# Species Status Assessment Report
# for the
# Canoe Creek Clubshell
# (*Pleurobema athearni*)

## Version 1.1

*Photo Credit: Todd Fobian, ADCNR.*

**February 2020**

**U.S. Fish and Wildlife Service**
**Region 4**
**Atlanta, GA**

## ACKNOWLEDGEMENTS

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*Figure A-1: Gravid CCC (70 mm) collected from LCC (east), May 15, 2019. Photo credit: Todd Fobian, ADCNR.*

Suggested reference:

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Canoe Creek Clubshell (*Pleurobema athearni*)

# EXECUTIVE SUMMARY

This report summarizes the results of a Species Status Assessment completed for the Canoe Creek clubshell (*Pleurobema athearni*) (CCC) to assess the species' overall viability. The CCC is a narrow endemic mussel that is only known from Big Canoe Creek (BCC), a western tributary to the Coosa River in St. Clair and Etowah counties, Alabama (Figure ES-1) (Williams *et al.* 2008, pp. 505-507; MRBMRC 2010, p. 26). Current records and a paucity of museum records suggests that this species has always been uncommon to rare (Gangloff *et al.* 2006, pp. 46-47; MRBMRC 2010, p. 26; Shelton-Nix 2017, p. 69; Fobian *et al.* 2017, pp. 9-10)

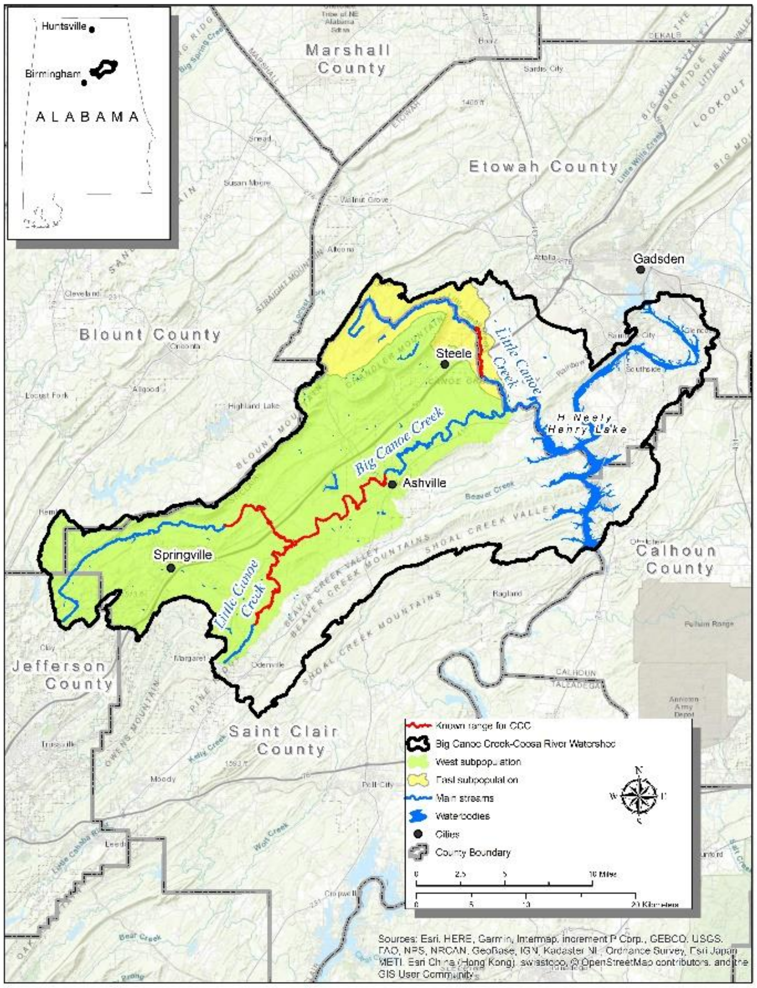

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*Figure ES-1. Canoe Creek clubshell subpopulations based on HUC-12 watershed boundaries and tributaries flowing into Neely Henry Lake on the Coosa River.*

To evaluate the viability of the CCC, we characterized the needs, estimated the current condition, and predicted the future condition of the species' in terms of its resiliency, representation, and redundancy (together the 3Rs). This species has only been recently (2006) recognized as a distinct taxon and little is known about its historic range outside of a small number of museum records. None of those older museum records occur outside of the current occupied range. The CCC occurs within approximately 32 km of the BCC mainstem, from approximately 6 km NE of Springville to 1 km NW of Ashville; and within approximately 15 km of the Little Canoe Creek (west), 9 km SE of Springville, to its confluence with BCC. The CCC is also known to occur within approximately 5 km of Little Canoe Creek (east) due east of Steele, Alabama (along the St. Clair and Etowah County line). In total, the CCC is extant in less than 52 km of river within the BCC watershed. Two subpopulations were delineated using Hydrologic Unit Code (HUC) 12 watershed boundaries and tributaries leading to the Coosa River (Neely Henry Reservoir) (Figure ES-1), which includes a western subpopulation near Springville and Ashville and an eastern subpopulation near Steele. The two subpopulations are isolated from one another by a stretch of unsuitable habitat, and as a result, no genetic exchange is believed to be occurring between these two subpopulations.

The CCC is a medium sized mussel up to 97 mm in length, with a moderately thick ovate to sub-ovate shell tawny to brown in color and without rays (Gangloff *et al.* 2006, p. 48; Williams *et al.* 2008, p. 505; Fobian *et al.* 2017, p. 10). The CCC is found primarily in shoal habitat and prefers gravel substrates (Williams *et al.* 2008, p. 506).

Individual CCCs need flowing water with appropriate water quality and temperature; stable in-stream substrates with appropriate sediment quality; and suitable host, food, and nutrients for growth and reproduction. At the subpopulation and species levels, the CCC needs appropriate abundance in each subpopulation with appropriate density of CCC within those beds. Each subpopulation needs to be healthy and resilient, with multiple age classes, and show evidence of recent recruitment. For each subpopulation to be resilient, there must be multiple mussel beds of sufficient density such that local stochastic events do not eliminate most or all the bed(s). There needs to be appropriate connectivity among the mussel beds in a stream reach in order to recover and be recolonized by one another following stochastic events. A non-linear distribution over a large area (occurrence in tributaries, in addition to the mainstem) also helps buffer against stochastic events that may impact subpopulations. Similarly, having multiple subpopulations that are connected to one another protects the species from catastrophic events, such as spills, because subpopulations can recolonize each other following events that impact one of the subpopulations. Mussel abundance also facilitates reproduction; mussels do not actively seek mates, rather males release sperm into the water column, where it drifts until a female hopefully takes it into the incurrent siphon. Therefore, successful individual reproduction, and subpopulation resilience, requires sufficient numbers of female mussels downstream of sufficient numbers of male mussels. Additionally, given their natural reproductive inefficiencies, it is likely a minimum viable population size does exist and is required to maintain natural recruitment. While this number is not currently known, the current lack of documented natural recruitment and the current skewed size class distribution towards older cohorts, is concerning.

We identified sedimentation, water quality, climate events (especially drought), connectivity, and conservation efforts as the primary factors influencing the viability of the CCC. Development and climate change were the two primary sources of these factors that we identified. In addition, having small subpopulation sizes (few numbers of collections despite survey efforts) and a lack of recent recruitment puts CCC at greater risk of extirpation from stochastic events.

To assess the current condition of the CCC, we developed a population model and described the species' in terms of its resiliency, representation, and redundancy (the 3Rs). The results of our population model indicate that currently, the CCC subpopulations likely have reduced to little ability to recover from a severe stochastic event, and thus have very limited resiliency. It is also likely that the current observed size class distribution is indicative of recruitment failure across the CCC's range. Current demographics may already indicate the species is in an extinction debt, where one or both subpopulations are in a downward spiral from which they are unable to recover naturally.

The CCC is represented by a single watershed (the BCC watershed). Given that the CCC is so limited in range and individuals of each subpopulation do not vary markedly in their genetic, morphology, ecology, or behavior, the adaptive capacity of the species is likely very limited. Although historical data on the species is limited, we believe the species has likely always been a narrow endemic and that the current, limited adaptive capacity of the CCC is likely similar to that which the species had historically.

Similar to its adaptive capacity, current redundancy for the CCC likely remains relatively unchanged from its historical state and is generally very limited. The CCC's redundancy is currently characterized by two subpopulations that exist within the species' narrow range. However, the relatively recent structuring of the species into two subpopulations likely does not provide a benefit to the species since it is a result of a human-caused inundation, the Neely Henry Reservoir, which creates a stretch of unsuitable habitat for the mussel and its host fish. Indeed, we understand this unsuitable stretch of the species' range as primarily having a negative impact on the species, as it is a cause of isolation and prevents genetic exchange and the opportunity of recolonization among the subpopulations. Therefore, while the species' redundancy is characterized by having two subpopulations, the species' distribution across its range likely provides the greatest protection against catastrophic events. However, since the range of the species is so limited, many catastrophic events, such as a severe drought or flood event, that may impact an entire subpopulation, are likely to impact both subpopulations. Events such as a contaminant spill would be unlikely to affect both subpopulations, as they do not occur directly downstream of one another. However, if a subpopulation were to be extirpated as a result of such an event, natural recolonization would be near impossible given its isolation from its counterpart. Therefore, the CCC currently has limited redundancy to protect against catastrophic events.

To assess the future condition of the CCC, we forecasted what the CCC may have in terms of the 3Rs under three plausible future scenarios. Habitat decline and climate change (*e.g.*, severe drought) were the primary factors identified as influencing the viability of the CCC in the future. Propagation was also examined as a way to recover the species. All three scenarios assumed a moderate (6%) or enhanced (11%) probability of severe drought (PDSI < -3), and either propagation or no propagation of the species. We modeled the probability of extirpation of CCC subpopulations under these three scenarios at four time periods: 2045, 2070, 2095, and 2120 (Table ES-1).

The three scenarios examined were:

- Scenario 1: Static habitat availability with moderate probability of severe drought (6%) and no propagation of the species;
- Scenario 2: Static habitat availability with enhanced probability of severe drought (11%) and no propagation of the species; and
- Scenario 3: Static habitat availability with enhanced probability of severe drought (11%) and propagation of the species.

To quantify the future risk of extirpation of each subpopulation and the species as a whole under these future scenarios, we ran a simple population model that estimates the probabilities of one subpopulation or both subpopulations becoming extirpated (*i.e.*, extinction of the species). The model predicted a high to extremely high probability that each or both subpopulations will be extirpated under Scenario 1 and Scenario 2 (25-100 years) (when CCC propagation is not utilized). Scenario 3 indicated that propagation could likely improve demographic factors such that the species may circumvent the downward spiral that is likely an extinction debt (Haag 2012, pp. 384-385).

Table ES-1. Summary of the probability of extirpation of one CCC subpopulation (*i.e.*, subpopulation extirpation) and both CCC subpopulations (*i.e.*, species extinction) given future scenarios. Time periods of 2045, 2070, 2095, and 2120 were used for the three future scenarios.

| Year | Recruitment Survival Coefficient | Probability of Subpopulation Extirpation Scenario 1 | Probability of Species Extinction Scenario 1 | Probability of Subpopulation Extirpation Scenario 2 | Probability of Species Extinction Scenario 2 | Probability of Species Extinction Scenario 3 |
|---|---|---|---|---|---|---|
| 2045 | 0.6 | 0.73 | 0.53 | 0.97 | 0.94 | 0 |
| | 0.4 | 0.84 | 0.71 | 0.97 | 0.94 | 0 |
| | 0.2 | 0.80 | 0.64 | 1 | 1 | 0 |
| 2070 | 0.6 | 0.89 | 0.79 | 1 | 1 | 0 |
| | 0.4 | 0.91 | 0.83 | 1 | 1 | 0 |
| | 0.2 | 0.99 | 0.98 | 1 | 1 | 0 |
| 2095 | 0.6 | 0.97 | 0.94 | 1 | 1 | 0 |
| | 0.4 | 0.99 | 0.98 | 1 | 1 | 0 |
| | 0.2 | 1 | 1 | 1 | 1 | 0 |
| 2120 | 0.6 | 0.99 | 0.98 | 1 | 1 | 0 |
| | 0.4 | 1 | 1 | 1 | 1 | 0 |
| | 0.2 | 1 | 1 | 1 | 1 | 0 |

In the future, the model indicates a high to extremely high probability of species extinction (Table ES-1) when introduced to future drought scenarios (Scenario 1 and 2) if species propagation (Scenario 3) was not considered, across all year projections (25-100 years). Both subpopulations of CCC shows critically limited ability to withstand, or be resilient to, stochastic events or disturbances into the future (*e.g.* drought, major storms and flooding, spills, or fluctuations in reproduction rates). It is extremely likely that extirpation of either or both subpopulations will occur in the future and what little representation and redundancy exists within the CCC will be also be reduced under all scenarios and time periods unless active propagation is conducted. The recolonization of sites (or one of the subpopulations) following a catastrophic event would be very difficult given the loss of additional sites (and one or both subpopulations) and reduced available habitat to the remaining population due to urban growth and no connectivity between subpopulations.

*Figure ES-2. CCC in situ, displaying its incurrent and excurrent apertures, photographed at Little Canoe Creek near Steele Station Road, St. Clair/Etowah County line, Alabama, on May 29, 2018. Photo credit: Lee Holt, USFWS.*

## VERSION HISTORY

**V. 1.0 – preliminary draft reflecting peer and partner review and submitted for manager consideration (July 18, 2019)**

**V. 1.1 – minor revisions including late suggestions following manager meeting, and reported results of the host trial by the Alabama Department of Conservation and Natural Resources (February 2020)**

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*Figure TC-1: LCC (east) downstream of Steele Station Road taken May 15, 2019. Photo credit: Todd Fobian, ADCNR.*

# ACRONYMS USED

| | |
|---|---|
| 3Rs | resiliency, representation, and redundancy |
| AABC | Alabama Aquatic Biodiversity Center |
| ADCNR | Alabama Department of Conservation and Natural Resources |
| ANHP | Alabama National Heritage Program |
| ARSN | Alabama Rivers and Streams Network |
| BCC | Big Canoe Creek |
| BMP | best management practice |
| CBD | Center for Biological Diversity |
| CCC | Canoe Creek clubshell |
| CPUE | catch per unit effort |
| CSP | Conservation Stewardship Program |
| DNA | deoxyribonucleic acid |
| EPA | U.S. Environmental Protection Agency |
| EQIP | Environmental Quality Incentives Program |
| ESA | Endangered Species Act |
| EWPP | Emergency Watershed Protection Plan |
| FR | Federal Register |
| FSA | Farm Service Agency |
| GSA | Geological Survey of Alabama |
| GIS | geographic information system |
| HUC | Hydrologic unit codes |
| LCC (East) | Little Canoe Creek in lower BCC watershed (St. Clair County) |
| LCC (West) | Little Canoe Creek in upper BCC watershed (St. Clair/Etowah County line) |
| MRBMRC | Mobile River Basin Mollusk Restoration Committee |
| mtDNA | Mitochondrial DNA |
| NCEI | National Center for Environmental Information |
| NFWF | National Fish and Wildlife Foundation |
| NGO | non-governmental organization |
| NIDIS | National Integrated Drought Information System |
| NOAA | National Oceanic and Atmospheric Administration |
| NPDES | National Pollutant Discharge Elimination System |
| NRCS | Natural Resource Conservation Service |
| PDSI | Palmer Drought Severity Index |
| PFW | Partners for Fish and Wildlife Program |
| Service | U.S. Fish and Wildlife Service |
| SHU | Strategic Habitat Unit |
| SSA | Species Status Assessment |
| TAN | total ammonia-nitrogen |
| TNC | The Nature Conservancy |
| TSS | total suspended solids |
| USDA | U.S. Department of Agriculture |
| USFS | U.S. Forest Service |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |

# CHAPTER 1 - INTRODUCTION

The Canoe Creek clubshell (*Pleurobema athearni*) (CCC) is a freshwater mussel known only from Big Canoe Creek (BCC), a western tributary to the Coosa River in St. Clair and Etowah counties, Alabama. The U.S. Fish and Wildlife Service (Service) is responsible for identifying species in need of protection under the Endangered Species Act of 1973 (ESA) as amended (16 U.S.C. 1531-1543). On April 20, 2010, the Service was petitioned by the Center for Biological Diversity (CBD), Alabama Rivers Alliance, Clinch Coalition, Dogwood Alliance, Gulf Restoration Network, Tennessee Forests Council, West Virginia Highlands Conservancy, Tierra Curry, and Noah Greenwald (referred to as the CBD petition) to list 404 aquatic, riparian, and wetland species from the southeastern United States under the ESA. The CCC was included under the CBD petition. In 2011, the Service made a 90-day finding for the CCC indicating that listing may be warranted, and initiated a status review (76 FR 59836). As a result of the Service's stipulated settlement agreement with CBD (August 30, 2016), the Service is required to submit a 12-month finding to the Federal Register by September 30, 2020. Therefore, a review of the status of the species was initiated to determine if the petitioned action is warranted. Based on the status review, the Service will issue a 12-month finding for the CCC. As such, we have conducted this Species Status Assessment (SSA) to compile the best available data regarding the species' biology and factors that influence the species' viability. The CCC SSA Report is a summary of the information assembled and reviewed by the Service and incorporates the best scientific and commercial data available. This SSA Report documents the results of the comprehensive status review for the CCC and will be the biological underpinning of the Service's forthcoming decision on whether the species warrants protection under the ESA.

The SSA framework (USFWS 2016, entire) is intended to be an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA Report to be easily updated as new information becomes available, and to support all functions of the Ecological Services Program of the Service, from Candidate Assessment to Listing to Consultations to Recovery. As such, the SSA Report will be a living document that may be used to inform ESA decision making, such as listing, recovery, Section 7, Section 10, and reclassification decisions (the former four decision types are only relevant should the species warrant listing under the ESA). Therefore, we have developed this SSA Report to summarize the most relevant information regarding life history, biology, and considerations of current and future risk factors facing the CCC. In addition, we forecasted the possible response of the species to predicted demographic and habitat factors including various future risk factors and environmental conditions to formulate a complete risk profile for the CCC.

The objective of this SSA is to thoroughly describe the viability of the CCC based on the best scientific and commercial information available. Through this description, we determined what the species needs to support viable populations, its current condition in terms of those needs, and its forecasted future condition under plausible future scenarios. In conducting this analysis, we took into consideration the likely changes that are happening in the environment – past, current, and future – to help us understand what factors drive the viability of the species. For the purpose of this assessment, we define viability as the ability of the CCC to sustain populations in natural river systems over time (25, 50, 75, 100 years based on future scenarios). Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time (USFWS 2016, p. 9). Using the SSA framework (Figure 1-1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (USFWS 2016, entire; Wolf *et al.* 2015, entire).

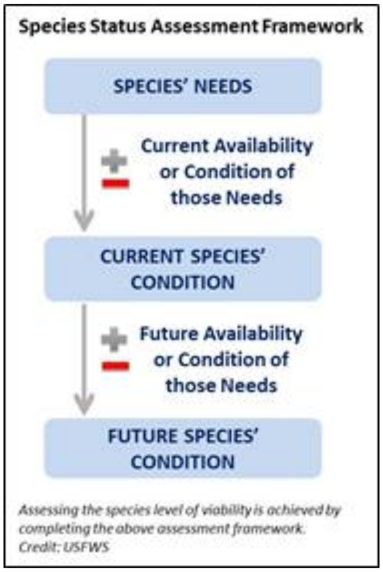


*Figure 1-1. Species Status Assessment Framework.*

- Resiliency describes the ability of a population to withstand stochastic disturbance. Stochastic events are those arising from random factors such as weather, flooding, or fluctuations in birth rates. Resiliency is positively related to population size and growth rate and may be influenced by connectivity among populations. Generally speaking, populations need enough individuals, within habitat patches of adequate area and quality, to maintain survival and reproduction in spite of disturbance. Resiliency is measured using metrics that describe population condition and habitat; in the case of the CCC, we developed a population model based on demographic information including species abundance and recruitment.

