p. 83). All cave beetles collected and observed at the site were in the same area, "about 5 to 6.5 feet (one and a half to two meters) above the stream in dry loamy silt banks." VADCR notes that "inventory work at Lane Cave has produced several very interesting biological collections over the course of this study resulting in the discovery of two undescribed species that are also apparent single site endemics. A new *Fontigens* sp. snail and an isopod in the genus *Lirceus* were discovered, and both are currently being described. These discoveries certainly support the theory that something about Lane Cave has contributed to it being a site where single site endemics or very rare species may reside."

Land within the species range and conservation site for the silken cave beetle includes privately owned residential parcels that are predominantly forested.

Analysis Units

The best available information currently indicates the silken cave beetle is a single site endemic in Lane Cave, Scott County, VA. As such we consider this species to consist of a single analysis unit. VADCR has established a conservation site associated with this EO that delineates the area of influence surrounding the cave. The Coley Herron conservation site (5.31 km^2 or 2.05 mi^2) is our spatial unit for threats analyses (Figure 6.9).

Ease of Detection

In the absence of information on absolute abundance or density, we focus on ease of detection for the silken cave beetle. The original collection in October of 1967 yielded five males and five females from Lane Cave (Barr 1981). In 2016-2019 survey efforts, 13 beetles were collected in August 2016, and two additional beetles were collected in October 2019, for a total of 15 collected individuals confirmed to be the silken cave beetle over two cave visits (average detection rate of 7.5 individuals per visit). This species is in the "readily observed" category.

Influences

The petition to list the species cited recreational spelunking and mountaintop removal coal mining as potential threats to the species. We have no information indicating recreational spelunking is affecting the viability of the species, and there are no active coal mining permits within the range or conservation site for the species.

Within the species' range and conservation site are privately owned residential parcels that are predominantly forested. VADCR notes that the entrance to Lane Cave is immediately adjacent to a road; however, outside of that and its apparent limited range, "there is no reason to suspect this species is vulnerable" (Malabad *et al*. 2021, p. 83).

Conservation Efforts

The Cave Conservation Act enacted in 1966 and was established to protect the cave and karst resources of the Commonwealth. In 1978, the Virginia legislature formed the Virginia Cave Commission, and in 1979 enacted a new comprehensive Virginia Cave Protection Act that defined the role of the Commission, which is now known as the Virginia Cave Board. The Virginia Cave Board is an advisory committee and tasked the board with researching and surveying Virginia's caves, creating reports to be used by other agencies, reporting dangers or threats to caves, and increasing public awareness of the importance of caves and cave fauna. In addition, the 1979 Virginia Cave Protection Act spells out penalties for vandalism, pollution, and disturbance of endemic species, and how to go about getting permits to conduct any sort of disturbing action within a cave.

The Virginia Cave Board maintains a list of caves designated as "Significant" and Lane Cave is included as a "Significant" cave. "Significant" caves as designated by the Virginia Cave Board under the Cave Protection Act are treated as element occurrences by the VADCR NHP, and each significant cave lies within a Conservation Site. Any projects passing through the VADCR Office of Environmental Project Review are screened to see if they intersect conservation sites. When conservation sites are intersected, VADCR NHP staff inform the project proponent and provide guidance on protection of the associated resources that may be affected by their project, including "Significant" caves and species within. Although no legal status accompanies this designation, VADCR NHP reports success in avoiding impacts to element occurrences via this review and communication process. In addition, "Significant" caves are given priority for implementation of conservation efforts such as easements, cost-share programs, and fee simple acquisition for long-term protection.

Viability Under Current Conditions

Silken cave beetle was readily detected at its only known location in surveys from 2016-2019. The species' restricted geographical extent and single known location renders it vulnerable to stochastic and catastrophic events. There are no apparent immediate threats to the species. We lack genetic information to inform an assessment of the species' ability to adapt to changing conditions. As a single site endemic, the species does not have the genetic advantage of multiple sites that are likely to be genetically distinct. Overall, silken cave beetle's ability to withstand stochasticity and catastrophic events is currently constrained due to its single occurrence location, and its ability to adapt to changing conditions is unknown. This synthesis is predicated upon the assumption that there are no other occurrences of the species.