- Representation describes the ability of a species to adapt to changing environmental conditions over time. 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. Theoretically, the more representation the species has, the higher its potential of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluated representation based on Subpopulation East's drainage area being represented by two different physiographic provinces (Cumberland Plateau and Alabama Valley and Ridge), though all portions of it present range occurs within the Alabama Valley and Ridge.

- Redundancy describes the ability of a species to withstand catastrophic events. A catastrophic event is defined as a rare, destructive event or episode involving multiple sites (or populations) that occurs suddenly. Redundancy is about spreading the risk among populations, and thus, is assessed by characterizing the number of resilient populations across the range of the species.  The more resilient populations the species has, distributed over a larger area, the better chances that the species can withstand catastrophic events.  For the CCC (a narrow endemic), we used the number of resilient subpopulations, and the geographic distribution of those subpopulations, to measure redundancy within BCC.

To evaluate the viability of the CCC, we estimated and predicted the current and future condition of the species in terms of resiliency, redundancy, and representation.

This SSA Report includes the following chapters:

1. Introduction;
2. Individual and Species Needs: Life History, Biology, and Defining Populations. The life history of the species and resource needs, historical and current range and distribution, and populations;
3. Factors Influencing Viability. A description of likely causal mechanisms, and their relative degree of impact, on the status of the species;
4. Current Condition. A description of what the species needs across its range for viability, and estimates of the species' current range and condition; and,
5. Future Conditions and Viability. Descriptions of plausible future scenarios, and predictions of their influence, on CCC resiliency, representation, and redundancy.

This SSA Report provides a thorough assessment of the biology and natural history of the CCC and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the species.  Importantly, this SSA Report does not result in, nor predetermines, any decisions by the Service under the ESA.  In the case of the CCC, this SSA Report does not determine whether the CCC warrants protections of the ESA, or whether it should be proposed for listing as a threatened or endangered species under the ESA.  That decision will be made by the Service after reviewing this document, along with the supporting analysis, any other relevant scientific information, and all applicable laws, regulations, and policies.  The results of the decision will be announced in the *Federal Register*.  The contents of this SSA Report provide an objective, scientific review of the available information related to the biological status of the CCC.

# CHAPTER 2 – INDIVIDUAL AND SPECIES NEEDS: LIFE HISTORY, BIOLOGY, AND DEFINING SUBPOPULATIONS

In this chapter, we provide biological information about the CCC, including its taxonomic history, morphological description, and known life history. We then outline the resource needs of individuals. Lastly, we review the information on the current and historical range and distribution of the species, then define its known subpopulations, and describe subpopulation- and species-level needs.

## 2.1 Taxonomy

The CCC belongs to the Family Unionidae, also known as unionids, the naiads, and pearly mussels; a group of bivalve mollusks that have been in existence for over 400 million years and now representing over 600 species worldwide and nearly 300 in North America (Strayer *et al.* 2004, p. 429; Bogan and Roe 2008, p. 350; Lopes-Lima *et al.* 2018, p. 3; Williams *et al.* 2017, p. 33). This report on the CCC follows the most recently published and accepted taxonomic treatment of North American freshwater mussels as provided by Williams *et al.* (2017, entire).

The currently accepted classification of the CCC (Williams *et al.* 2017, pp 35, 41) is:

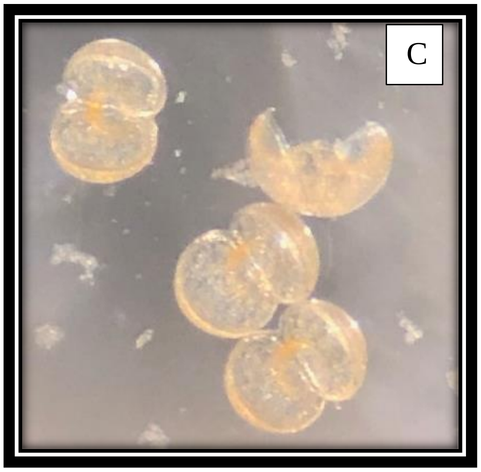
| | |
|---|---|
| Kingdom: | Animalia (Linnaeus, 1758) |
| Phylum: | Mollusca (Linnaeus, 1758) |
| Class: | Bivalvia (Linnaeus, 1758) |
| Intraclass: | Heteroconchia (Hertwig, 1895) |
| Cohort: | Uniomorphi (Gray, 1854) [=Paleoheterodonta] |
| Order: | Unionida (Gray, 1854) |
| Superfamily: | Unionoidea (Rafinesque, 1820) |
| Family: | Unionidae (Rafinesque, 1820) |
| Subfamily: | Ambleminae (Rafinesque, 1820) |
| Tribe: | Pleurobemini (Hannibal, 1912) |
| Genus: | *Pleurobema* (Rafinesque, 1819) |
| Species: | *Pleurobema athearni* (Gangloff, Williams, and Feminella, 2006) |

The CCC was only recently (2006) described as a distinct species and was placed into the genus *Pleurobema* (Gangloff *et al.* 2006, entire document). It was first collected by H. D. Athearn (1967 and 1969), its namesake, and later by J. C. Hurd (1973). Athearn mistakenly identified CCC as the gulf pigtoe (*Fusconaia cerina*) and Hurd mistakenly identified it as the ovate clubshell (*Pleurobema perovatum*) (Gangloff and Feminella 2007, p. 43). It superficially resembles the southern pigtoe (*Pleurobema georgianum*) that also co-occurs within the BCC watershed (Williams *et al.* 2008, pp. 506, 532). Gangloff *et al.* (2006) found CCC to be morphologically different from other similar taxa, as it differs in both shell width/length and width/height ratios from southern pigtoe, Tennessee pigtoe (*Fusconaia barnesiana*), and gulf pigtoe, which it superficially resembles and that also occurs in the same general geographic area (Gangloff *et al.* 2006, p. 43). Relatively small mtDNA (mitochondrial DNA) differences between CCC and southern pigtoe suggest these species may represent a recent evolutionary divergence (Gangloff *et al.* 2006, p. 52; Campbell *et al.* 2005, p. 143; Campbell *et al.* 2008, p. 717). Other Mobile Basin unionids also have relatively small genetic differences between species (Mulvey *et al.* 1997, pp. 875-877; Campbell *et al.* 2008, p. 717; Campbell and Lydeard 2012, pp. 24-27). It is difficult to rely solely on the limited available genetic data to be certain of CCC as a distinct species (Gangloff *et al.* 2006, p. 52). However, given that it is morphologically quite distinct, in addition to the mitochondrial percent differences that are lower than average for interspecies comparisons and higher than average for intraspecies comparisons (Campbell *et al.* 2008, p. 719), the evidence supports CCC as a distinct species.

## 2.2 Species Description

The CCC (Figure 2-1) is a medium sized mussel up to 97 mm in length, with a moderately thick shell, that is thickest anteriorly and thinnest posteriorly near the apertures (Gangloff *et al.* 2006, p. 48; Williams *et al.* 2008, p. 505; Fobian *et al.* 2017, p. 97). The shell outline is roughly ovate or sub-ovate, with slight sculpturing on the posterior-dorsal third of the valves (Gangloff *et al.* 2006, p 48). The periostracum of the shell is tawny to brown in color and without rays (Williams *et al.* 2008, p. 505), with dark yellow to faint green growth rests (a ridge formed during an intermediate stage of growth when this area was the edge of the shell) present on smaller individuals (< 40 mm) (Gangloff *et al.* 2006, p. 48). The nacre is also white, usually iridescent posteriorly (Gangloff *et al.* 2006, p 48).

*Figure 2-1. A) Adult CCC collected from Little Canoe Creek, Steele Station Road, St. Clair/Etowah County line, Alabama, on October 17, 2018; B) CCC conglutinates recovered from gravid specimen from Big Canoe Creek near the U.S. Highway 231 bridge crossing, St. Clair County, Alabama, on May 26, 2004; C) CCC glochidia (larval mussels) collected from a gravid female on May 29, 2019. Photo Credit: A) Todd Fobian, ADCNR, B) Paul Johnson, ADCNR, C) Michael Buntin, ADCNR.*



The soft tissues are salmon orange in living animals, with the aperture margins appearing as brown to black, but are typically reddish-brown or brown (Gangloff *et al.* 2006, p. 49). The mantle, visceral mass (some are rusty tan to grayish brown outside of apertures), and foot are all pale tan in color (Williams *et al.* 2008, p. 505). The papillae are either single or bifid and usually larger along the margin of the incurrent aperture; and large bifid papillae are interspersed with the smaller, single bifid papillae along the apertures (Figure ES-2) (Gangloff *et al.* 2006, p. 49). The inner gills are approximately 1.5 times larger (in surface area) than the outer gills (Gangloff *et al.* 2006, p. 49). Gravid females have been documented in May and June in water temperatures between 16.5-22 degrees Celcius (°C ) (Fobian 2019, p. 10), suggesting that the species is a short-term brooder (similar to other *Pleurobema spp*.). The conglutinates are lanceolate-shaped with developed glochidia scattered throughout unfertilized structural eggs, measure 10-15 mm in length, 1-2 mm in width, and are either cream white, orange, or pink in color (Gangloff *et al.* 2006, p. 49; Fobian 2019, p. 5). Glochidia vary in color from white to orange were unhooked (Figure 2-1) and measured 135.2 ± 8.29 micrometer (µm) in length, 134.7 ± 8.67 µm in height, with a length/height ratio of 1.01 ± 0.07 (glochidial measurements are micrometers ± standard deviation) (Fobian 2019; pp. 5-6, 16).

The CCC superficially resembles the southern pigtoe, but can be differentiated by the deeper umbo cavity and is absent of the green rays on the upper part of the disk or posterior ridge, which is present on the southern pigtoe (Williams *et al.* 2008, p. 506; Gangloff *et al.* 2006, pp. 47-48). Additionally, CCC is typically more compressed and round than the southern pigtoe, and less elongate and more compressed than the southern clubshell (*Pleurobema decisum*) or Georgia pigtoe (*Pleurobema hanleyianum*) (other *Pleurobema* spp. that co-occur with CCC within BCC) (Gangloff *et al.* 2006, p. 47-48; Fobian *et al.* 2017, p 24). Additionally, Gangloff *et al.* (2006) found variation in shell morphometry ratios of CCC to be significantly different when compared to other similar species within the Mobile and Tennessee drainage basins (Gangloff *et al.* 2006, pp. 47, 49-51).

## 2.3 Range and Distribution

The CCC is only known to occur within the BCC watershed in St. Clair and Etowah counties, Alabama (Gangloff *et al.* 2006, p. 53; Williams *et al.* 2008, p. 506). BCC is a western tributary of the Coosa River and encompasses 583 km$^2$ (Wynn *et al.* 2016, p. 6). The BCC watershed is located in two physiographic provinces, the Cumberland Plateau in the north and the Alabama Valley and Ridge to the south (Figure 2-2) (Wynn *et al.* 2016, p. 7). The BCC mainstem originates in the Ridge and Valley Physiographic Province near Springville, Shelby County, Alabama and flows northeast for 84 km before joining the Coosa River (H. Neely Henry Reservoir) on the St. Clair and Etowah County line, Alabama (Gangloff *et al.* 2006, p. 53; Wynn *et al.* 2016, p. 6-7). Historically BBC flowed unimpeded for another 15 km, prior to the impoundment of this reach, before reaching the Coosa River mainstem (Gangloff *et al.* 2006, p. 53).

Limited historical distribution data is available for the CCC due to only recently being described and the scarcity of previously vouchered individuals within museum collections (Gangloff *et al.* 2006, p. 47, MRBMRC 2010, p. 26). However the most recent comprehensive survey of BCC mussels (Fobian *et al.* 2017, pp. 26-29) verified the continued presence of CCC at historical locations (*i.e*., individuals vouchered in museum collections) (Gangloff *et al.* 2006, p. 47) and documented new range extensions within lower Little Canoe Creek (LCC-east) on the St. Clair and Etowah County line.

The CCC are currently known to be confined to 50.6 km of stream length within the BCC watershed. Survey records of CCC are known from 4.7 km of stream length in LLC (east) along the St. Clair/Etowah County line, within 31.3 km of the BCC mainstem, and 14.6 km within LCC (west), St. Clair County. Occupied habitat consists of survey data from the past 20 years (1999-2019), where live CCC or shell material (fresh dead, weathered dead, or relic shells) were documented.

The type locality (Holotype, USNM 1078388, length 84 mm) of the CCC is BCC, approximately 1 km downstream of St. Clair County Road 36, near the mouth of Muckleroy Creek, St. Clair County, Alabama (Collected: September 23, 2001) (Gangloff *et al.* 2006, p. 47).

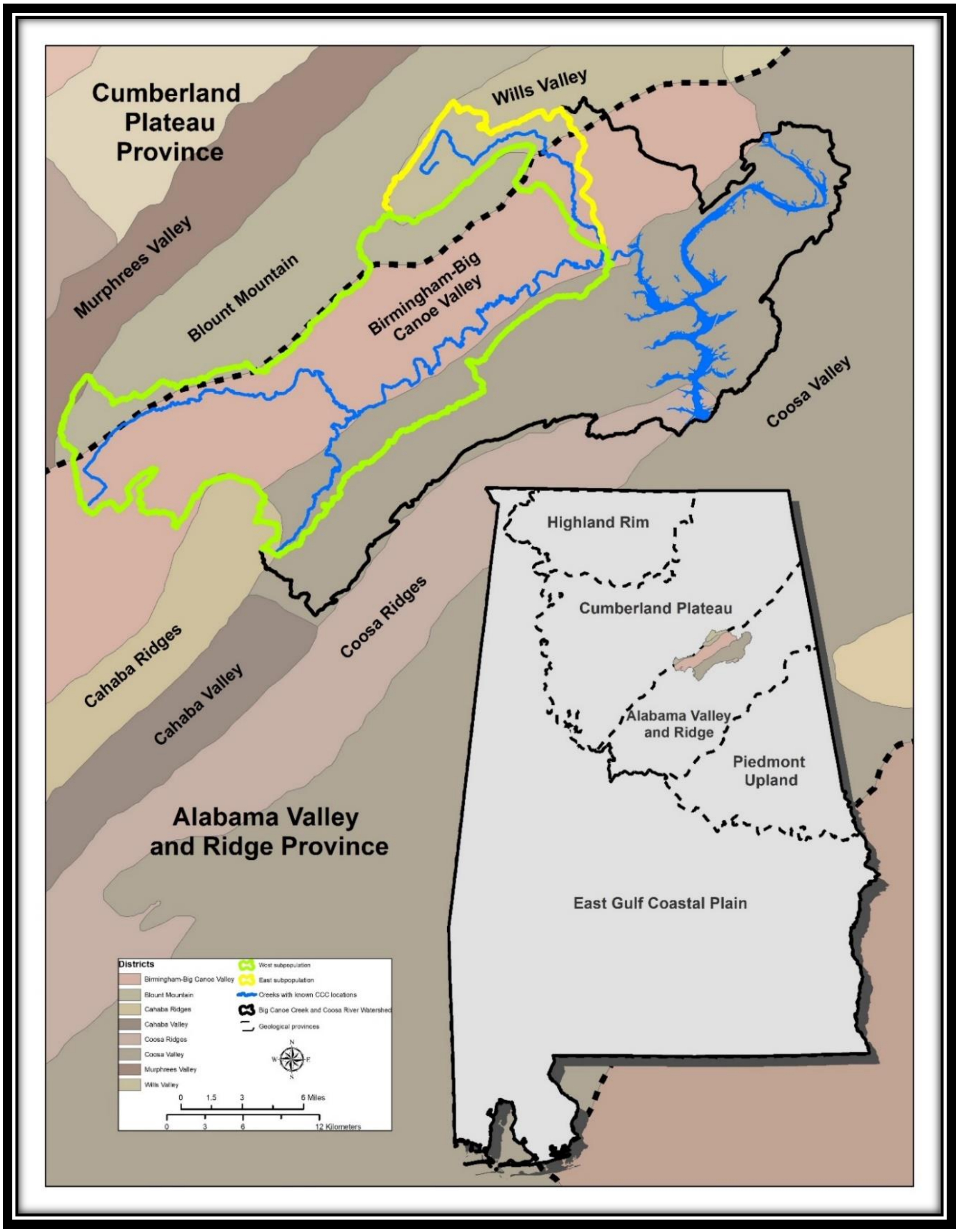


*Figure 2-2. Big Canoe Creek watershed physiography.*

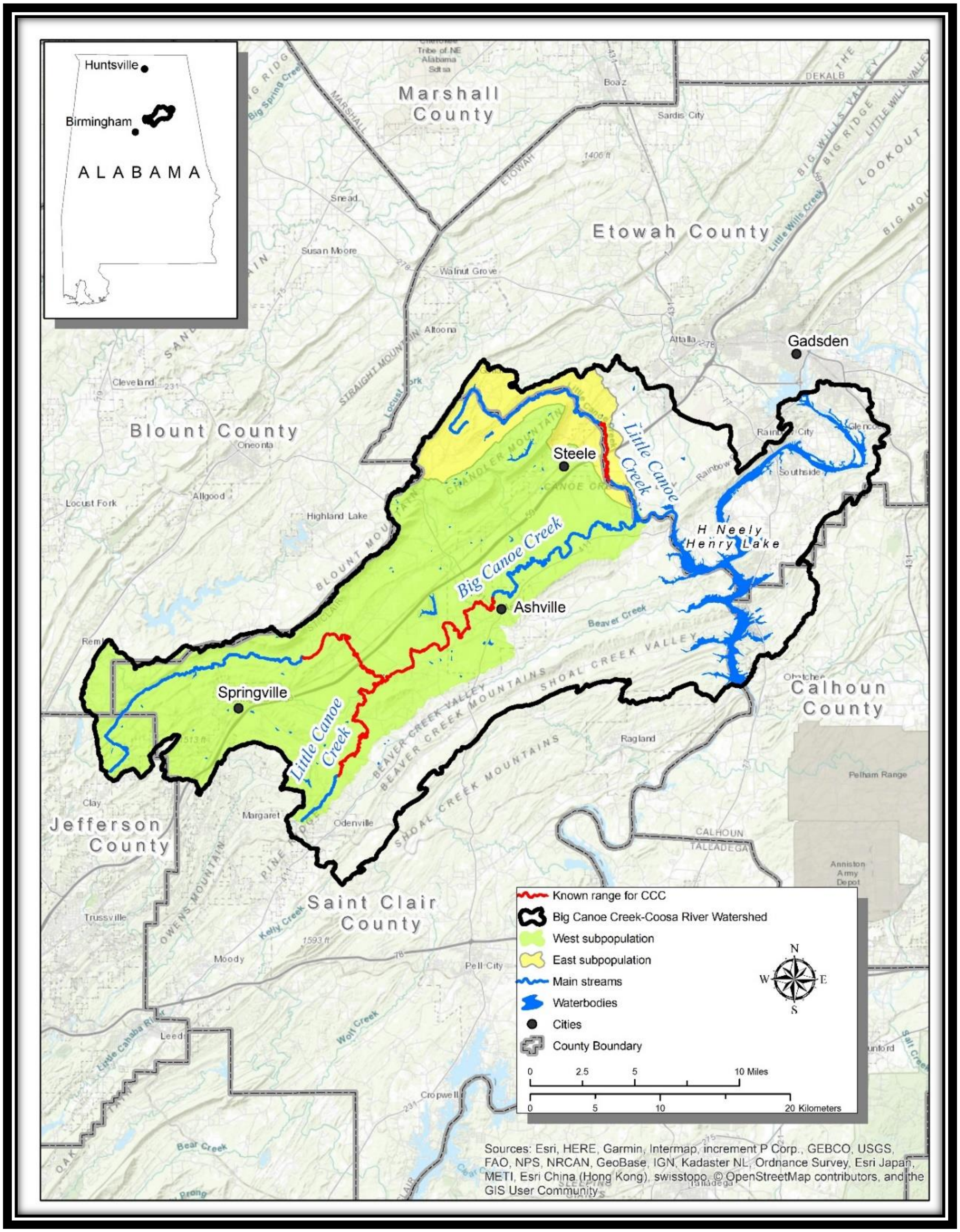


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*Figure 2-3. Canoe Creek Clubshell (CCC) subpopulation ranges within Big Canoe Creek watershed (HUC-10) based on HUC-12 watershed boundaries and tributaries flowing into H. Neely Henry Lake. The Big Canoe Creek-Little Canoe Creek West (West) subpopulation is highlighted in green; the Little Canoe East (East) subpopulation is highlighted in yellow.*

## 2.4 Life History

There are no studies on the average life expectancy of the CCC. However, members of the tribe Pleurobemini, to which CCC belongs, are long lived and slow growing (Reategui-Zirenaet *et al.* 2013, p. 167). Haag and Rypel (2010, p. 6) reported multiple (9) maximum ages for both Pleurobema and Fusconaia species, these ages ranged between 15-51 years with a mean age of 32.5 years. The maximum documented age estimate for a *Pleurobema* species (the fuzzy pigtoe (*P. strodeanum*)) is 74.5 years (Reategui-Zirenaet *et al.* 2013, p. 167). The closely related southern clubshell (Campbell *et al.* 2008, p. 717), which is also endemic to BCC and can obtain a similar maximum size (Williams *et al.* 2008, pp. 505-506, 519-523), has been found to live an estimated 45 years (Haag and Rypel 2010, p. 6). At this time, the best available information suggests that the CCC is a relatively long-lived species estimated at 25 to 35 years, but possibly up to 50 years given the large size it can attain.