6.8.3 Future Condition

Impervious Surface Projections

Following Theobald *et al*. (2009), we classify the impact of impervious surface on conservation sites as follows: Unstressed (0–0.9 percent), Lightly stressed (1–4.9 percent), Stressed (5–9.9 percent), Impacted (10–24.9 percent), and Damaged (>25 percent). Under this classification, the silken cave beetle conservation site is currently lightly stressed and projected to remain lightly stressed under both scenarios through 2070 (Table 6.16).

Table 6.16: Percent impervious surface projections for conservation site of silken cave beetle.

Area	**Mean percent impervious surface**					
	ICLUS A1			**ICLUS B1**		
Conservation Site	**2020**	**2040**	**2070**	**2020**	**2040**	**2070**
Coley Herron	1.06	1.06	1.06	1.06	1.06	1.06

County Population

The VACDR report (Malabad *et al*. 2021, entire) indicates that proximity to roads is a threat for several cave beetle species. The mechanisms given include runoff of sediment, hydrocarbons, and deicing agents; trash from the roadway entering the mouth of a cave; and the possibility of spills of hydrocarbons and other hazardous materials. The severity of these threats depends on usage of roads in areas draining into the habitat of the assessed species. We use projected changes in county (human) populations as a proxy for future road usage and development potential. The population of Scott County, VA is projected to decline through 2070, which indicates road usage is likely to decline by proxy (Table 6.17).

Table 6.17: ICLUS county population projections through 2070 under the SRES A1 and B1 scenario for silken cave beetle.

County	**County population**					
	ICLUS A1			**ICLUS B1**		
	2020	**2040**	**2070**	**2020**	**2040**	**2070**
Scott	12,918	4,003	1,890	19,022	13,519	7,207

Land Ownership

As noted above, land within the species range and conservation site is largely forested, privately owned residential parcels. While it is challenging to predict future changes in land use on private lands, the impervious surface projections are intended to capture expected changes in development within our spatial units of analysis.

Viability Under Future Conditions

We do not expect silken cave beetle's abundance or spatial extent to change relative to their current status through 2070, and thus, nor will the species' viability. The rationale for our conclusion rests primarily on two facets. First, the conservation site is projected to remain lightly stressed through 2070. Secondly, there is a projected decline in the human population in Scott County, indicating less road usage. Under future conditions, silken cave beetle will remain vulnerable to stochastic and catastrophic events and its ability to adapt to shifting and novel conditions remains unknown.

7 Literature Cited

Balogh, A., L. Ngo, K.S. Zigler, and G. Dixon. 2020. Population genomics in two cave-obligate invertebrates confirms extremely limited dispersal between caves. Scientific Reports 10:17554. 11pp. https://doi.org/10.1038/s41598-020-74508-9.

Barber, H.S. 1928. Two new cave-beetles related to Anophthalmus pusio Horn. Journal of the Washington Academy of Sciences 18(7): 194–196.

Barr, Thomas C. Jr. 1959. New Cave Beetles (Carabidae, Trechini) from Tennessee and Kentucky. Journal of the Tennessee Academy of Science 34(1): 5–30.

Barr, Thomas C. Jr. 1960. Introduction. The American Midland Naturalist 64(1). The University of Notre Dame: 1–9.

Barr, Thomas C. Jr. 1965. The *Pseudanophthalmus* of the Apalachian Valley (Coleoptera: Carabidae). The American Midland Naturalist 73(1): 41–72.

Barr, Thomas C. Jr. 1967. Observations on the ecology of caves. The American Naturalist 101(922): 475–491.

Barr, Thomas C. Jr. 1981. *Pseudanophthalmus* from Appalachian Caves (Coleoptera: Carabidae): The Engelhardti Complex. Brimleyana 5: 37–94.

Barr, Thomas C. Jr. and John R. Holsinger. 1985. Speciation in Cave Faunas. Annual Review of Ecology and Systematics 16: 313–337.

Bradic, M, P. Beerli, F.J. Garcia-de Leon, S. Esquivel-Bobadilla, and R.L. Borowsky. 2012. Gene flow and population structure in the Mexican blind cavefish complex (*Astayanax mexicanus*). BMC Evolutionary Biology 12:9. 16pp. http://www.biomedcentral.com/1471-2148/12/9

British Geological Survey. 2022. https://www.bgs.ac.uk/mendips/aggregates/environment/water.html; accessed 7/8/22.