No studies have been conducted on CCC to indicate sex ratios or age at sexual maturity; however, we do have recent estimates of growth and fecundity for CCC (Fobian 2019, pers. comm.). Using external shell annuli from CCC, we can estimate an animal is approximately 11 mm at the end of the first growth season, 23 mm at the second, 33 mm at the third, 42 mm at the forth, 49 mm at the fifth, 55 mm at the sixth (Figure 2-4) (Fobian 2019, pers. comm.). Sexual maturity for CCC is likely somewhere between the 4th-6th growth seasons, as growth slows following the 4th growth season (Fobian 2019, pers. comm.), likely indicating a diversion of resources from growth to reproduction (Haag and Rypel 2010, p. 19), even though the closely related southern clubshell has been shown to reach sexual maturity when as small as 26.3 mm (Haag and Staton 2003, p. 2122). Fecundity was recently recorded for three CCC females (lengths of 61, 75, and 76 mm); total glochidia (larval mussels) ranged between 5,500-46,000 and total viable glochidia ranged from 5,400-17,400 (Fobian 2019, p. 12). Conglutinates were orange or white in color with each female producing between 60-70 conglutinates each (Figure 2-1) (Fobian 2019, pers. comm., Fobian 2019, p. 5). The closely related southern clubshell has even sex ratios (Haag and Staton 2003, pp. 2122). We believe that CCC also likely has similar sex ratios (*i.e.*, 1:1), given similar breeding strategies among those in the *Pleurobema* genus (*e.g.*, pelagic conglutinates), and the similar sizes of these two species (CCC and southern clubshell).

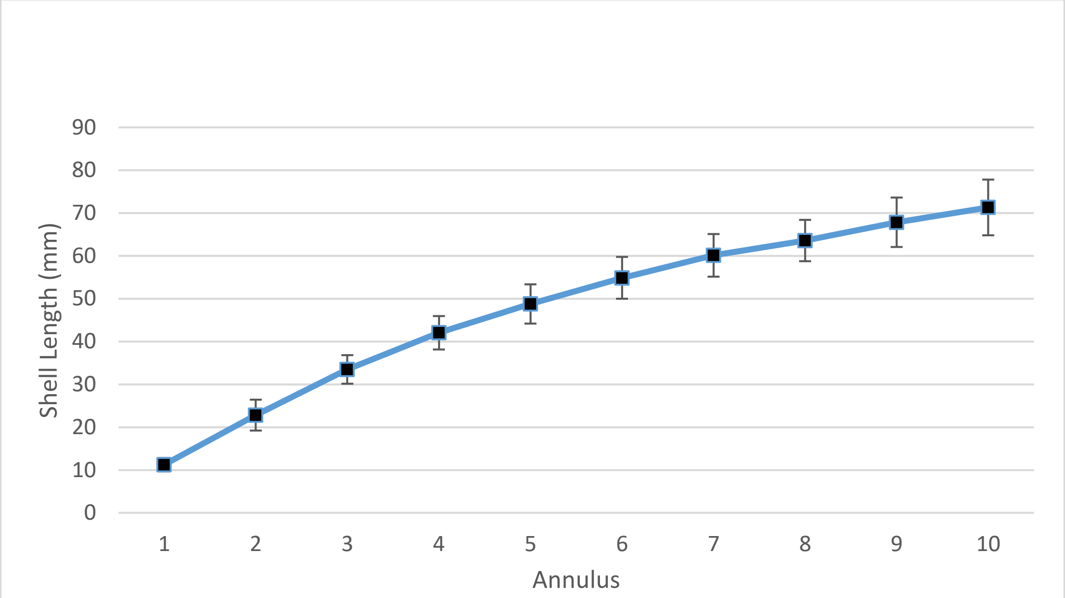


*Figure 2-4. CCC mean annuli growth points ± standard deviation (N=10, mean length 72 mm, range 62-89 mm) (Measurements courtesy of Todd Fobian 2019 pers. comm.).*

### 2.4.1 Reproduction

The CCC has a complex life cycle that relies on fish hosts for successful reproduction, similar to other mussels. In general, mussels are either male or female (Haag 2012, p. 37). Males release sperm into the water column, which is taken in by the female through the incurrent aperture (Figure ES-2), where water enters the mantle cavity. The sperm fertilizes eggs that are held within the female's gills in the marsupial chamber. The developing larvae remain in the gill chamber until they mature (called glochidia) and are ready for release. (See Figure 2-5 for a generalized freshwater mussel life cycle.) Freshwater mussels such as the CCC have a complex life history involving an obligate parasitic larval life stage, which are wholly dependent on a suitable host fish (Haag 2012, pp. 38-41).

The CCC is believed to be tachytictic (a short-term brooder) and gravid in spring and summer, similar to other *Pleurobema* species (Williams *et al.* p. 506; MRBMRC 2010, p. 26; Gangloff *et al.* 2006, p. 47). Gravid CCC have been collected from LCC (east) in May and June (2019), with water temperatures between 16.5-22.0 degrees Celsius (°C ) (Fobian 2019, p. 10). Similar to other species in the tribe Pleurobemini, the CCC targets drift-feeding minnow species (*e.g.*, members of *Cyprinidae*) as their host fish by releasing glochidia contained in packets called conglutinates (Figure 2-1) (Haag 2012, p. 163); more specifically, pelagic conglutinates (Haag 2012, p. 148; Williams *et al.* 2008, p. 506) (Figure 2-1). A host trial was conducted for the CCC in May-June 2019, and identified the tricolor shiner (*Cyprinella trichroistia*), Alabama shiner (*C. callistia*) as primary hosts with metamorphosis rates of 78.5 and 73.6, respectively (Fobian 2019, pp. 6, 14). Eight other species of fish were determined to be marginal hosts. Striped shiner (*Luxilus chrysocephalus*) had the best metamorphosis rate (34.6%) of the marginal hosts (Fobian 2019, pp. 6, 14); while the others: stoneroller (*Campostoma oligolepis*), Coosa shiner (*Notropis xaenocephalus*), silverstripe shiner (*N. stilbius*), longear sunfish (*Lepomis megalotis*), bronze darter (*Percina palmaris*), fathead minnow (*Pimephales promelas*), and golden shiner

(*Notemigonus cysoleucas*); had less than 7% metamorphosis (Fobian 2019, pp. 6, 14). Juvenile CCC were recovered from host fish during this trial between 10 to 25 days post glochidial attachment to fish with peak juvenile recovery occurring at 19 days post-inoculation (Fobian 2019, pp. 6).

Mussels in the genus *Pleurobema* (*e.g.*, southern clubshell) have been shown to forcefully eject their conglutinates approximately 15-20 cm into the water column, where they drift in the current, usually in the mid-water column of deep riffles and runs (Haag 2012, p. 163). Drift feeding minnows *(e.g., Cyprinella spp.*), which are sight feeders and forge predominately in the mid-water column, will attack these conglutinates (Haag 2012, p. 163). At which time, the glochidia snap shut when they come in contact within the gills or fins of these fishes. For most mussels, the glochidia will die if they do not attach to a fish within a short period (2-14 days, depending on species and water temperature, Haag 2012, p. 141). Once on the fish, the glochidia are engulfed by tissue from the host fish (encyst). The cyst protects the glochidia and aids in their maturation. The larvae draw nutrients from the fish and develop into juvenile mussels, weeks to months after initial attachment (Arey 1932, p. 213-214; Haag 2012, p. 42). Glochidia usually remain encysted on the host for a variable period lasting 2-4 weeks (especially for short-term brooders like *Pleurobema*), but can range to more than 100 days (Haag 2012, p. 42). During the 2019 host trial of CCC, when encystment was maintained at 18 °C ± 2 °C, peak excystment (when juveniles mussels drop from the fish host) occurred 19 days post infection (M. Fobian 2019, pp. 6, 17). When the metamorphosis is complete, juvenile mussels exit the cyst, fall to the stream bottom, and begin their free-living benthic existence for the remainder of their lives (Haag 2012, p. 42).

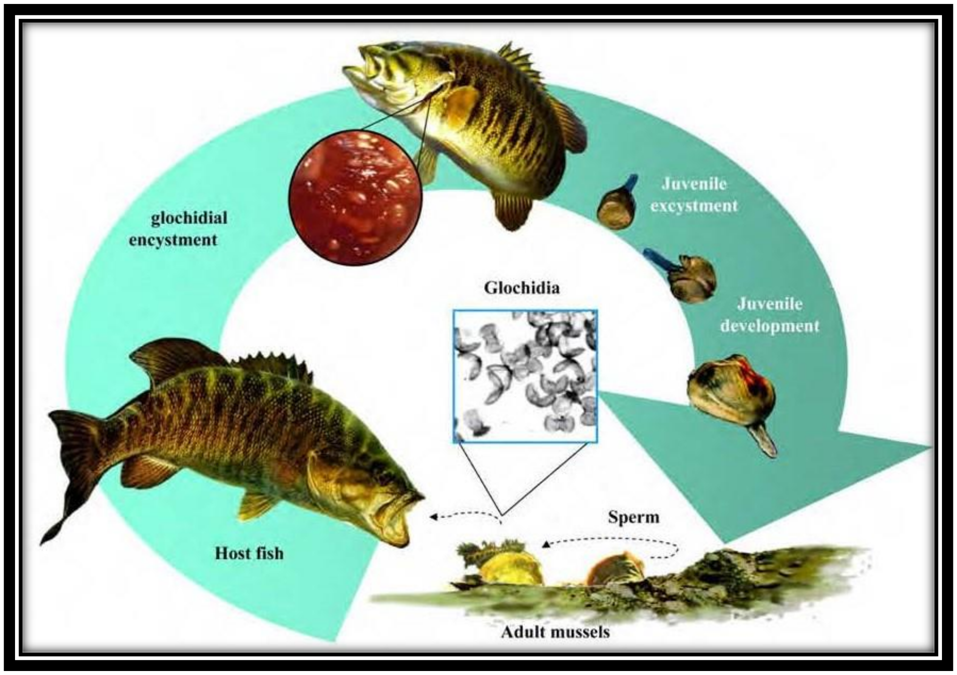


*Figure 2-5. Generalized freshwater mussel life cycle. (Image courtesy of Shane Hanlon, USFWS)*

### 2.4.2 Recruitment Success

Survival of adult mussels is generally high with annual adult survival of more than 90% for many mussel species, including closely related *Fusconaia* species (Haag 2012, p. 218). Conversely, the survival from the glochidial stage is exceptionally low (to the order of $10^{-5}$ (0.00001%) to $10^{-6}$ (0.000001%)) with individual females successfully producing only 0.1 to 1.3 juveniles/year (Haag 2012, p. 220), despite annual fecundity of many thousands to millions of glochidia (Haag and Staton 2003, pp. 2122-2123; Haag 2013, pp. 748-751). While no information is available from the wild for survival of recruits immediately after settlement, it is believed to be extremely low. Survival of newly settled juveniles in a hatchery setting has been recorded at about 50% during the first 50 days after excysting (Hanlon and Neves 2006, p. 47-48). But, survival does increase significantly after settlement. Long-lived mussel species within culture facilities can be as high as 83%, after reaching 4 mm in length (Haag 2012, p. 220). The closely related southern clubshell has a recruitment survival of 98% and an adult survival of 88% (Haag 2012, p. 221).

### 2.4.3 Mussel movement and dispersion

Mussels are generally immobile but experience their primary opportunity for dispersal and movement within the stream as glochidia attached to a mobile host fish (Smith 1985, p. 105). Even though, movement of the family Cyprinidae (shiners and minnows) (CCC’s likely host) is relatively small (Radinger and Wolter 2014, p. 461). An example of distance moved by a member of that family was documented in a study of movement patterns by the blue shiner (*Cyprinella caerulea*). During that study, the blue shiner moved an average distance of just 130.7 meters with the longest distance moved by that species during the study, 332 meters (Johnston 2000, pp. 170, 174). After being transported by the host fish,the newly transformed juveniles drop to the substrate on the bottom of the stream. Those juveniles that drop in unsuitable substrates die because their immobility prevents them from relocating to more favorable habitat. Juvenile freshwater mussels burrow into interstitial substrates and grow to a larger size that is less susceptible to predation and displacement from high flow events (Yeager *et al.* 1994, p. 220). Adult mussels typically remain within the same general location where they are dropped off (excysted) of their host fish as juveniles.

### 2.4.4 Feeding

Adult freshwater mussels, including CCC, are primarily suspension-feeders that filter water and nutrients to eat. Filter feeding also allows for oxygen uptake, waste excretion, and gamete dispersal and acquisition through the inhalant and exhalent apertures (Haag 2012, p. 27). Filter rates can be up to 1 liter/hour/individual (Haag 2012, p. 28). Mussels may also shift to deposit feeding, and the reasons for this are poorly known but it may depend on flow conditions or temperature. Deposit feeding can occur in two ways, including uptake of material through the shell gape by the suction created by the cilia on the foot and pedal feeding by the cilia on the foot (Haag 2012, p. 28). For their first several months, juvenile mussels use pedal feeding (deposit feeding) extensively by sweeping their foot through the sediment, using the cilia on the foot to uptake material (Haag 2012, p. 28), although they may also filter interstitial pore water and soft sediments (Yeager *et al.* 1994, p. 221; Haag 2012, p. 26). The importance of pedal feeding declines during the first year as the filtering mechanism (suspension feeding) becomes better developed (Haag 2012, p. 28). During suspension or deposit feeding, it is necessary for the shell to be slightly agape to either filter water or extend the foot for deposit feeding (Haag 2012, p. 28).

Mussels are omnivores and their diet consists of a wide variety of particulate material (primarily less than 20 µm in size), including algae, bacteria, detritus, and microscopic animals (Gatenby *et al.* 1996, p. 606; Haag 2012, p. 26). It has also been surmised that dissolved organic matter may be a significant source of nutrition (Vaughn *et al.* 2008, p. 411). Such an array of foods, containing essential long-chain fatty acids, sterols, amino acids, and other biochemical compounds, may be necessary to supply total nutritional needs (Strayer *et al.* 2004, p. 431).

## 2.5 Individual Needs

As discussed above, the CCC has a multi-staged life cycle: fertilized eggs to glochidia to juveniles and sub adults to adults. Each life stage has specific requirements (resource needs) that must be met for the mussel to progress to the next stage. Table 2-1 outlines these resource needs for each stage.

*Table 2-1. Resource needs for CCC to complete each life stage.*

| Life Stage | Resources needed | Information Source |
|---|---|---|
| Fertilized Eggs (early spring – broadcast sperm, egg development, to fertilization) | • Clear, flowing water<br>• Sexually mature males upstream from sexually mature females<br>• Appropriate spawning temperatures. | Berg *et al.* 2008, p. 397;<br>Haag 2012, pp. 38-40 |
| Glochidia<br>(late spring to early summer – from attachment through excystment) | • Clear, flowing water<br>• Enough flow to keep glochidia or conglutinates adrift and to attract drift-feeding host fish (*Pleurobema* species utilize pelagic conglutinates (requires sight feeding) to attract suitable host fish).<br>• Presence of host fish for attachment, where they obtain nutrients from the host's tissues and blood plasma for approximately 2-4 weeks. | Strayer 2008, p. 65;<br>Haag 2012, pp. 40-42 |
| Juvenile and sub adult (excystment through sexual maturity) | • Clear, flowing water<br>• Host fish dispersal<br>• Appropriate interstitial chemistry; high dissolved oxygen, low salinity, low | Williams *et al.* 2008, pp 505-506; Haag 2012 pp. 26-28, 363; Dimmock and Wright 1993, pp. 188-190; Sparks and Strayer |

| Life Stage | Resources needed | Information Source |
|---|---|---|
|  | ammonia, low copper, and other contaminants, high dissolved oxygen.<br>• Appropriate substrate (clean gravel, sand/cobble) for settlement<br>• Adequate food availability (phytoplankton, zooplankton, bacteria, and dissolved organic matter)<br>• Appropriate water temperature. | 1998, p. 132; Augspurger *et al.* 2003, p. 2574; Augspurger *et al.* 2007, p. 2025; Stayer and Malcom 2012, pp. 1787-1788; Yeager *et al.* 1994, p. 221; Nichols and Garling 2000, p. 881; Chen *et al.* 2001, p. 214; Spooner and Vaughn 2008, p. 308 |
| Adults | • Clear, flowing water<br>• Appropriate substrate (stable gravel and course sand free from excessive silt)<br>• Adequate food availability (phytoplankton, zooplankton, bacteria, and dissolved organic matter)<br>• High dissolved oxygen<br>• Appropriate water temperature. | Yeager *et al.* 1994, p. 221; Nichols and Garling 2000, p. 881; Chen *et al.* 2001, p. 214; Spooner and Vaughn 2008, p. 308; Haag 2012, p 26-28, 156 |

### 2.5.1 Clean, Flowing Water

CCC habitat includes rivers and streams with natural flow regimes within the BCC watershed. While many mussels can survive seasonally low flows and periodic short-term drying events, intermittent stream habitats generally cannot support mussel populations.