Cave Conservancy of the Virginias (CCV). 2022. https://caveconservancyofvirginia.org/. Accessed 11/21/22.

Center for Biological Diversity. 2022. Withdrawal of Petitions for 21 Species. Letter to C. Snyder, USFWS, from D.N. Greenwald, CBD. 2pp.

Colado, R., S. Pallares, J. Fresneda, S. Mammola, V. Rizzo, and D. Sanchez-Fernandez. 2022. Climatic stability, not average habitat temperature, determines thermal tolerance of subterranean beetles. Ecology 103(4): 11pp.

Constantin, S., I.C. Mirea, A. Petculescu, R.A. Arghir, D.S. Mantoiu, M. Kenesz, M. Robu, and O.T. Moldovan. 2021. Monitoring human impact in show caves. A study of four Romanian caves. Sustainability 13(1619). 26pp.

Culver, D.C. and T. Pipan. 2019. The Biology of Caves and Other Subterranean Habitats. Second Edition. New York, NY. Oxford University Press. 336pp.

Green, R.H. and R.C. Young. 1993. Sampling to detect rare species. Ecological Applications 3(2): 351–356.

Griffith, D.M. and T.L. Poulson. 1993. Mechanisms and consequences of intraspecific competition in a carabid cave beetle. Ecology 74(5): 1373–1383.

Hawes, R.S. 1939. The flood factor in the ecology of caves. Journal of Animal Ecology 8(1): 1–5.

Hobbs, S.L. and J. Gunn. 1998. The hydrogeological effect of quarrying karstified limestone: options for prediction and mitigation. Quarterly Journal of Engineering Geology 31: 147–157.

Holsinger, J. R., Culver, D. C., Hubbard, D. A. Jr., Orndorff, W. D., Hobson, C. S., (2013) The Invertebrate Cave Fauna of Virginia. Banisteria, 42: 9–56.

Hobson, C.S. 2001. A Status Survey and Assessment of Holsinger's Cave Beetle (*Pseudanophthalmus* holsingeri) at Young-Fugate Cave, Lee County, Virginia, 2000-2001. Natural Heritage Technical Report 01-15 . Virginia Department of Conservation and Recreation, Division of Natural Heritage. Richmond. 9 pp.

Hubbard, D.A. and W.M. Balfour. 1993. An investigation of engineering and environmental concerns relating to proposed highway construction in a karst terrane. Environmental Geology 22: 326–329.

Jeannel, R. 1931. Insectes Coléoptères Et Révision Des Trechinae De L'amérique Du Nordarchives De Zoologie Expérimentale Et Générale 79: 403–500.

Kamimura, Y., Abe, J., Ferreira, R. L. & Yoshizawa, K. 2019. Microsatellite markers developed using a next-generation sequencing technique for *Neotrogla* spp. (*Psocodea: Prionoglarididae*), cave dwelling insects with sex-reversed genitalia. Entomol. Sci. 22: 48–55.

Kane, T.C. and T.L. Poulson. 1976. Foraging by cave beetles: spatial and temporal heterogeneity of prey. Ecology 57(4): 793–800.

Kane, T.C and T. Ryan. 1983. Population ecology of carabid cave beetles. Oecologia 60:46–55.

Krekeler, C.H. 1958. Speciation in cave beetles of the genus *Pseudanophthalmus* (Coleoptera: Carabidae). The American Midland Naturalist 59(1): 167–189.

Langer, W.H. 2001. Potential Environmental Impacts of Quarrying Stone in Karst, A Literature Review. U.S. Geological Survey Open-File Report OF–01–0484. 39pp.

Lera, T. 2016. The Virginia Cave Board: The First Fifty Years (1966-2015). https://www.dcr.virginia.gov/natural-heritage/document/the-virginia-cave-protection-act.pdf. Accessed 10/13/22.

Lewis, J.J. 2001a. Conservation Assessment for Dry Fork Valley Cave Beetle (*Pseudanophthalmus* montanus). Report to the USDA Forest Service, Eastern Region. 8pp.