Because a lotic (*i.e.*, flowing water) environment is a critical need for the CCC, perturbations that disrupt natural flow patterns (*e.g.*, dams) have a potential negative influence on CCC resilience metrics. CCC habitat must have adequate flow to deliver oxygen, enable passive reproduction, and deliver food to filter-feeding mussels (see Table 2-1, above). Further, flowing water removes contaminants and fine sediments from interstitial spaces preventing mussel toxicity or suffocation. Stream velocity is not static over time, and variations may be attributed to seasonal changes (with higher flows in winter/spring and lower flows in summer/fall), extreme weather events (*e.g.*, drought or floods), or anthropogenic influence (*e.g.*, flow regulation via impoundments). The CCC relies on sight-feeding fishes as part of its life cycle like many other mussels that use conglutinates; therefore, turbidity during critical reproductive periods may impact glochidial attachment and ultimately decrease recruitment in any given population (McLeod *et al.* 2017, p. 348).

While mussels have evolved in habitats that experience seasonal fluctuations in discharge, global weather patterns can have an impact on the normal regimes (*e.g.*, El Niño or La Niña). Even during naturally occurring low flow events, mussels can become stressed because either they exert significant energy to move to deeper waters or they may succumb to desiccation (Haag 2012, p. 109). Droughts during the late summer and early fall may be especially stress-inducing because streams are already at their naturally occurring lowest flow rate during this time.

### 2.5.2 Appropriate Water Quality and Temperatures

Freshwater mussels, as a group, are particularly sensitive to changes in water quality parameters, including (but not limited to): dissolved oxygen (generally below 2–3 parts per million (ppm)), ammonia (generally above 0.5 ppm total ammonia-nitrogen (TAN)), elevated temperature (generally above 30 °C), excessive total suspended solids (TSS), and other pollutants. Habitats with appropriate levels of these parameters are considered suitable, while those habitats with levels outside of the appropriate ranges are considered less than suitable.

Appropriate water temperature thresholds for the CCC are still largely unknown; what information does exist, primarily focuses on temperatures necessary for reproduction. The host fish trials for CCC conducted in May-June, 2019, collected gravid females within LCC (east) at stream temperatures between 16-22 °C. Four gravid female CCC were brought back to the laboratory where temperatures were raised to match natural temperature timing into LCC (east). Conglutinates matured after being held at 21.5 °C, and excystment occurred between 22-24 °C (Fobian 2019, pp. 5-6; M. Buntin 2019 pers. comm.). Analogous species (*i.e.*, *Pleurobemini* species) responded in a similar manner. Gravid southern clubshell released all of their glochidia within 24-48 hours when brought back to a laboratory and placed within beakers at 21-25 °C (Haag and Stanton 2003, p. 2121). A 1986–1987 study of the fine-rayed pigtoe (*F. cuneolus*) in the Clinch River suggests that glochidia are released between 21 and 27 °C, and metamorphosis on fishes occurs at water temperatures between 22 and 25 °C (Bruenderman and Neves 1993, p. 86). In addition, the highest glochidial release densities were at 23 °C weekly median temperature (at Slant, Virginia; Bruenderman and Neves 1993, p. 86).

### 2.5.3 Stable In-Stream Substrate

Optimal substrate for the CCC is predominantly gravel without excessive accumulation of silt and detritus (Williams *et al.* 2008, p. 506). Riparian condition strongly influences the composition and stability of substrates that mussels inhabit (Allan *et al.* 1997, p. 149).

### 2.5.4 Food and Nutrients

Adult freshwater mussels, including the CCC, are filter-feeders, drawing in suspended phytoplankton, zooplankton, rotifers, protozoans, detritus, and dissolved organic matter from the water column (Strayer *et al.* 2004, p. 430) and from sediment; juvenile mussels are capable of pedal and deposit feeding to collect food items from sediments (Vaughn *et al.* 2008, pp. 409-411). Glochidia can derive what nutrition they need from their obligate fish hosts (Barnhart *et al.* 2008, p. 372). Freshwater mussels must keep their shells open, or gaped, to obtain food and facilitate gas exchange, but they often respond to water quality impairments by closing their shells (Bonner *et al.* 2018, p. 141). Food supply is not generally considered limiting in environments inhabited by the CCC. However, food limitation may be important during times of elevated water temperature, as both metabolic demand and incidence of valve closure increases concomitantly, resulting in reduced growth and reproduction (Bonner *et al.* 2018, p. 6).

## 2.6 Subpopulation- and Species-level Needs

### 2.6.1 Defining Subpopulations

The CCC is a narrow endemic within the Big Canoe Creek (BCC) (0315010603) Hydrologic Unit Code (HUC) 10 (U.S. Geological Survey) watershed and is comprised of two subpopulations: Subpopulation West (Figure 2-6) and Subpopulation East (Figure 2-7). Subpopulation West includes the Middle Big Canoe Creek (031501060305), Upper Big Canoe Creek (031501060303), Headwaters Big Canoe Creek (031501060302), and Little Canoe Creek (031501060301) HUC 12 Units in St. Clair County, Alabama (Figure 2-6). Subpopulation East includes the Lake Sumatanga-Little Canoe Creek (031501060304) HUC 12 unit in Etowah and St. Clair Counties, Alabama (Figure 2-7).

Likely no genetic exchange occurs between these two subpopulations, given the significant distance between them (~28 km) that exceeds the dispersal range of any expected shiner hosts (Radinger and Wolter 2014, p. 461). Additionally, because both subpopulations empty into H. Neely Henry Reservoir near the confluence of LCC (east), neither subpopulation receives direct flow from the other, which prevents exchange of gametes. LCC (east) flows an additional 4.5 km downstream of Subpopulation East before reaching its confluence with BCC. BCC flows an additional 23.5 km downstream of Subpopulation West before reaching the mouth of LCC (east).

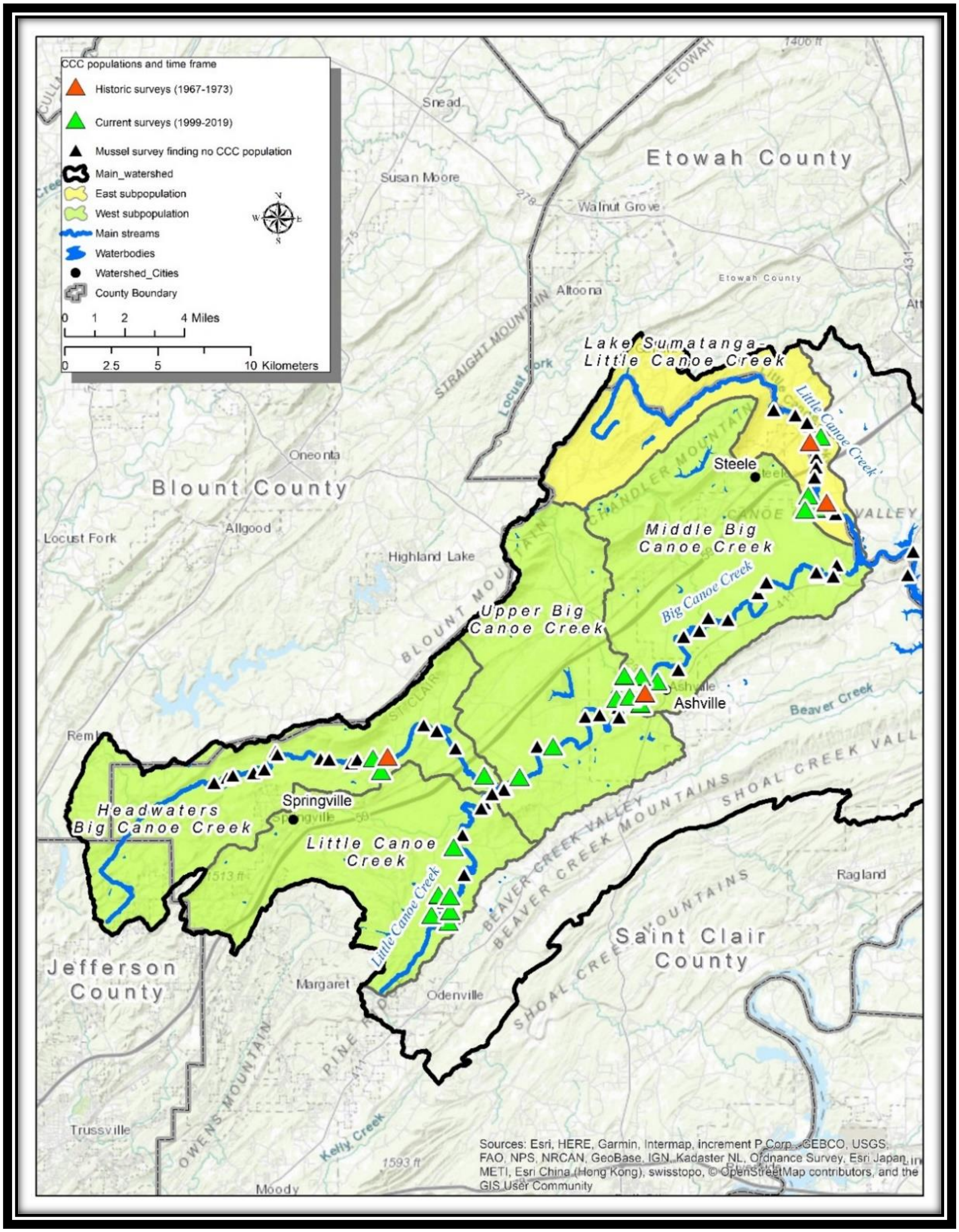


*Figure 2-6. Map of the West and East CCC subpopulation survey data. CCC subpopulations based on HUC-12 watershed boundaries and tributaries flowing into H. Neely Henry Lake. The BCC-LCC East (East) subpopulation is highlighted in green; the Little Canoe East (East) subpopulation is highlighted in yellow. The red stream lengths include the current and historical known range of CCC. Survey data is provided as triangles. Red triangles represent historical surveys (1967-1973) with CCC present, green triangles represent current surveys (1999-2019) with CCC present, and the smaller black triangles represent mussel surveys where no CCC were present. CCC were considered present if they were found alive, or as a fresh dead, weathered dead, or relic shell.*

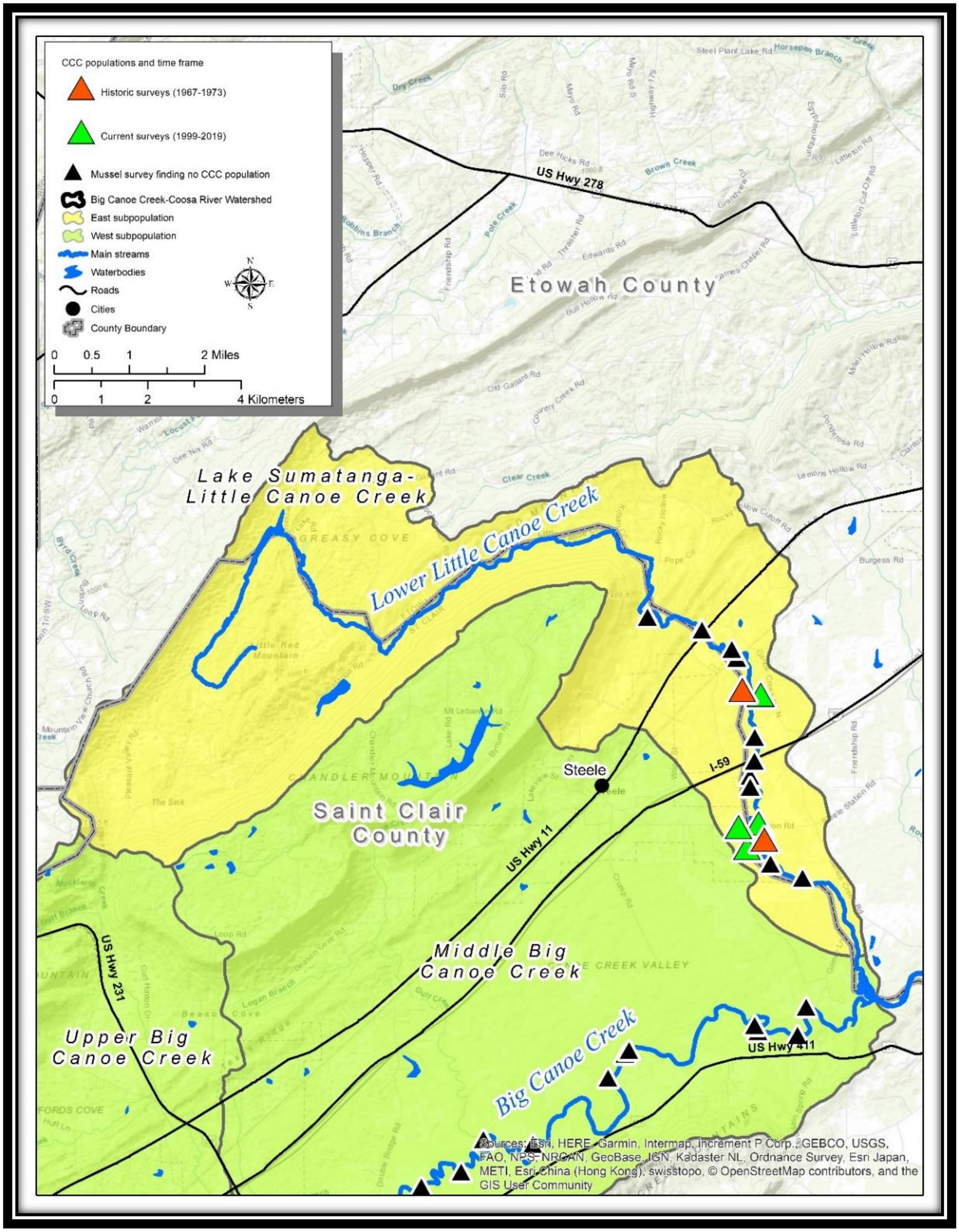


*Figure 2-7. Map of the East CCC subpopulation survey data. CCC subpopulations based on HUC-12 watershed boundaries and tributaries flowing into H. Neely Henry Lake. The BCC-LCC East (East) subpopulation is highlighted in green; the Little Canoe East (East) subpopulation is highlighted in yellow. Survey data is provided as triangles. Red triangles represent historical surveys (1967-1973) with CCC present, green triangles represent current surveys (1999-2019) with CCC present, and the smaller black triangles represent mussel surveys where no CCC were present. CCC were considered present if they were found alive, or as a fresh dead, weathered dead, or relic shell.*

### 2.6.2 Needs

Mussel abundance in a given stream reach is a product of the number of mussel beds and the density of mussels within those beds (aggregations of freshwater mussels). For both subpopulations of CCC to be healthy and resilient, individuals must be numerous with multiple age classes, and show evidence of recent recruitment. For both BCC subpopulations to be resilient, there must be multiple mussel beds of sufficient density such that local stochastic events do not eliminate most or all the bed(s). Connectivity among beds within a subpopulations is needed to allow mussel beds within a stream reach to be recolonized by one another to recover from stochastic events. A non-linear distribution over a large area (occurrence in tributaries, in addition to the mainstem) also helps buffer against stochastic events that may impact subpopulations. Similarly, having multiple subpopulations that are connected to one another protects the species from catastrophic events, such as spills, because subpopulations can recolonize each other following events that impact one of the subpopulations.

Additionally, mussel abundance facilitates reproduction; mussels do not actively seek mates, rather males release sperm into the water column, where it drifts until a female hopefully takes it in (Moles and Layzer 2008, p. 212). Therefore, successful individual reproduction, and subpopulation resilience, requires sufficient numbers of female mussels downstream of sufficient numbers of male mussels.

## CHAPTER 3 – FACTORS INFLUENCING VIABILITY

Note: This chapter contains summaries of factors and stressors that are or could be affecting the CCC. For further information and additional references, see the tables in Appendix A.

The following discussion provides a summary of the factors, both negative and positive, that are affecting or could be affecting viability of the CCC (outlined in Figure 3-1). Aquatic systems face a multitude of natural and anthropogenic threats and stressors (Neves *et al.* 1997, p.44). Generally, these factors can be categorized as either environmental stressors (*e.g.*, development, agriculture practices, or forest management) or systematic changes (*e.g.*, climate change, barriers, or conservation management practices). Current and potential future effects, along with current distribution and abundance help inform viability and, therefore, vulnerability to extinction. A catastrophic event or the chance juxtaposition of several smaller natural or human-induced impacts to the mussel fauna (*e.g.*, drought, flood, chemical spill, and sedimentation) could reduce populations to below minimum viable levels which, in the absence of sources of re-colonization, could result in a slow but unrecoverable downward spiral (Warren et. al 2004, p. 17).

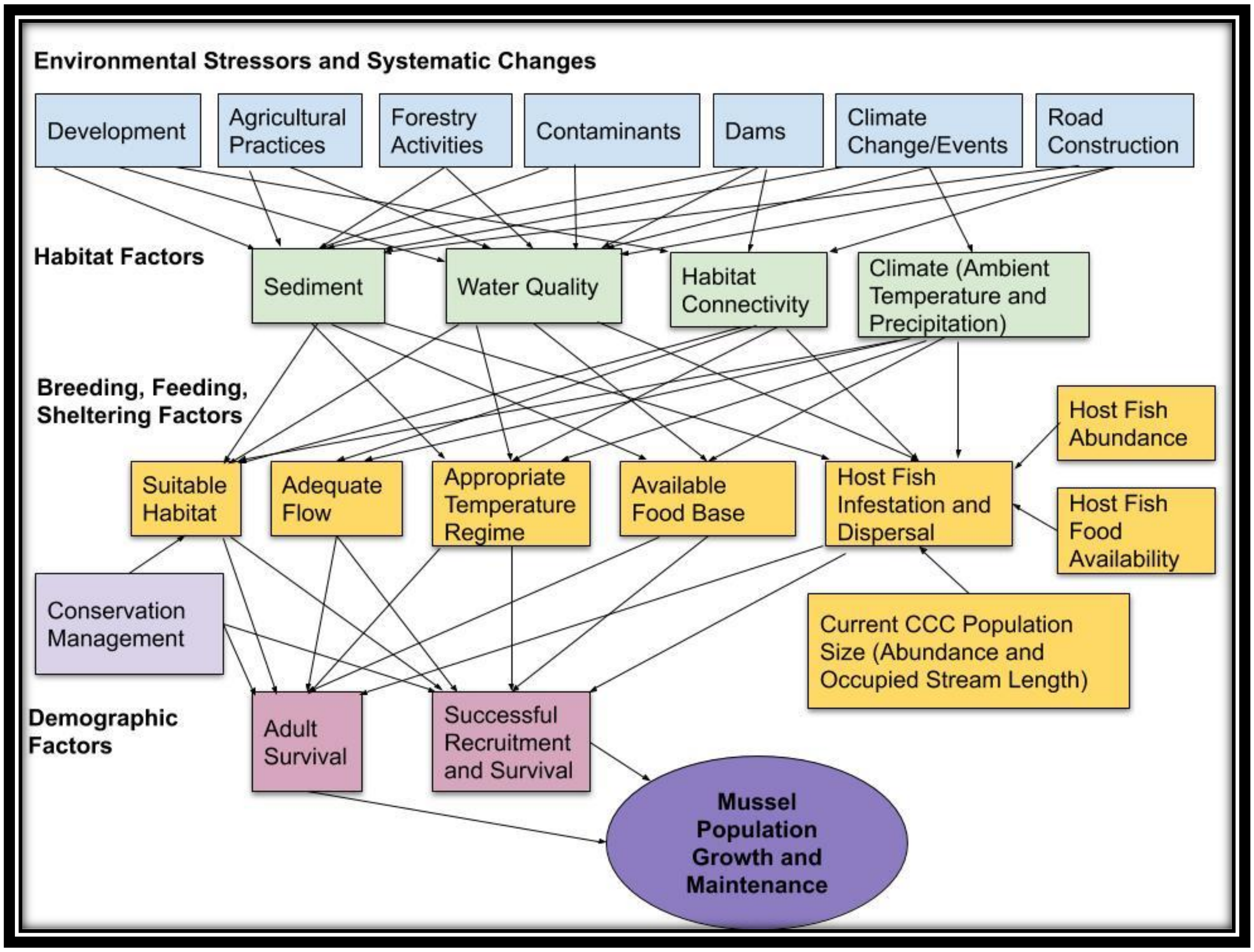


*Figure 3-1. Influence diagram illustrating how environmental stressors and systematic changes influence habitat factors which in turn influence breeding, feeding, and sheltering needs of the species; in turn, these affect demographic factors which ultimately influence mussel population growth and maintenance.*

The primary factors influencing the viability of the CCC are outlined in the following sections and include sedimentation, water quality, climate, connectivity, and conservation efforts.