Lewis, J.J. 2001b. Conservation Assessment for Greenbriar Cave Beetle (*Pseudanophthalmus* fuscus). Report to the USDA Forest Service, Eastern Region. 9pp.

Lewis, J.J. 2001c. Conservation Assessment for Marthas Cave Beetle (*Pseudanophthalmus* hypertrichosis). Report to the USDA Forest Service, Eastern Region. 8pp.

Lewis, J.J. 2002. Conservation Assessment for Marengo Cave Ground Beetle (*Pseudanophthalmus* stricticollis). Report to the USDA Forest Service, Eastern Region. 8pp.

Lovei, G.L. and K.D. Sunderland. 1996. Ecology and Behavior of Ground Beetles (Coleoptera: Carabidae). Annu. Rev. Entomol. 41: 231–256.

Lyons, M.P., Nikiel, C.A., LeDee, O.E., and Boyles, R. 2023. Potential effects of climate change on Appalachian stoneflies (Remenus kirchneri, Acroneuria kosztarabi, and Tallaperla lobata): U.S. Geological Survey Open-File Report 2021–1104–B, 41 p. https://doi.org/10.3133/ofr20211104B..

Malabad, Thomas E., Kosič Ficco, Katarina and William D. Orndorff. 2021. Review of rare cave beetles of the genus *Pseudanophthalmus* in Virginia. With a revised status assessment of 17 candidate species (January 14, 2015 through September 8, 2021): Natural Heritage Technical Report 2021-18. Virginia Department of Conservation and Recreation Division of Natural Heritage, Richmond, Virginia. 221pp.

Manes, S., M. J. Costello, H. Beckett, A. Debnath, E. Devenish-Nelson, K-A. Grey, R. Jenkins, T. M. Khan, W. Kiessling, C. Krause, S. S. Maharaj, G. F. Midgley, J. Price, G. Talukdar, and M. M. Vale. 2021. Endemism increases species' climate change risk in areas of global biodiversity importance. Biological Conservation. 257:109070

Nixon, Jedidiah John. 2020. Delineation of Undescribed, Morphologically Cryptic Cave Beetles of the *Pseudanophthalmus* pubescens Species-Group (Coleoptera: Carabidae: Trechinae). Masters Theses & Specialist Projects. Paper 3208.

Ober, K. 2019. Systematics and evolution of *Pseudanophthalmus* cave beetles. Presentation at USFWS 17 Cave Beetles SSA kickoff meeting, 2/27/2019, Christiansburg, VA. 27pp.

Poulson, T.L. and W.B. White. 1969. The Cave Environment. Science 165(3897): 971–981.

Rizzo, V., D. Sanchez-Fernandez, J. Fresneda, A. Cieslak, and I. Ribera. 2015. Lack of evolutionary adjustment to ambient temperature in highly specialized cave beetles. BMC Evolutionary Biology 15:10. 9pp.

Sanchez-Fernandez, D., V. Rizzo, A. Cieslak, A. Faille, J. Fresneda, and I. Ribera. 2016. Thermal niche estimators and the capability of poor dispersal species to cope with climate change. Scientific Reports 6: 23381.

Simoes, M.H., M. Souza-Silva, and R.L. Ferreira. 2015. Cave physical attributes influencing the structure of terrestrial invertebrate communities in Neotropics. Sibterranean Biology 16: 103–121.

Smith D.R., N.L. Allan, C.P. McGowan, J.A. Szymanski, S.R. Oetker, and H.M. Bell. 2018. Development of a species status assessment process for decisions under the U.S. Endangered Species Act. Journal of Fish and Wildlife Management 9:1–19.

Strayer, D. L. 2013. Endangered freshwater invertebrates. Pages 176–187. Levin, S. (ed) Encyclopedia of Biodiversity (second edition) Elsevier Inc.

Theobald, D. M., Goetz, S. J., Norman, J. B., & Jantz, P. 2009. Watersheds at risk to increased impervious surface cover in the conterminous United States. Journal of Hydrologic Engineering 14(4): 362.

U.S. Environmental Protection Agency (EPA). 2009. Land-Use Scenarios: National-Scale Housing-Density Scenarios Consistent with Climate Change Storylines. Global Change Research Program, National Center for Environmental Assessment, Washington, DC; EPA/600/R–08/076F. Available from: National Technical Information Service, Springfield, VA, and online at http://www.epa.gov/ncea.

U.S. Fish and Wildlife Service (Service). 2016. Service species status assessment framework: an integrated analytical framework for conservation. Version 3.4.8, August 2016.

U.S. Fish and Wildlife Service (Service). 2022. Species Status Assessment Report for the Rye Cove Isopod (*Lirceus culveri*), Version 1.0. February 2022. Hadley, MA.

U.S. Forest Service (USFS). 2004. Revised Land and Resource Management Plan, Jefferson National Forest. Management Bulletin R8-MB 115A. 396pp.

Valentine, J.M. 1948. New Anophthalmid beetles (Fam. Carabidae) from the Appalachian Region. Museum Paper 27, Alabama Museum of Natural History. 22pp.

VADCR. 2012. (https://www.dcr.virginia.gov/pr-relz-detail?id=2012-12-03-11-12-56-78063; accessed 10/12/22)

VADCR. 2022. (https://www.dcr.virginia.gov/natural-heritage/natural-area-preserves/ogdenscave; accessed 2/16/22)

Valley Conservation Council (VCC). 2022. https://valleyconservation.org/the-valley-region/easements-land-protection/. Accessed 11/17/22.

Virginia Outdoors Foundation (VOF). 2022. https://www.vof.org/protect/easements/. Accessed 11/17/22.

8 Appendix A: Detailed Methods for Power Analysis

The VADCR recorded observations for all 17 species, which we summarized (Main text: Table 5.1, Figure 5.1). Cave visit records with substantial missing information were excluded from the summary. A visual search was conducted at all visits. Bait stations were deployed at 13 percent of the visits (14 out of 110), and pitfall traps were deployed at 11 percent of the visits (12 out of 110). We tabulated and graphed the VADCR data to evaluate the variation in counts of individuals across species and caves relative to the effort as indicated by the number of visits.

Evaluating survey effort

VADCR did not observe species at some caves despite multiple survey visits. Nevertheless, we can infer maximum detection under simplifying assumptions even though multiple visits result in zero counts. Green and Young (1993) showed how to calculate the maximum detection despite failing to detect the species during a series of surveys based on a given confidence level (e.g., 95 percent confidence). Logically, as the number of surveys resulting in no detection increases, the maximum detection decreases because a surveyor likely would have detected the species if densities were higher. The calculations assume that mean count during a survey is Poisson distributed, which has been shown empirically for rare species (Green and Young 1993).

The maximum detection declines rapidly between one to five cave visits (Figure A-1). When cave visits are less than five, the probable density (anything less than maximum detection) covers a wide range. For example, *P. hirsutus*, which is known to have been present in three caves which were visited only once or twice each. The possible density at the cave is consistent with 1.5 to 3 counts per cave visit, which are values in the 50^{th} to 75^{th} percentile of the observed mean counts. Thus, due to low sampling effort, the uncertainty around *P. hirsutus* abundance encompasses extirpation to an abundance higher than 50 percent of the assessed species. With only a couple visits per cave, at most, the magnitude of uncertainty prevents defensible conclusions about ease of detection for *P. hirsutus* because the data are consistent with a range of potential results encompassing both extirpation and a density level that is readily observable. However, there are several species with at least five visits per cave, on average, supporting moderate confidence in ease of detection.

The statistical power to detect the presence of a cave beetle species is another way to contextualize the VADCR data using the Green and Young (1993) statistical model. As seen in Figure A-1, densities consistent with mean counts >1 individual per visit show a high probability of species detection after only a few visits. However, where density is consistent with mean counts per visit <1 individual, three to five visits are required to expect to observe the species. When density is consistent with very low mean counts (e.g., 0.1 individual per visit), a low probability of detection is expected unless visits exceed 10. The power analysis is relevant to the assessment because absence of detection is not indicative of species absence unless the number of visits is sufficiently high. The number of visits per cave has not been high enough to ensure detection of cave beetles at low density in all cases.