## 3.1 Sedimentation

Under a natural flow regime, a river or stream is in equilibrium in the context of sediment load, such that as sediments are naturally washed away from one to another and the amount of sediment in the substrate is relatively stable. However, many current and past human activities result in enhanced sedimentation in river systems and legacy sediment, resulting from past land disturbance and reservoir construction, continues to persist and influence river processes and sediment dynamics leading to degradation of mussel habitats. This excessive stream sedimentation (or siltation) results from soil erosion associated with upland activities (*e.g.*, agriculture, forestry, unpaved roads, road construction, development, unstable streambanks, and urbanization) as well as activities that can destabilize stream channels themselves (*e.g.*, dredging, poorly installed culverts, pipeline crossings, or other instream structures) (Brim Box and Mossa 1999, p. 102; Wynn *et al.* 2016, pp. 36-52). The negative effects of increased sedimentation are relatively well understood for mussels (Brim Box and Mossa 1999, entire; Gascho Landis *et al.* 2013, entire; Poole and Downing 2004, pp. 118-124). Excessive sediments can cover the stream bottom and fill the interstitial spaces between bottom substrate particles (*i.e.*, sand, gravel, and cobbles) and in severe cases also cause stream bottoms to become "embedded," in which case substrate features including larger cobbles, gravel, and boulders are surrounded by, or buried in, sediment. These interstitial spaces (small openings between rocks and gravels) in the substrate provide essential habitat for juvenile mussels. Juvenile freshwater mussels burrow into interstitial substrates, making them particularly susceptible to degradation of this habitat feature. When clogged with sand or silt, interstitial flow rates and spaces may become reduced (Brim Box and Mossa 1999, p. 100), thus reducing juvenile habitat availability. While adult mussels can be physically buried by excessive sediment, "the main impacts of excess sedimentation on unionids are often sublethal" and include interference with feeding mediated by valve closure (Brim Box and Mossa 1999, p. 101).

Sediments deposited by large scale flooding or other disturbance may persist for several years until adequate flows can redistribute that sediment downstream. When water velocity decreases, which can occur from reduced streamflow or inundation, water loses its ability to carry sediment in suspension; sediment falls to the substrate, eventually smothering mussels not adapted to soft substrates (Watters 2000, p. 263). Sediment accumulation can be exacerbated when there is an increase in the sources of fine sediments in a watershed. In areas with ongoing development, runoff can transport substantial amounts of sediment from ground disturbance related to construction activities with inadequate or absent sedimentation controls. While these construction impacts can be transient (lasting only during the construction phase), the long-term effects of development are long lasting and can result in hydrological alterations as increased impervious cover increases run off and resulting shear stress causes streambank instability and additional sedimentation.

Streams with urbanized or agriculturally-dominated riparian corridors are subject to increased sediment- loading as soil erodes from banks that do not have a dense network of roots holding soil in place, or from the landscape in general in areas without sufficient ground cover. Streams in urban areas may be subject to excessive runoff from impervious surfaces, which can overwhelm a stream channel's capacity to carry the water, resulting in increased stream bed and bank erosion. Excess sediment in streams settles to the stream bottom, filling spaces needed by juvenile mussels and host fish eggs. The result is a less suitable in-stream habitat for mussels compared to habitat with forested corridors (Allan *et al.* 1997, p. 156).

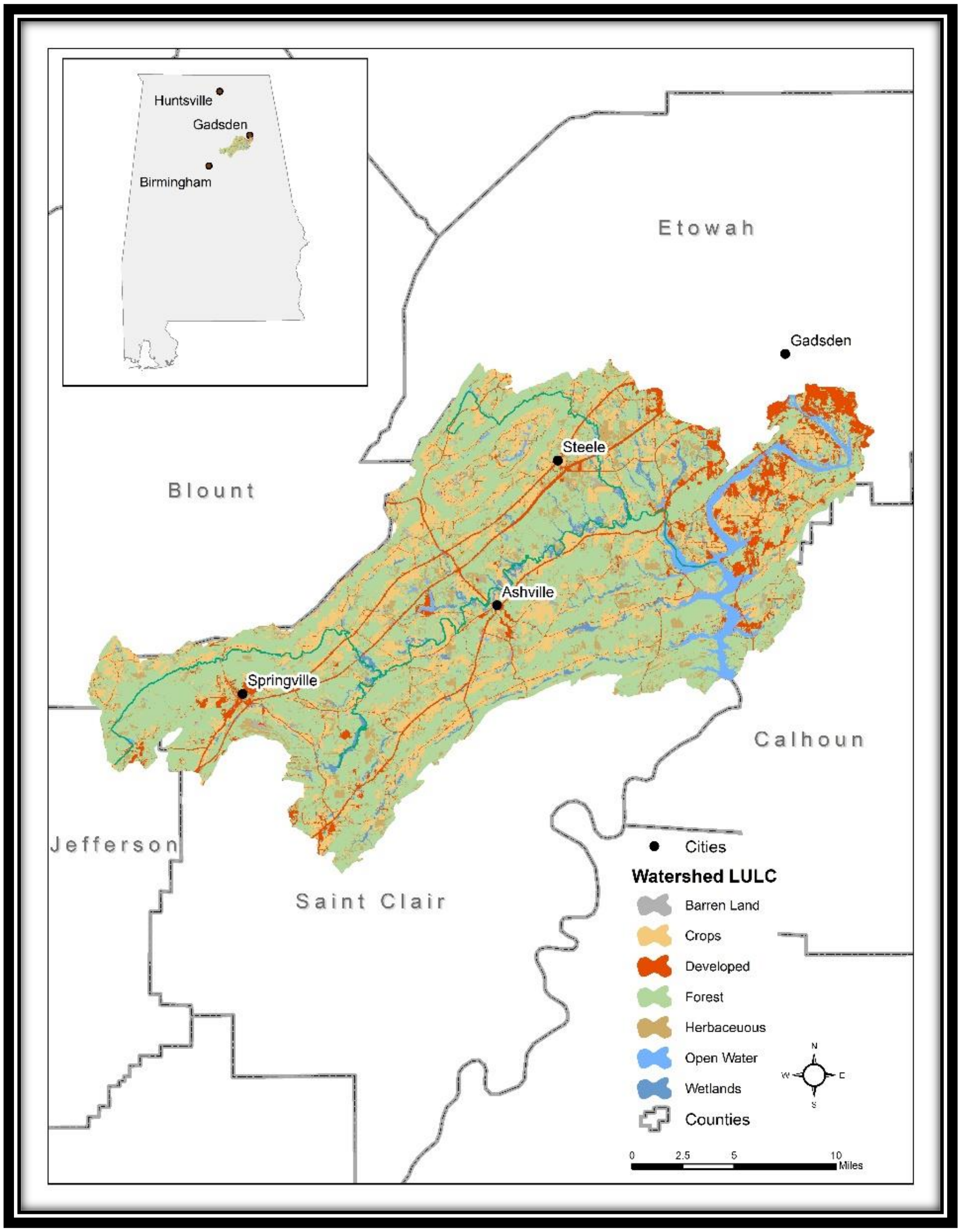
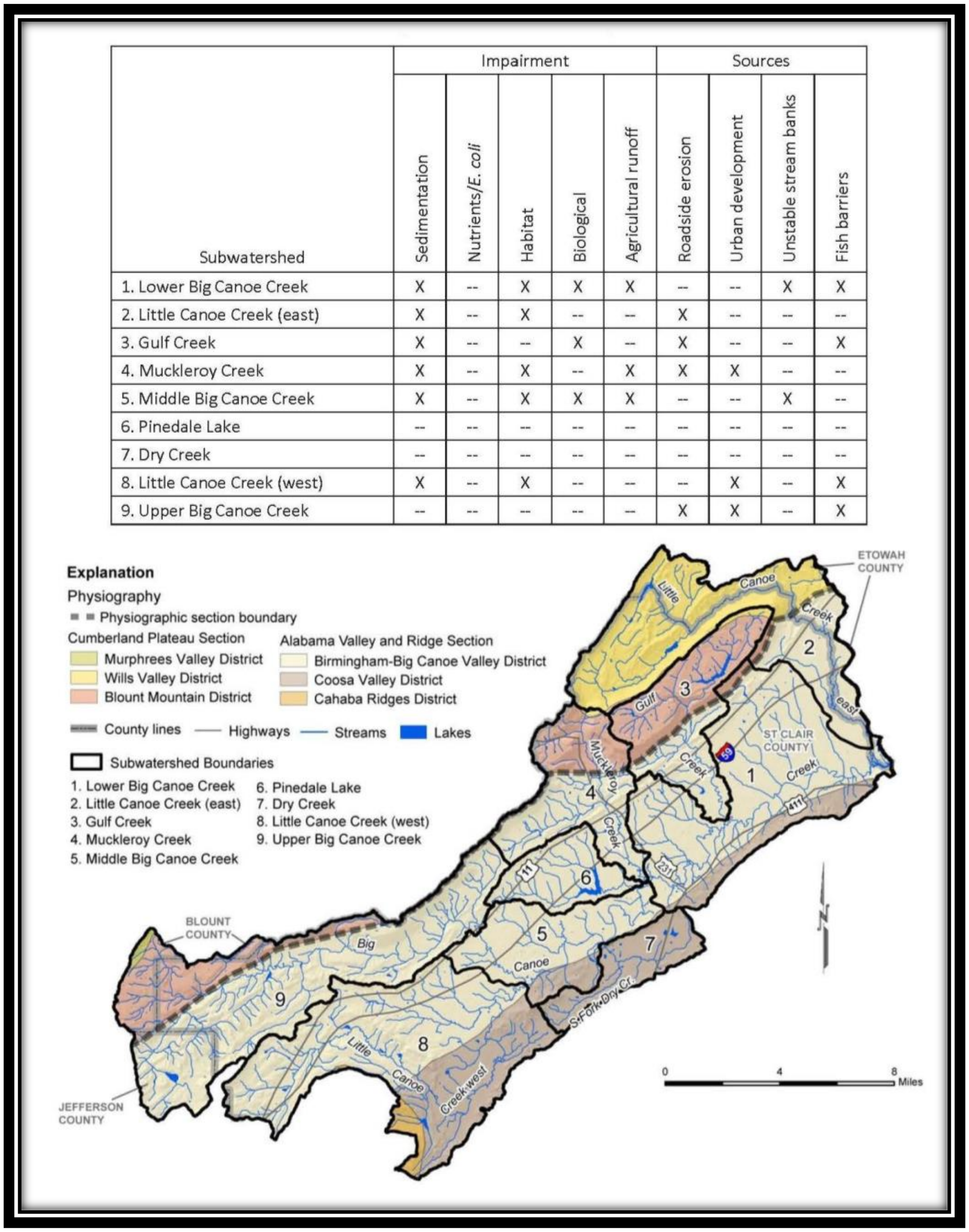


*Figure 3-2. Land use/land cover in the Big Canoe Creek watershed. Source: NLCD 2011 – Homer et al. 2015.*

Approximately 59% of the BCC watershed is in evergreen or mixed deciduous forest, and forestry activities are common in central BCC and LCC (West) (Figure 3-2) (Wynn *et al.* 2016, p. 9). Agriculture is common with pasture and small farms (18%) and cultivated crops (2.3%) common throughout the BCC watershed (Wynn *et al.* 2016, p. 9). Development is concentrated near the cities of Ashville, Springville, and Steele, making up 6% of the watershed. Urban growth from Birmingham is focused near the Springville area near the CCC subpopulation in upper BCC and LCC (West). LCC (East) is dominated by forest and pastureland (Wynn *et al.* 2016, p. 10)

Wynn *et al.* (2016) lists habitat and water resource impairments throughout many of the subwatersheds within BCC (Figure 3-3). A

A rapid habitat assessment survey was completed at 24 stations in BCC from 2008-2013 (Wynn *et al.* 2016, pp. 37-39). Habitat quality varied from poor to optimal within LCC (east). Ten sites scored optimal (>75% of the maximum habitat score), 11 sites suboptimal range (65 to 75% of the maximum habitat score), and 13 sites marginal to poor range (<65% of the maximum habitat score). Of the 13 marginal to poor scores, 6 were from the LCC (west) near Springville; 4 were from the main channel of BCC; 2 from LCC (east) near Steele; and one from Muckleroy Creek.



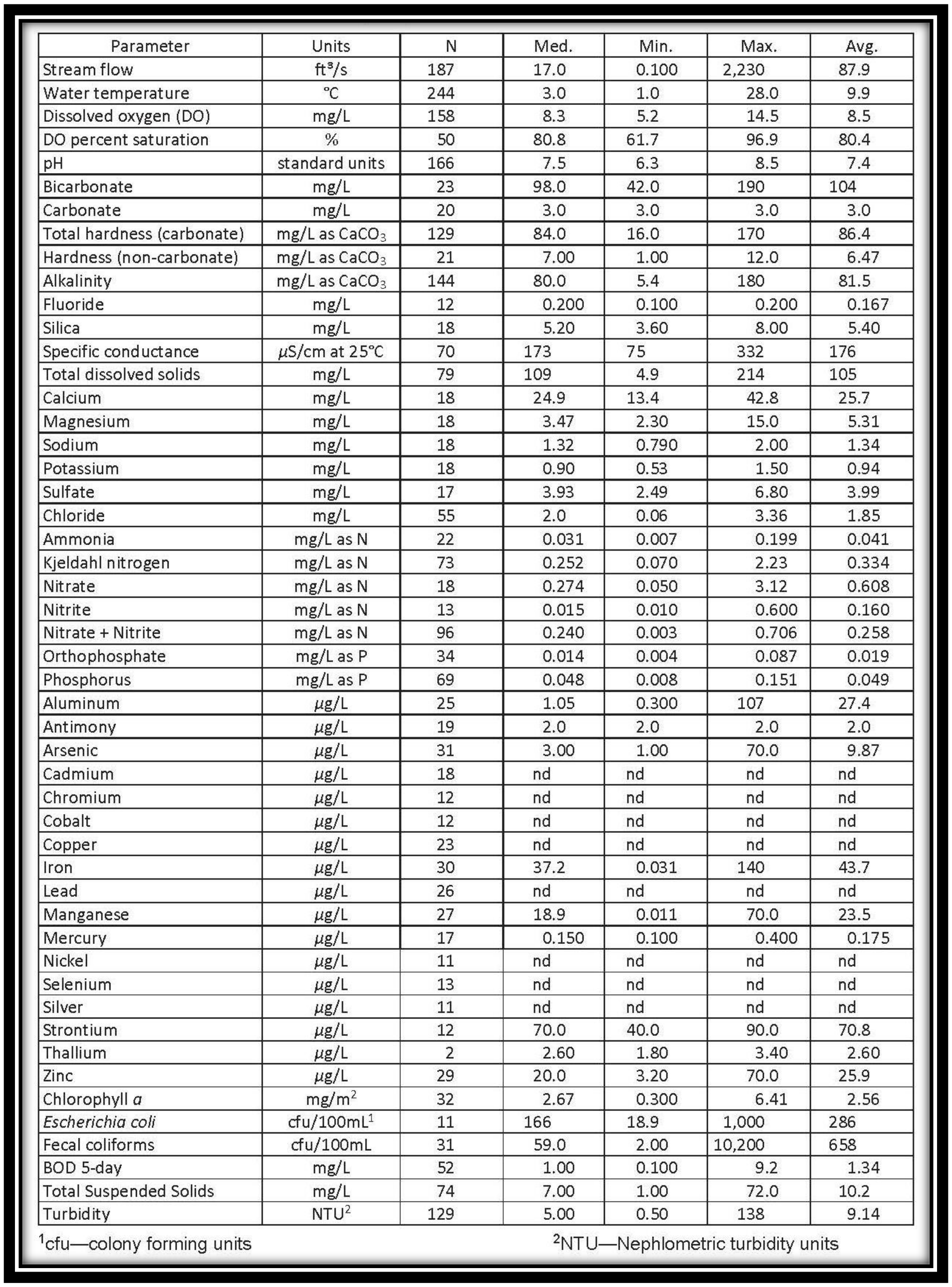
|  | Impairment |  |  |  |  | Sources |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| Subwatershed | Sedimentation | Nutrients/*E. coli* | Habitat | Biological | Agricultural runoff | Roadside erosion | Urban development | Unstable stream banks | Fish barriers |
| 1. Lower Big Canoe Creek | X | -- | X | X | X | -- | -- | X | X |
| 2. Little Canoe Creek (east) | X | -- | X | -- | -- | X | -- | -- | -- |
| 3. Gulf Creek | X | -- | -- | X | -- | X | -- | -- | X |
| 4. Muckleroy Creek | X | -- | X | -- | X | X | X | -- | -- |
| 5. Middle Big Canoe Creek | X | -- | X | X | X | -- | -- | X | -- |
| 6. Pinedale Lake | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 7. Dry Creek | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 8. Little Canoe Creek (west) | X | -- | X | -- | -- | -- | X | -- | X |
| 9. Upper Big Canoe Creek | -- | -- | -- | -- | -- | X | X | -- | X |

*Figure 3-3. Impairment matrix and map developed for the BCC watershed action plan. Source: Wynn et al. 2016 (pp. 51-52).*

### 3.2 Water Quality

Water quality can be impaired through contamination or alteration of water chemistry. Chemical contaminants are ubiquitous throughout the environment and are a major reason for the current declining status of freshwater mussel species nationwide (Augspurger *et al.* 2007, p. 2025). Chemicals enter the environment through both point and nonpoint discharges, including spills, industrial sources, municipal effluents, and agricultural runoff. These sources contribute organic compounds, heavy metals, pesticides, herbicides, and a wide variety of newly emerging contaminants to the aquatic environment. Ammonia is of particular concern below water treatment plants because freshwater mussels have been shown to be particularly sensitive to increased ammonia levels (Augspurger *et al.* 2003, p. 2569). An additional type of water quality impairment is alteration of water quality parameters such as dissolved oxygen and temperature. Dissolved oxygen levels may be reduced from increased nutrients in the water column from runoff or wastewater effluent, and juveniles seem to be particularly sensitive to low dissolved oxygen (Sparks and Strayer 1998, pp. 132–133). Increased water temperature from climate change and from low flows during drought can exacerbate low dissolved oxygen levels as well as have its own effects on both juvenile and adult mussels.