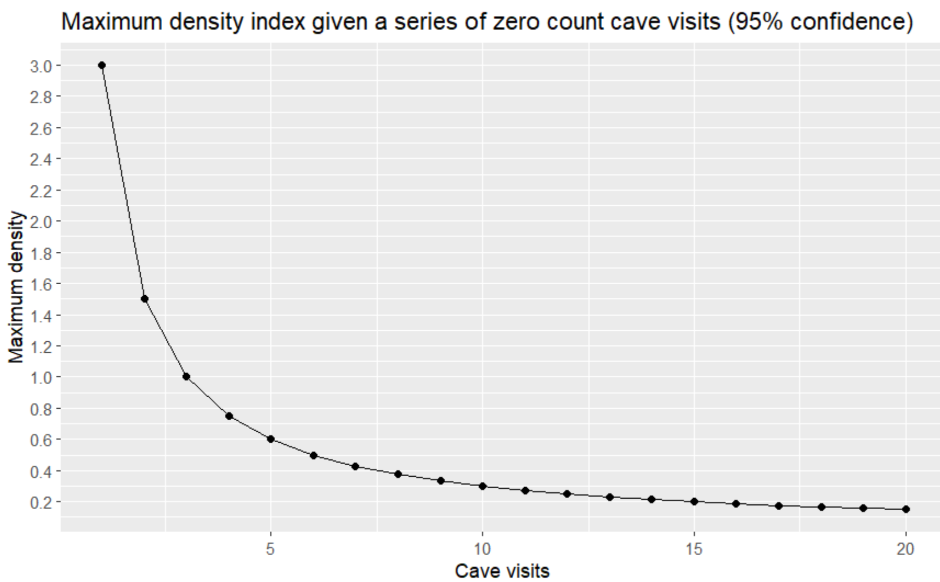

Figure A-1. Maximum detection (number of individuals counted per visit) expected with 95 percent confidence when a series of cave visits resulted in all zero counts (no individuals counted).

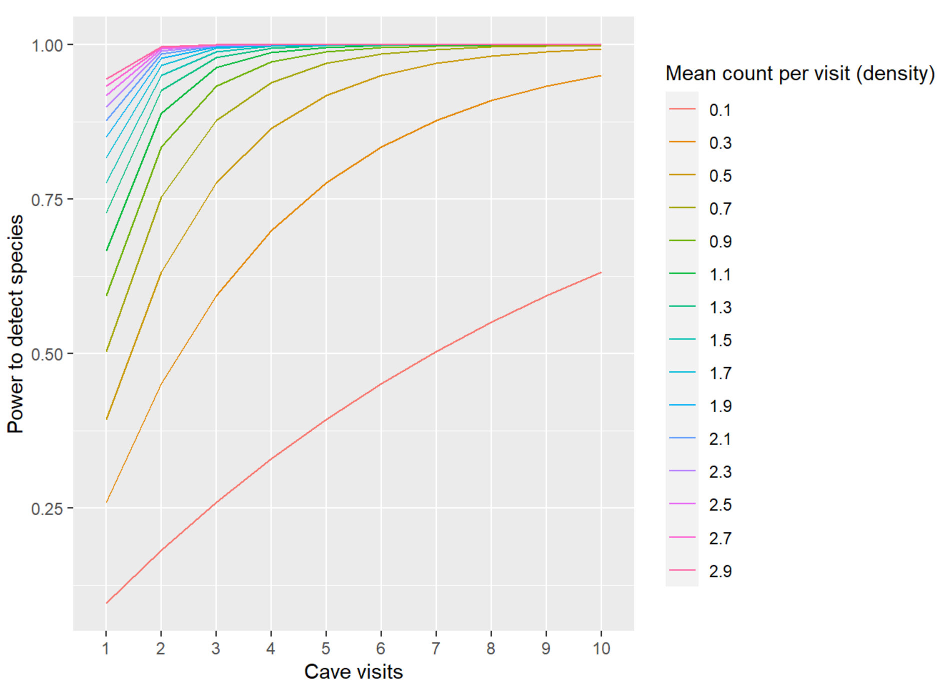

Figure A-2. Power to detect cave beetle species determined by the number of cave survey visits and expected mean count of individuals per visit.