*Table 3-1. Summary of water quality information from the BCC watershed, 1966 to 2013 (USGS 2013). Abbreviations: N-number of samples; nd-not detected or less than lower limit of detection. Source: Wynn et al. 2016 (p. 20).*



| Parameter | Units | N | Med. | Min. | Max. | Avg. |
|---|---|---|---|---|---|---|
| Stream flow | ft$^3$/s | 187 | 17.0 | 0.100 | 2,230 | 87.9 |
| Water temperature | ℃ | 244 | 3.0 | 1.0 | 28.0 | 9.9 |
| Dissolved oxygen (DO) | mg/L | 158 | 8.3 | 5.2 | 14.5 | 8.5 |
| DO percent saturation | % | 50 | 80.8 | 61.7 | 96.9 | 80.4 |
| pH | standard units | 166 | 7.5 | 6.3 | 8.5 | 7.4 |
| Bicarbonate | mg/L | 23 | 98.0 | 42.0 | 190 | 104 |
| Carbonate | mg/L | 20 | 3.0 | 3.0 | 3.0 | 3.0 |
| Total hardness (carbonate) | mg/L as $CaCO_3$ | 129 | 84.0 | 16.0 | 170 | 86.4 |
| Hardness (non-carbonate) | mg/L as $CaCO_3$ | 21 | 7.00 | 1.00 | 12.0 | 6.47 |
| Alkalinity | mg/L as $CaCO_3$ | 144 | 80.0 | 5.4 | 180 | 81.5 |
| Fluoride | mg/L | 12 | 0.200 | 0.100 | 0.200 | 0.167 |
| Silica | mg/L | 18 | 5.20 | 3.60 | 8.00 | 5.40 |
| Specific conductance | µS/cm at 25℃ | 70 | 173 | 75 | 332 | 176 |
| Total dissolved solids | mg/L | 79 | 109 | 4.9 | 214 | 105 |
| Calcium | mg/L | 18 | 24.9 | 13.4 | 42.8 | 25.7 |
| Magnesium | mg/L | 18 | 3.47 | 2.30 | 15.0 | 5.31 |
| Sodium | mg/L | 18 | 1.32 | 0.790 | 2.00 | 1.34 |
| Potassium | mg/L | 18 | 0.90 | 0.53 | 1.50 | 0.94 |
| Sulfate | mg/L | 17 | 3.93 | 2.49 | 6.80 | 3.99 |
| Chloride | mg/L | 55 | 2.0 | 0.06 | 3.36 | 1.85 |
| Ammonia | mg/L as N | 22 | 0.031 | 0.007 | 0.199 | 0.041 |
| Kjeldahl nitrogen | mg/L as N | 73 | 0.252 | 0.070 | 2.23 | 0.334 |
| Nitrate | mg/L as N | 18 | 0.274 | 0.050 | 3.12 | 0.608 |
| Nitrite | mg/L as N | 13 | 0.015 | 0.010 | 0.600 | 0.160 |
| Nitrate + Nitrite | mg/L as N | 96 | 0.240 | 0.003 | 0.706 | 0.258 |
| Orthophosphate | mg/L as P | 34 | 0.014 | 0.004 | 0.087 | 0.019 |
| Phosphorus | mg/L as P | 69 | 0.048 | 0.008 | 0.151 | 0.049 |
| Aluminum | µg/L | 25 | 1.05 | 0.300 | 107 | 27.4 |
| Antimony | µg/L | 19 | 2.0 | 2.0 | 2.0 | 2.0 |
| Arsenic | µg/L | 31 | 3.00 | 1.00 | 70.0 | 9.87 |
| Cadmium | µg/L | 18 | nd | nd | nd | nd |
| Chromium | µg/L | 12 | nd | nd | nd | nd |
| Cobalt | µg/L | 12 | nd | nd | nd | nd |
| Copper | µg/L | 23 | nd | nd | nd | nd |
| Iron | µg/L | 30 | 37.2 | 0.031 | 140 | 43.7 |
| Lead | µg/L | 26 | nd | nd | nd | nd |
| Manganese | µg/L | 27 | 18.9 | 0.011 | 70.0 | 23.5 |
| Mercury | µg/L | 17 | 0.150 | 0.100 | 0.400 | 0.175 |
| Nickel | µg/L | 11 | nd | nd | nd | nd |
| Selenium | µg/L | 13 | nd | nd | nd | nd |
| Silver | µg/L | 11 | nd | nd | nd | nd |
| Strontium | µg/L | 12 | 70.0 | 40.0 | 90.0 | 70.8 |
| Thallium | µg/L | 2 | 2.60 | 1.80 | 3.40 | 2.60 |
| Zinc | µg/L | 29 | 20.0 | 3.20 | 70.0 | 25.9 |
| Chlorophyll *a* | mg/m$^2$ | 32 | 2.67 | 0.300 | 6.41 | 2.56 |
| *Escherichia coli* | cfu/100mL[1] | 11 | 166 | 18.9 | 1,000 | 286 |
| Fecal coliforms | cfu/100mL | 31 | 59.0 | 2.00 | 10,200 | 658 |
| BOD 5-day | mg/L | 52 | 1.00 | 0.100 | 9.2 | 1.34 |
| Total Suspended Solids | mg/L | 74 | 7.00 | 1.00 | 72.0 | 10.2 |
| Turbidity | NTU[2] | 129 | 5.00 | 0.50 | 138 | 9.14 |

[1] cfu—colony forming units

[2] NTU—Nephlometric turbidity units

The Alabama Department of Environmental Management (ADEM) conducted an assessment of LCC (east) near AL Hwy 7 in 2005. A bioassessment of the site showed the macroinvertebrate community to be in fair condition, but concluded that habitat degradation and nutrient enrichment may contribute to degraded biological condition. Median concentrations of nutrients and total and dissolved solids were within the expected range, but the median Chlorophyll a concentration was higher than expected (ADEM 2005a, pp. 1-2). ADEM also looked at a site at BCC at County Road 31. It was determined that this site was rated fair for the macroinvertebrate assessment. Chlorophyll a and chloride found to be higher than expected for this stream type and sediment was also an issue within the reach. Median chlorophyll a and chloride concentrations were higher than expected but, all other parameters were within the expected ranges. Additional water quality information for the BCC watershed is summarized in Table 3-1 above for the years 1966-2013 (Wynn *et al.* 2013, p. 20).

### 3.3 Climate Events

Changing conditions that can influence freshwater mussels include increasing or decreasing water temperatures and precipitation patterns that increase flooding, prolong droughts, or reduce stream flows (Nobles and Zhang 2011 pp. 147–148). An increase in the number of days with heavy precipitation over the next 25 to 35 years is expected to increase across the CCC's range (https://science2017.globalchange.gov/chapter/7/). Although the effects of climate change have likely affected the CCC, the timing, frequency, and extent of these effects is currently unknown.

It is important to consider possible climate change impacts to CCC and its habitat. As mentioned in the Poff *et al.* (2002, pp. ii–v) report on Aquatic Ecosystems and Global Climate Change, impacts of climate change on aquatic systems can potentially include:

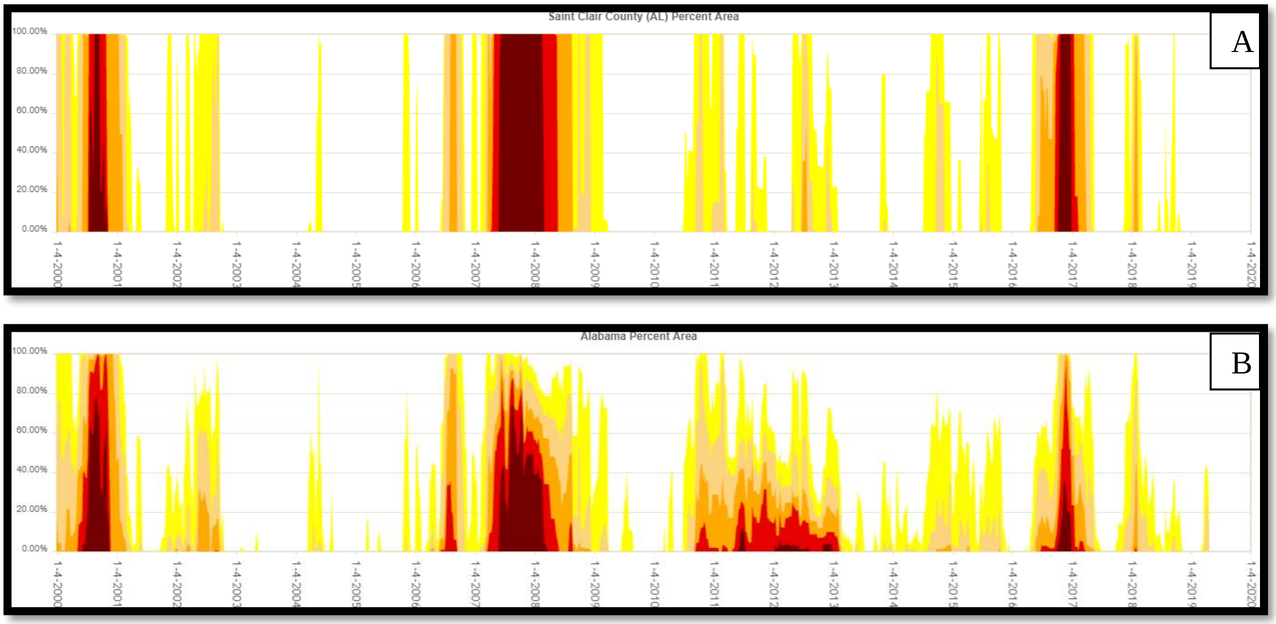
- Increases in water temperatures that may alter fundamental ecological processes, thermal suitability of aquatic habitats for resident species, and their geographic distribution, thus increasing the likelihood of species extinction and loss of biodiversity.
- Changes and shifts in seasonal patterns of precipitation and runoff, which can alter the hydrology of stream systems, affecting species composition and ecosystem productivity. Aquatic organisms are sensitive to changes in frequency, duration, and timing of extreme precipitation events such as floods or droughts, potentially resulting in interference of reproduction. Further, increased water temperatures and seasonally reduced streamflow can alter many ecosystem processes, including increases in nuisance algal blooms.
- Cumulative or synergistic impacts that can occur when considering how climate change may be an additional stressor to sensitive freshwater systems, which are already adversely affected by a variety of other human impacts, such as altered flow regimes and deterioration of water quality.
- Adapting to climate change may be limited for some aquatic species depending on their life history characteristics and resource needs. Reducing the likelihood of significant impacts would largely depend on human activities that reduce other sources of ecosystem stress to ultimately enhance adaptive capacity, which could include, but not be limited to: maintaining riparian forests, reducing nutrient loading, restoring damaged ecosystems, minimizing groundwater and stream withdrawal, and strategically locating any new reservoirs to minimize adverse effects.
- Changes in presence or combinations of native and nonnative, invasive species could result in specific ecological responses to changing climate conditions that cannot be easily predicted at this time. These types of changes (*e.g.*, increased temperatures that are more favorable to a nonnative, invasive species compared to a native species) can result in novel interactions or situations that may necessitate adaptive management strategies.
- Shifts in mussel community structure, which can stem from climate-induced changes in water temperatures since sedentary freshwater mussels have limited refugia from disturbances such as droughts and floods, and since they are thermo-conformers whose

physiological processes are constrained by water temperature within species-specific thermal preferences (Galbraith *et al.* 2010, p. 1,176).

Severe drought and major floods have been documented to have significant impacts to mussel communities with severe declines in mussel abundance (Haag and Warren, p. 1165; Hastie *et al.* 2001, p. 107; Hastie *et al.* 2003, pp. 40-45). The U.S. Drought Monitor documents the intensity and impacts of drought with a rating scale of D0 to D4 (Table 3-2). These ratings include: D0 (Abnormally Dry), D1 (Moderate Drought), D2 (Severe Drought), D3 (Extreme Drought), and D4 (Exceptional Drought). In the past 20 years, the state of Alabama has experienced four droughts that have reached D4 in intensity, three of these exceptional droughts have been documented within BCC (*i.e.*, St. Clair County, Alabama) (Figure 3-4).

*Table 3-2. Drought classification table showing range of drought intensity (NDMC 2019, unpaginated)*

| | | Ranges | | | | |
|---|---|---|---|---|---|---|
| **Category** | **Description** | Palmer Drought Severity Index (PDSI) | CPC Soil Moisture Model (Percentiles) | USGS Weekly Streamflow (Percentiles) | Standardized Precipitation Index (SPI) | Objective Drought Indicator Blends (Percentiles) |
| **D0** | Abnormally Dry | -1.0 to -1.9 | 21 to 30 | 21 to 30 | -0.5 to -0.7 | 21 to 30 |
| **D1** | Moderate Drought | -2.0 to -2.9 | 11 to 20 | 11 to 20 | -0.8 to -1.2 | 11 to 20 |
| **D2** | Severe Drought | -3.0 to -3.9 | 6 to 10 | 6 to 10 | -1.3 to -1.5 | 6 to 10 |
| **D3** | Extreme Drought | -4.0 to -4.9 | 3 to 5 | 3 to 5 | -1.6 to -1.9 | 3 to 5 |
| **D4** | Exceptional Drought | -5.0 or less | 0 to 2 | 0 to 2 | -2.0 or less | 0 to 2 |



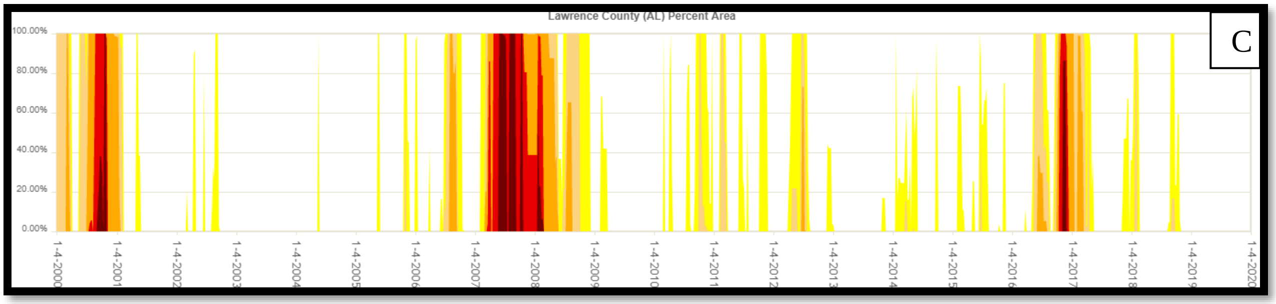


*Figure 3-4. U.S. Drought Monitor map of St. Clair County, AL (A), the State of Alabama (B), and Lawrence County, AL (C) (NDMC 2019, unpaginated).*

While impacts to the mussel fauna within BCC has not been studied, the impacts of the D4 drought of 2000 were documented to mussels within five small stream sites in Bankhead National Forest, Lawrence and Winston counties, Alabama (Haag and Warren 2008, entire). Figure 3-4 above records the severity of this drought and compares to the drought observed in BCC (St. Clair County, Alabama), to that in Bankhead National Forest (Lawrence County, Alabama), and Alabama statewide. Haag and Warren (2008, p. 1165) found that mussels are highly sensitive to the secondary effects of drought (*e.g.*, dissolved oxygen, warm temperatures, and high biological oxygen demand) in addition to direct drying of mussel habitat. Additionally, they found that in small streams, overall mussel density before and after the drought declined by 65–83%, and the magnitude of the decline did not differ among streams regardless of whether the channel dried or remained wetted (Haag and Warren 2008, p. 1165) (Table 3-3).

*Table 3-3. Changes in mussel abundance of two Pleurobema mussels (small and large watersheds) in Alabama and Mississippi in response to severe drought in 2000 as reported in Haag and Warren 2008 (pp. 1166, 1170, 1172-1173). BCC sites and the same or similar Pleurobema species occurrence are reported at the bottom of the table for comparison. Warrior pigtoe (Pleurobema rubellum) could be considered an analog of CCC given the similar biology, habitat, and stream size.*

| Stream | Drainage Area (km$^2$) | Mussel Abundance Estimated Change (%) | Densities of Warrior pigtoe (individuals/m$^2$) | | |
|---|---|---|---|---|---|
| | | | Predrought | Postdrought | Difference |
| Brown Creek | 9 | -83 (36-95) | --- | --- | --- |
| Brushy Creek | 24 | -83 (54-97) | --- | --- | --- |
| Flannagin Creek | 24 | -80 (65-87) | 0.12 | 0 | -0.12 |
| Rush Creek | 30 | -65 (25-85) | 0.08 | 0 | -0.08 |
| Sipsey Fork | 267 | -66 (40-83) | 0.48 | 0.18 | -0.3 |
| | | | Densities of Southern clubshell (individuals/m$^2$) | | |
| Stream | Drainage Area (km$^2$) | Mussel Abundance Estimated Change (%) | Predrought | Postdrought | Difference |
| Sipsey River, Site 1 | 1,729 | No Significant Difference | 5.73 | 7.26 | +1.53 |
| Sipsey River, Site 2 | 1,765 | No Significant Difference | 7.61 | 10.49 | +2.88 |
| Little Tallahatchie River | 4,002 | No Significant Difference | --- | --- | --- |
| BCC sites that are comparable in drainage size and taxa to those studied in Haag and Warren 2008. | | | | | |
| **Big Canoe Creek (Sites)** | Drainage Area (km$^2$) | Canoe Creek Clubshell | | Southern Clubshell | |
| LCC (east) near Steele | 58 | Yes | | No | |
| BCC near Springville at US Hwy 11 | 117 | Yes | | No | |
| BCC at US Hwy 231 in Ashville | 365 | Yes | | Yes | |
| BCC near Gadsden at Rainbow Drive | 655 | No | | Yes | |

While the U.S. Drought Monitor database (Figure 3-4) only has data dating back to the year 2000 (NDMC 2019, unpaginated), the USGS has maintained a discharge station (02401390) on BCC in Ashville at the U.S. Highway 231 bridge crossing since 1966. This is the only continuous stream flow gauge currently operating in the watershed (USGS 2019, unpaginated). Average annual discharge for BCC at this site is 259 cubic feet per second (ft$^3$/sec) from 1966 to 2018 (Figure 3-5, USGS 2019, unpaginated). This flow gauge (Figure 3-5) clearly shows a significant reduction in flows during the exceptional drought (D4) for the years 2000 and 2007-08. Additionally it shows 13 years with mean annual flow of less than 200 ft$^3$/sec, 7 years of less than 150 ft$^3$/sec (*e.g.*, 1981, 1887, 2000, 2008) and 2 years of less than 100 ft$^3$/sec (*i.e.*, 1986, 2007).

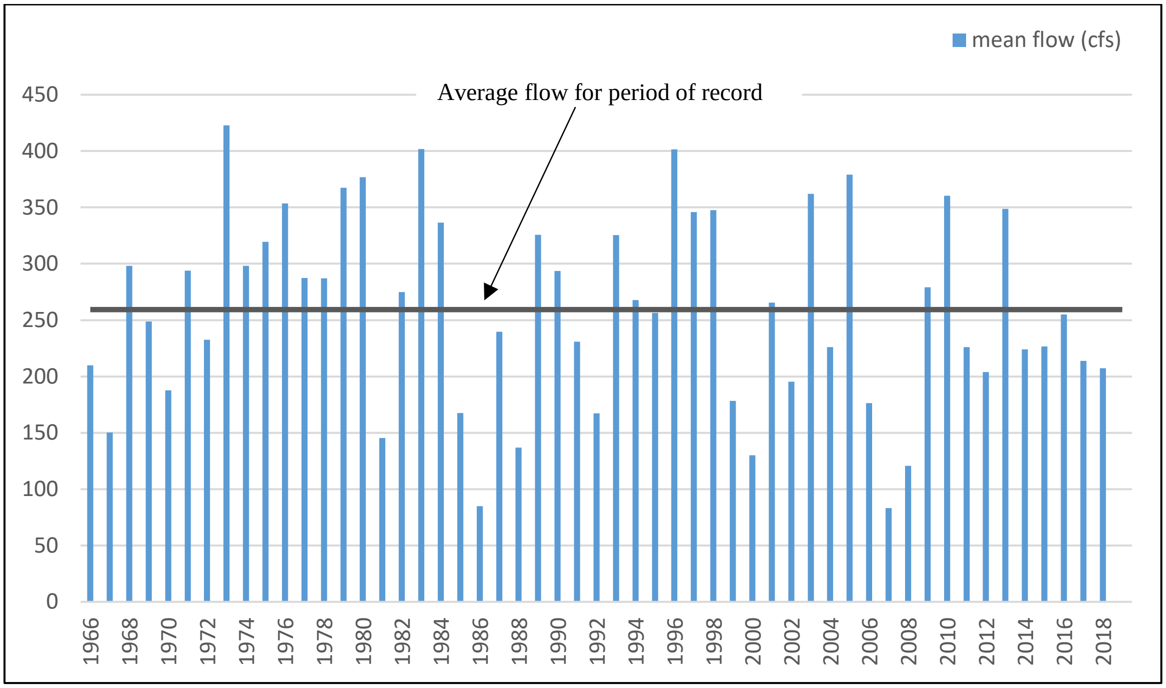


*Figure 3-5. Average annual discharge (ft$^3$/second) for USGS site 02401390, BCC at Ashville, Alabama, for years 1966-2018 (USGS 2019, unpaginated).*

The Palmer Drought Severity Index (PDSI) is a measurement of dryness based on recent precipitation and temperature and is kept by the National Oceanic and Atmospheric Administration's (NOAA) National Integrated Drought Information System (NIDIS) program (www.ncdc.noaa.gov). The PDSI database for Alabama goes back to 1895. PDSI value is a standardized index that spans -10 (dry) to +10 (wet) (Table 3-2). In the past 100 years, 15 years have been rated as moderate to extreme drought (PDSI $\leq$ -2) in the state of Alabama. The three biggest droughts (mean annual PDSI) in the past 100 years (1918-2018) have been -3.01 (2000), -3.07 (1954), and -3.95 (2007). Conversely in the past 100 years, 14 years have been rated as moderate to extreme precipitation (PDSI greater than +2). The two largest flood years had PDSI values of +3.08 (1976) and +4.16 (1975). In the past 20 years, the most severe years for precipitation have been 2003, 2009, and 2013, each with a PDSI value of +2.03 to +2.08. Figure 3-6 plots annual PDSI over the past 100 and past 50 years. The trend line for the past 100 years (+0.04 PDSI trend/decade) represents a positive, but relatively even distribution of wet to dry years. The trend line the past 50 years (-0.28 PDSI trend/decade), however seems to trend more toward drought, and could indicate a climate shift with a higher frequency toward drought.

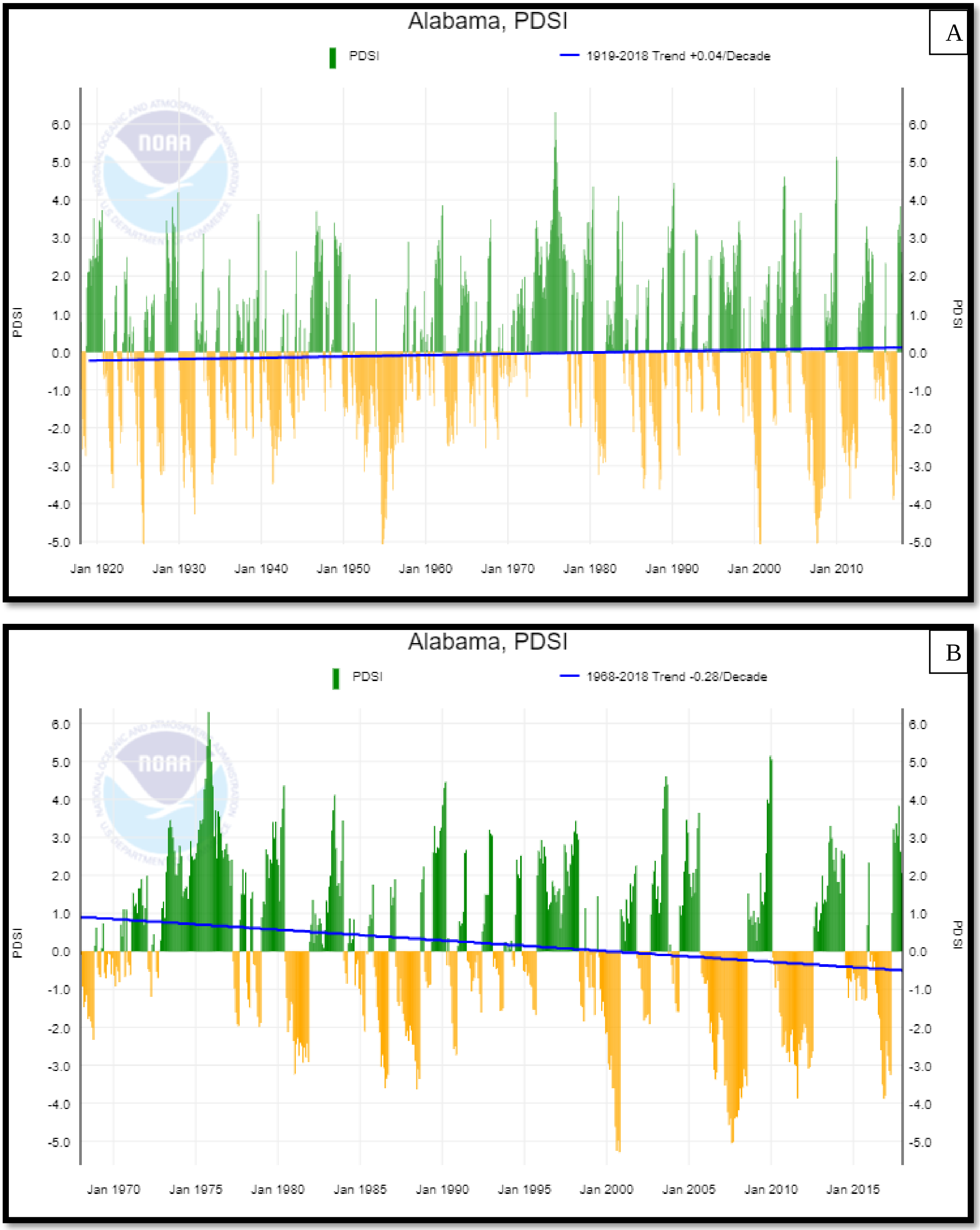


*Figure 3-6. Palmer Drought Severity Index for the State of Alabama for the last 100 years (1918-2018) (A) and for the last 50 years (B) (NOAA 2020, unpaginated).*

Additionally, NOAA's National Center for Environmental Information (NCEI) has recorded temperature at the Birmingham Airport, approximately 35 miles to the southwest since 1930 to present (Figure 3-7). Four of the five highest mean annual temperature readings have occurred within the past twenty years, possibly indicating a climate shift towards a warming trend.

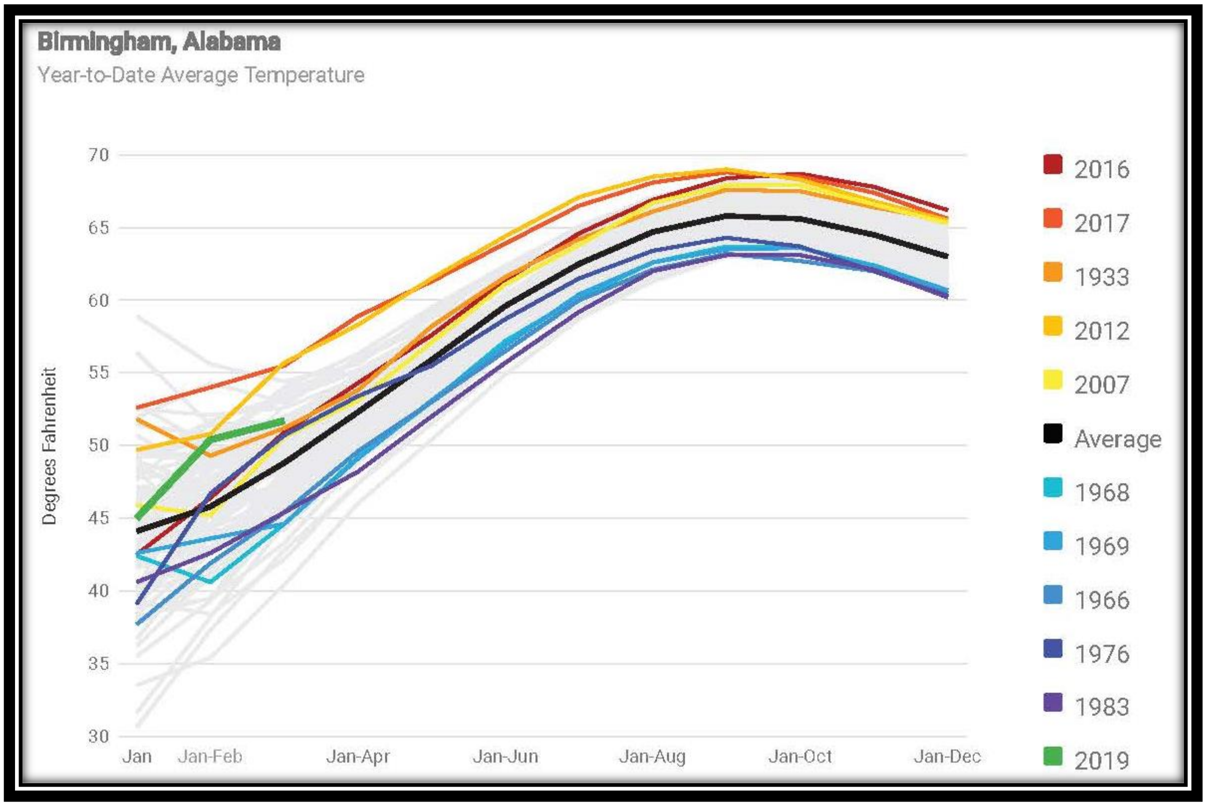


*Figure 3-7. Annual mean temperature data at the NOAA NCEI station at the Birmingham Airport (Station ID: USW00013876) between years 1930-2019 (NOAA 2019, unpaginated).*

## 3.4 Connectivity

The effects of impoundments and barriers on aquatic habitats and freshwater mussels are relatively well-documented (Watters 2000, p. 261). This section is intended to be a summary of the effects, as opposed to a comprehensive overview, dams and other barriers have on the CCC. Extinction/extirpation of North American freshwater mussels can be traced to impoundment and inundation of riffle habitats in all major river basins of the central and eastern United States (Haag 2009, p. 107).

Humans have constructed dams for a variety of reasons: flood prevention, water storage, electricity generation, irrigation, recreation, and navigation (Eissa and Zaki 2011, p. 253). Dams, either natural (by beavers or by aggregations of woody debris) or man-made, have many impacts on stream ecosystems. Reductions in the diversity and abundance of mussels are primarily attributed to habitat shifts caused by impoundments (Neves *et al.* 1997, p. 63). The survival of mussels and their overall reproductive success are influenced:

- *Upstream of dams* – the change from flowing to impounded waters, increased depths, increased buildup of sediments, decreased dissolved oxygen, and the drastic alteration in resident fish populations.
- *Downstream of dams* – fluctuations in flow regimes, minimal releases and scouring flows, seasonal dissolved oxygen depletion, reduced or increased water temperatures, and changes in fish assemblages.

Interestingly, recent studies have shown that some mussel populations may be more temporally persistent immediately downstream of small dams, more abundant and diverse, and attain larger sizes and grow faster than do conspecifics in populations further upstream or downstream (Gangloff 2013, p. 476). In today's rapidly changing landscape, it is possible that these small dams and their impoundments may perform some key ecological functions that benefit mussel and fish species, including filtration and detoxification of anthropogenically elevated nutrient loads, oxygenating low-gradient streams during low-water periods, and stabilizing portions of the stream beds (Gangloff 2013, pp. 478-479). Additional benefits of impoundments may include retention of fine sediments and associated toxicants, impediments to the spread of invasive species, and attenuation of floods from urban or highly agrarian watersheds (Gangloff 2013, p. 476).

The fragmentation of river habitat by dams and other aquatic barriers (*e.g.*, perched or undersized culverts) is one of the primary threats to aquatic species in the U.S. (Martin and Apse 2014, p. 7). Dams (whether man-made or nature-made (*e.g.*, from beavers (*Castor canadensis*) or wind thrown debris)) have a profound impact on in-stream habitat as they can change lotic systems (flowing water) to lentic systems (stationary or relatively still water). Moreover, fragmentation by dams or culverts generally involves loss of access to quality habitat for one or more life stages of freshwater species. In the case of mussels, fragmentation can result in barriers to host fish movement, which in turn, may influence mussel distributions. Mussels that use small host fishes such as darters (family Percidae) and minnows (family Cyprinidae), are more susceptible to impacts from habitat fragmentation due to increasing distance between suitable habitat patches and low likelihood of small host fish swimming over that distance as compared to large host fishes (Vaughn 2012, p. 7). Barriers to movement can cause isolated or patchy distributions of mussels, which may limit both genetic exchange and recolonization (*e.g.*, after a high flow, scouring event) (Jones *et al.* 2006, p. 528).

The backwaters of H. Neely Henry Reservoir backs up into lower Big Canoe Creek past the mouth of Little Canoe Creek (east). Construction of H. Neely Henry Dam, completed by the Alabama Power Company in 1966, resulted in the loss of most of the mussel fauna and riverine habitat in the lower 12.5 km of BCC. Additionally, a small mill dam "Goodwin Mill" (Figure 3-8) was recently removed from the LCC (west). This removal reestablished connectivity in a portion of CCC range that previously had been blocked and a barrier to mussel and fish migration. A rapid habitat assessment conducted prior to the removal of Goodwin's Mill Dam had noted impairments in the form of embeddedness, velocity/depth regime, sediment deposition, and riffle frequency. Following the removal of the dam in 2013, this reach began to restore itself to a higher quality stream habitat (Wynn *et al.* 2016, p. 41).

A survey of stream crossings was conducted in October 2012 to April 2013 within BCC. A total of 366 stream crossing structures were surveyed. Twenty crossings were determined to be barriers to fish. While a majority of these were on smaller tributaries and not habitat utilized by the CCC, one crossing was located on LCC (west) within the range of the CCC. Additionally, sedimentation risk was evaluated at each of the 366 stream crossings. Fifteen sites (4.1%) were determined to be high risk for sedimentation, while 79 sites (21.6%) were determined to be at moderate risk for sedimentation (Wynn *et al.* 2016, pp. 45-48).

## 3.5 Conservation Efforts

### 3.5.1 State Protections

The CCC is currently ranked as a priority 1 (highest conservation concern) species of greatest conservation need in Alabama (Shelton-Nix 2017, p. 51; ANHP 2017, p. 41), but is not currently listed as state threatened or endangered (ADCNR 2015, p. 23, ANHP 2017, p. 41). However, all mussel species not listed as a protected species under the Invertebrate Species Regulation are partially protected by other regulations of the Alabama Game, Fish, and Fur Bearing Animals Regulations. Regulation 220-2-.104 prohibits the commercial harvest of all but the 11 mussel species for which commercial harvest is legal (ADCNR 2015, p. 438).

### 3.5.2 Alabama Rivers and Streams Network

The Alabama Rivers and Streams Network is a group of non-profit organizations, private companies, state and federal agencies and concerned citizens that recognize the importance of clean water and working together to maintain healthy water supplies and investigate water quality, habitat conditions, and biological quality in rivers and streams and make these findings to the public (www.alh2o.org/). BCC been designated as a Strategic Habitat Unit (SHU) by the Alabama Rivers and Streams Network (ARSN) for the purpose of facilitating and coordinating watershed management and restoration efforts as well as focus funding to address habitat and water quality issues (Wynn *et al.* 2016, p. 11, Wynn *et al.* 2018, entire). In total, ARSN has

*Figure 3-8. Goodwin's Mill Dam on BCC, St. Clair County, Alabama, prior to (2011) (A) and after (B) removal by the ARSN partnership in 2013. Photo Credit: Eric Spadgenske, USFWS.*

outlined a total of 60 SHUs or Strategic River Reach Units (SRRUs) where conservation activities are critical for the management, recovery, and restoration of populations of rare fishes, mussels, snails, and crayfishes in Alabama or adjacent states with joint drainage of these watersheds. The SHU project was developed for species restoration and enhancement. In 2016, the Geological Survey of Alabama (GSA) completed a watershed assessment of the BCC system for the recovery and restoration of imperiled aquatic species (Wynn *et al.* 2016, entire). This assessment is being used by multiple federal, state, and non-government organizations (NGO) to contribute to restoration projects that will improve habitat and water quality for at risk and listed species like the CCC. An example of organizations working to together under ARSN is the removal of the Goodwin's Mill Dam (Figure 3-8) in 2013 on BCC, which restored connectivity to a portion of the range of the CCC within LCC (west). Multiple agencies and groups came together for this removal including: the Service's Partners for Fish and Wildlife Program (PFW), Ecological Services, and Fisheries programs, Alabama Department of Conservation and Natural Resources (ADCNR), GSA, ADEM, Alabama Power Company, The Nature Conservancy (TNC), Coosa RiverKeeper, and Friends of Big Canoe Creek.

### 3.5.3 Mussel Propagation Effort

The Alabama Aquatic Biodiversity Center (AABC) is located in Marion, Alabama, and is a program of the ADCNR (www.outdooralabama.com/research/aquatic-biodiversity-center) and is the largest state non-game recovery program of its kind in the United States. AABC's mission is to promote the conservation and restoration of rare freshwater species in Alabama. Between 2010 and 2017, AABC has propagated and released 179,437 individuals of 18 species of rare snail and mussel species. AABC collected gravid CCC during Spring-Summer of 2019 and will continue this work during Spring-Summer of 2020 in order to begin a host trail work for the species (Fobian 2019, entire; P. Johnson pers. comm. 2019). Given the lack of recent recruitment observed within BCC for the CCC (Fobian *et al.* 2017, pp. 9-10), propagation of CCC will likely be required in order to recover this species (MRBMRC 2010, p. 26; Shelton-Nix 2017, p. 69).

### 3.5.4 Governmental Programs - Water and Habitat Quality Conservation

The U.S. Department of Agriculture (USDA) Farm Service Agency (FSA) spearheads the Conservation Reserve Program under the Farm Bill. This is a voluntary program that contracts with farmers and landowners to use their environmentally sensitive agricultural land for conservation benefit (USDA 2016, p. 1). The USDA Natural Resources Conservation Service (NRCS) also administers conservation programs under the Farm Bill that work with private landowners for the conservation of water and soil. These programs include the Environmental Quality Incentives Program (EQIP), Conservation Stewardship Program (CSP), Emergency Watershed Protection Plan (EWP), Watershed Protection and Flood Prevention program, (www.nrcs.usda.gov/wps/portal/nrcs/main/al/programs). These efforts are active in the range of the CCC and may improve water quality in the agricultural landscape within the BCC watershed.

USFWS PFW provides technical and financial assistance to private landowners and Tribes who are willing to work with us and other partners on a voluntary basis to help meet the habitat needs of our Federal Trust Species (www.fws.gov/partners). The BCC SHU is a priority watershed for the PFW, and conservation efforts are focused on project opportunities within BCC that improve overall stream health and aquatic habitat. Currently several projects are in various developmental stages and are expected to be completed within the next 1-1.5 years. The types of projects include, but are not limited to, bank stabilization, exclusion fencing, and barrier removal. Bank stabilization and exclusion fencing projects are being implemented to reduce erosion and improve water quality within target streams. Barrier removal projects are being implemented to improve connectivity for aquatic species and restore the natural hydrology of target streams. To identify, implement, and complete such projects, PFW coordinates with various partners which include landowners, non-governmental organizations (NGOs), and local municipalities.