Current condition

We combined criteria for redundancy, ease of detection level, and presence of threats to evaluate current condition. Viability declines as the number of redundant populations declines (USFWS 2022, p. 39). Thus, we defined redundancy as low if the species was found at only one cave, moderate if the species was found at two or three caves, and high if the species was found at more than three caves.

We defined ease of detection level based on how rarely, infrequently, or readily a species was observed during a survey visit. Rarely observed species are those where less than one individual was counted per two visits. Infrequently observed species are those where one individual was counted per two visits. Readily observed species are those where more than one individual was counted per visit.

Our confidence in the ease of detection level depends on survey effort. Very low confidence was associated with two or fewer cave visits. Low confidence was associated with less than or equal to four cave visits and rare or infrequent density level. Moderate confidence was associated with more than four cave visits or readily observed density level. We did not have high confidence for any of the species because of the lack of information on detectability for cave beetle sampling.

Threat levels were based on presence of major threats in the vicinity of occupied caves. The major threats include the presence of active mines or quarries, impervious surface within the watershed above the 5 percent threshold associated with impacts to aquatic species, and cave de-humification typically associated with commercialization of the cave.

The elements of current condition are summarized in Table A-1. Vulnerable species are identified by low or moderate redundancy and rarely or infrequently observed densities. Based on these factors, Hupp's Hill cave beetle, Hubbard's cave beetle, and the overlooked cave beetle fall into the vulnerable category; however for the latter two species we have low confidence in this conclusion given the low amount of effort conferring high uncertainty.

Table A-1. Summary of VADCR data relevant to assessment of current condition. Redundancy level based on number of caves: low = 1 cave, moderate = 2 or 3 caves, high = >3 caves. Resilience based on ease of detection and threat level. Ease of detection based on count (number of individuals) per visit: rarely observed = <1 per 2 visits, infrequently observed = 1 per 2 visits, readily observed = >1 per visit. Threat level is based on the presence of major threats (threat level provided only for assessed species).

			Count per visit								
Status	Species	Number of caves	Mean	Minimum	Maximum	Total visits	Average visits	Redundancy	Ease of Detection	Confidence	Major threats present
A	*Little Kennedy cave beetle*	7	1.3	0.2	3.0	22	3.1	Low	Infrequently	low	No
A	*Holsinger's cave beetle*	1	4.0	4.0	4.0	3	3.0	None	Readily	moderate	No
A	*Hubbard's cave beetle*	1	0.3	0.3	0.3	3	3.0	None	Rarely	low	Yes
A	*Hubricht's cave beetle*	2	0.8	0.6	1.0	10	5.0	Low	Infrequently	moderate	No
A	*Shenandoah cave beetle*	2	0.5	0.0	1.0	7	3.5	Low	Infrequently	low	No
A	*Hupp's Hill cave beetle*	2	0.1	0.0	0.2	14	7.0	None	Rarely	moderate	Potential
A	*Overlooked cave beetle*	1	0.7	0.7	0.7	4	4.0	None	Infrequently	low	No
W	*Avernus cave beetle*	1	3.0	3.0	3.0	2	2.0	None	Readily	moderate	
W	*New River Valley cave beetle*	4	4.9	0.5	15.0	8	2.0	Low	Readily	moderate	
W	*Cumberland Gap cave beetle*	3	0.0	0.0	0.0	5	1.7	Low	Rarely	very low	
W	*Crossroads cave beetle*	3	1.7	0.5	4.0	6	2.0	Low	Infrequently	very low	
W	*Natural Bridge cave beetle*	3	1.3	1.0	2.0	5	1.7	Low	Readily	moderate	

W	*South Branch Valley cave beetle*	3	2.7	0.0	6.0	3	1.0	Low	Readily	moderate	
W	*St. Paul cave beetle*	4	3.3	1.0	6.0	5	1.3	Low	Readily	moderate	
A	*Silken cave beetle*	1	7.5	7.5	7.5	2	2.0	None	Readily	moderate	No
W	*Thomas' cave beetle*	3	3.0	0.5	5.5	6	2.0	Low	Readily	moderate	
W	*Maiden Spring cave beetle*	2	4.3	2.5	6.0	3	1.5	Low	Readily	moderate	