### 3.5.5 Non-governmental Organizations - Water and Habitat Quality Conservation

The Nature Conservancy is a global environmental conservation organization working to conserve lands and waters (www.nature.org). This organization is very active in Alabama, and has listed Big Canoe Creek as a priority watershed for focused conservation efforts. The Nature Conservancy has been awarded a National Fish and Wildlife Foundation (NFWF) grant to create a watershed coordinator position for the BCC watershed that will work with landowners on headwater protection through land acquisition and easements; protect water quality by restoring and bolstering riparian buffers on public and private lands; install on the ground restoration projects that stabilize eroding streambanks and increase overall water quality and instream habitat on public and private lands; and promote public access and recreational use of the river through conservation and protection of the water resource.

The Friends of Big Canoe Creek is a NGO that was formed in 2008 for purpose of preserving and protecting the BCC watershed through education and participation of on the ground conservation efforts (www.bigcanoecreek.org). The group primarily focuses on educational, recreational and community-service activities like; rain barrel workshops, float trips, and creek cleanups. However, they were instrumental in advocating for and nominating land along the creek for inclusion into Forever Wild, a state program that buys land to protect and preserve it. As of 2018, there is a 382 acre BCC Nature Preserve with about a mile of creek frontage near Springville in St. Clair County. The new preserve will be retained by the Alabama Land Trust and maintained by the City of Springville (Atchison 2018, entire).

The Coosa Riverkeeper is a conservation NGO founded in 2010 with a mission to protect, restore, and promote the Coosa River in Alabama (www.coosariver.org). The Coosa River Riverkeeper is an environmental advocacy organization focused on water quality. Their programs focus on pollution issues, but they also collect and maintain water quality data through their Swim Guide program, which is active in the BCC watershed (Chitwood 2019, entire).

## CHAPTER 4 - CURRENT CONDITION

In this chapter, we describe the current condition of the CCC. First, we assess known survey data including (catch per unit effort and river km occupied) and occupancy of known sites. Then, we develop a population model for the CCC to clarify our understanding of mortality and survival of age classes within the species. Lastly, we describe the current condition of the CCC in terms of its resiliency, representation, and redundancy (the 3Rs).

## 4.1 Demographics and Distribution

### 4.1.1 Abundance

Mussel abundance is indicated by the number of individuals found during a sampling event (Table 4-1 and Table 4-2). Mussel surveys rarely are a complete census of the population, instead density is estimated by the number of individuals found during a survey event using various standardized quadrats. As a result, we used data on the number of individuals captured per standardized effort (search time) (a measure of catch per unit effort (CPUE)) to estimate CCC abundance.

The most recent survey of mussels in the BCC watershed, conducted by Fobian *et al.* (2017, entire), looked for mussels at 48 sites throughout BCC watershed. A total of 497 mussels (Table 4-2) were found during 45.4 person-hours, resulting in a CPUE of 10.9 mussels/person-hour. Eight sites were surveyed in LCC (east) for a total of 7 person hours and a single live CCC was found. This search effort resulted in a CCC CPUE of 0.14 individuals per person hour. Additionally, 29 sites in BCC proper were searched for a total of 32 person hours, and yielded nine live CCC at 2 of 29 sites for a CPUE of 0.28 individuals per person hour. Ten sites were surveyed in LCC West for 7.7 person hours, but resulted on no additional live CCC. A total CPUE of CCC from the west subpopulation equals 0.125 individuals per person hour**.** These low CPUE results indicate the abundance of CCC is very low. Fobian *et al.* (2017, p. 10) noted that the low abundance and absence of sub adults (SL < 50 mm) in the present survey suggests a continued species decline.

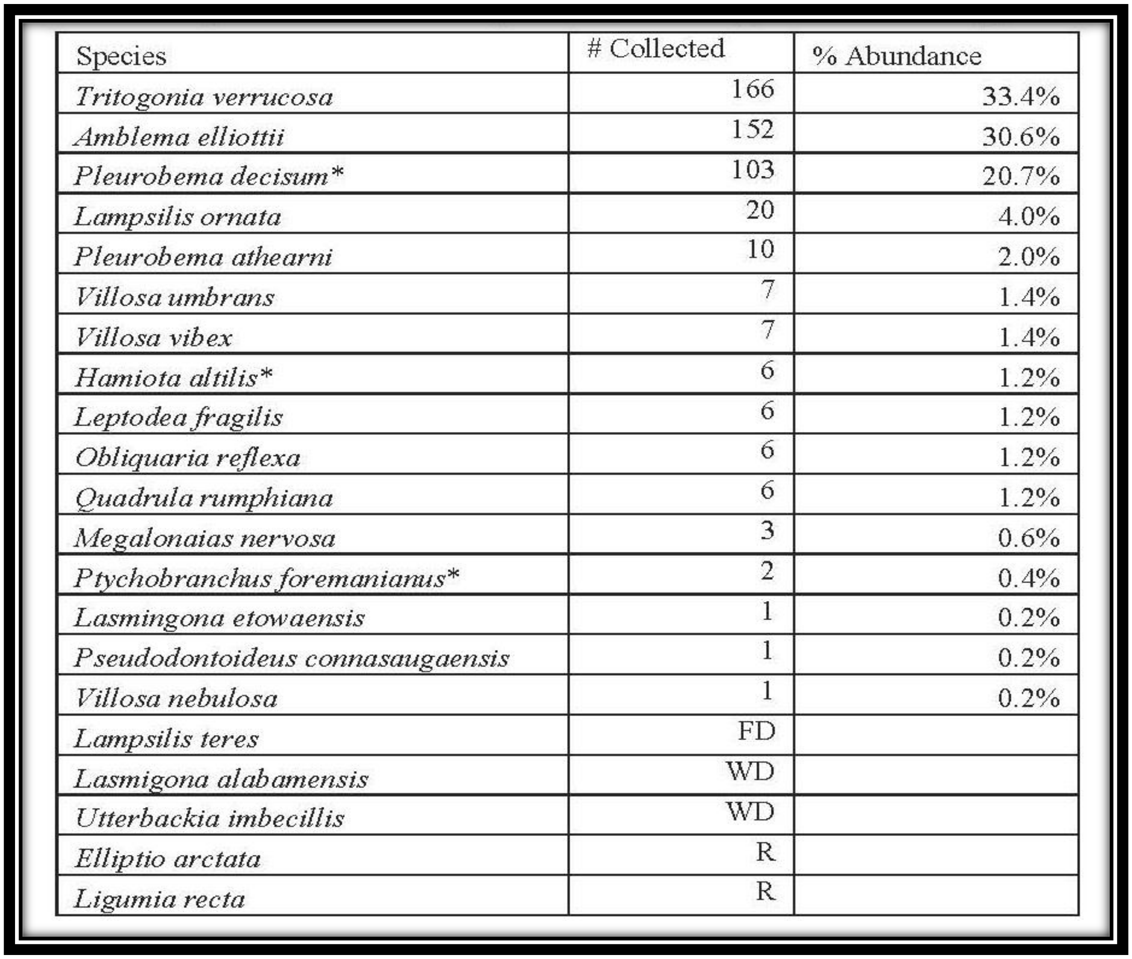
If we consider the relative abundance of southern clubshell in BCC (20% relative abundance and CPUE of 2.2 individuals per person hour) as an estimate for a mussel population expected to be in a moderate to healthy status in BCC, then the substantially lower relative abundance of the CCC (2% of all mussels collected) and CPUE (2.2 individuals per person hour) provides additional support for the conclusions made by Fobian *et al* (2017, p. 10) that the species is currently not sustainable or in a state of decline.

*Table 4-1. Abundance (total number collected) and size (length) distribution for the CCC recently (2017-2018) collected within BCC West and East subpopulations. Source: Fobian et al. 2017 (pp. 9-10) and Fobian 2018 (pp. 1-2). * Single site was resurveyed 4 times.*

| Subpopulation | Number of Sites | Number Sites with Live CCC Collections | Number of Adults | Number of Juveniles or Subadults (<50 mm) | Size Range (mm) |
|---|---|---|---|---|---|
| West | 40 | 2 | 9 | 0 | 61-97 |
| East | 8 | 1* | 16 | 0 | 57-80 |

Previous collections of CCC during the 25 years prior to this study equaled less than 15 live individuals (Fobian *et al.* 2017, pp. 9-10). Subsequent surveys by Fobian (2018, pp. 1-2) to the comprehensive BCC watershed survey found an additional 15 live CCC at a single location (LCC (east) at the Steele Station Road crossing), for a total of 25 individual CCC over the past two years of survey effort (Table 4-1).

*Table 4-2. Overall mussel species abundance of BCC during Fobian et al. 2017. Source: Fobian et al. 2017 (pp. 23).*



| Species | # Collected | % Abundance |
|---|---|---|
| *Tritogonia verrucosa* | 166 | 33.4% |
| *Amblema elliottii* | 152 | 30.6% |
| *Pleurobema decisum** | 103 | 20.7% |
| *Lampsilis ornata* | 20 | 4.0% |
| *Pleurobema athearni* | 10 | 2.0% |
| *Villosa umbrans* | 7 | 1.4% |
| *Villosa vibex* | 7 | 1.4% |
| *Hamiota altilis** | 6 | 1.2% |
| *Leptodea fragilis* | 6 | 1.2% |
| *Obliquaria reflexa* | 6 | 1.2% |
| *Quadrula rumphiana* | 6 | 1.2% |
| *Megalonaias nervosa* | 3 | 0.6% |
| *Ptychobranchus foremanianus** | 2 | 0.4% |
| *Lasmingona etowaensis* | 1 | 0.2% |
| *Pseudodontoideus connasaugaensis* | 1 | 0.2% |
| *Villosa nebulosa* | 1 | 0.2% |
| *Lampsilis teres* | FD | |
| *Lasmigona alabamensis* | WD | |
| *Utterbackia imbecillis* | WD | |
| *Elliptio arctata* | R | |
| *Ligumia recta* | R | |

### 4.1.2 Recruitment

Size distributions of live CCC recovered in recent surveys suggests the species is experiencing recruitment failure (*i.e.*, individuals are not able to survive into reproductive ages) (Table 4-1) (Strayer and Malcom 2012, p. 1783). Of sixteen CCC collected from LCC (east) in 2017-18, sizes of live specimens have ranged between 57-80 mm, with a mean length of 67.5 mm (Fobian *et al*. 2017, pp 10-11; Fobian 2018, p 1-2). The nine individual CCC collected from BCC/LCC (west) have ranged between 61-97 mm in length, with a mean length of 79 mm (Fobian *et al.* 2017, pp 10-11). Fobian *et al.* (2017, p. 10) noted that the low abundance and absence of sub adults (SL < 50 mm) in the recent survey suggests a continued species decline.

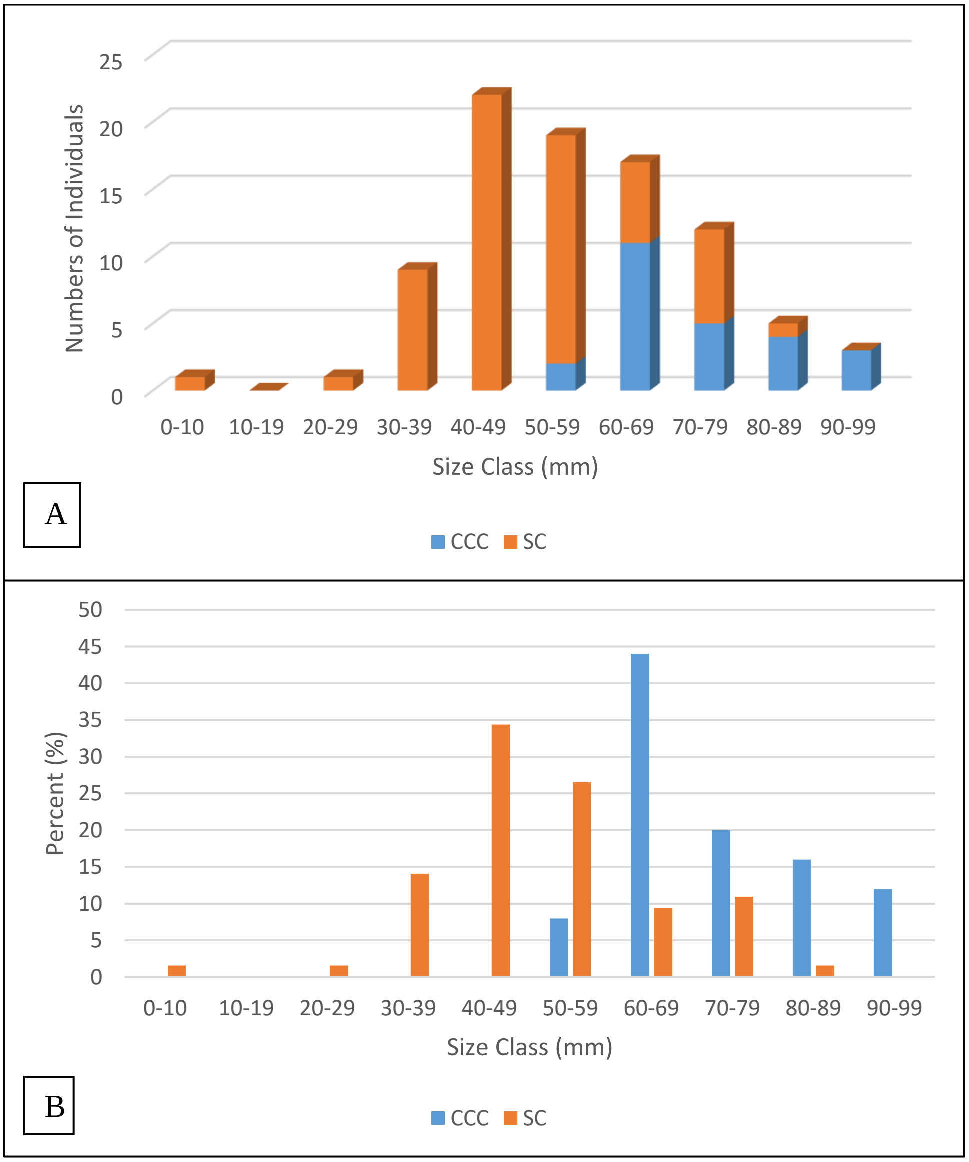


*Figure 4-1. Size class distribution of CCC and southern clubshell (SC) (for comparison with a moderately healthy species) from recent survey data in BCC based on (A) the number of individuals found and (B) proportion of total animals found that fall within each size class (B). Stage classes of CCC are estimated at the following: Juveniles are > 35 mm, Sub-adults are >50 mm, and adults are 50-90+ mm. N=25 (CCC) and 64 (SC). Source data: Fobian et al. 2017, Fobian 2018, and Buntin 2017.*

## 4.2 Population Model

Field observations (Section 4.1) of the CCC indicate that subpopulations are low in abundance and skewed toward larger and older animals. The CCC, like many other members of the Pleurobemini tribe are considered to exhibit an equilibrium life history strategy (Haag 2012, p 211). Such a life-history strategy is analogous to a K-selected vertebrate and is expected have a high age to maturity, higher age to reproduction, typically low reproductive capacity, and low growth rates (Haag 2012, p 210). Size class distributions for equilibrium species are expected to be uniformly distributed, multiple cohorts tend to accumulate into fewer size classes in these populations (Haag 2012, p 217). Therefore, a skewed size-class distribution may indicate that additional mortality is occurring to smaller size classes before they are able to recruit into the population and may suggest a declining population (Strayer and Malcom 2012, p. 1783).

To explore the potential of additional recruitment mortality in populations of CCC, we built a simple age-based population model using Microsoft Excel 10 and the PopTools add-in (Hood 2010, unpaginated). Additionally, we used our model to explore population trends of the CCC using estimated survival rates and considering the potential for environmental stochasticity from droughts and estimated quantities of available habitat to assess future conditions (Chapter 5.3).

### 4.2.1 Development

Little has been done on the CCC to further our understanding of its life-history. However, considerable work has been done on related taxa within its genus (Haag and Rypel 2010, p. 6; Haag and Staton 2003, p. 2118-2125). Therefore, we used literature that reports on demographic estimates such as survival for other *Pleurobema* species to inform the parameterization of our population model. However, fecundity was recently recorded for three CCC females (lengths of 61, 75, and 76 mm); total glochidia ranged between 5,500-46,000 and total viable glochidia ranged from 5,400-17,400 (Fobian 2019, p. 12). We calculated the mean infective (viable) glochidia (9,543 infective glochidia per reproductive female) using these recent data and incorporated it in the model. Initial model parameterization was concluded when a simulated population converged on a stable age distribution that matched the expected uniform size-class distribution of an equilibrium strategy mussel (Haag 2012, p 217).

The number of recruits per year was estimated in our population model by incorporating the Beverton-Holt stock recruitment model.

*Equation 4-1. Beverton-Holt stock recruitment equation.*

$$R = \frac{aS}{1 + bS} e^{w}$$

The Beverton-Holt stock recruitment model estimates the number of recruits (R) by considering some measure of stock abundance (S), the number of recruits per spawner at very low stock abundance (a), a maximum number of recruits produced (a/b) and normally distributed error

(W). We parameterized the Beverton-Holt stock recruitment model with an estimate of 0.7 juveniles produced per female (the median of the range reported in Haag 2012, p 220). The b parameter was adjusted to reflect an abundance that ranged between approximately 3000 and 6000 (range-wide) and approximately 1500 to 3000 (per subpopulation). These ranges provide an approximation of the number of CCC that are present throughout the occupied range. They were calculated using population estimates of a related taxon, Southern pigtoe (*Pleurobema georgianum*), in Shoal Creek, Alabama (Warren *et al.* 2004, p. 27). This related taxon has been observed at a relative abundance similar to CCC in BCC. In Shoal Creek, the Southern pigtoe was estimated to occur at an abundance of 800 animals in an approximated 10 km stream reach. If the CCC occurs at similar densities as the Southern pigtoe across its entire range (approximately 50 km), the CCC estimated population size is approximately 4000 animals. However, initializing the population with these estimated ranges assumes that the entire occupied range of the CCC provides suitable habitat and the species is distributed evenly throughout. Furthermore, Shoal Creek is located within National Forest boundaries and likely has more, higher quality habitat. Therefore, a range of 3000 to 6000 is likely an over-estimate of the number of CCC, however, it represents our best estimate for modelling purposes.

In this population model, we assume that a minimum of 50 reproductive females per subpopulation are required for successful reproduction to occur within a particular year. This is approximately two females per stream kilometer (density approximately 0.0002 individuals/square meter) in the current range of the CCC. We further use this estimate of 50 reproducing females per subpopulation (100 reproducing females range-wide) as an estimate of the minimum viable subpopulation. We consider these estimates to be very conservative and that much higher number of females are required to sustain natural populations. These estimates are only used for modelling purposes.

To understand if additional mortality on CCC recruits is occurring and to what degree, we iteratively ran the population model 100 times under scenarios that assumed 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, and 1% survival of recruits. Mean lengths were calculated under each recruitment survival scenario.

### 4.2.2 Results

Based on our population modeling exercise, we found that the modeled size class distribution and mean length matched observed size class distributions and mean lengths under scenarios where recruit survival varied between 60%-20% (Figure 4-3). This result indicates that additional mortality is likely present on young CCC and that recruitment is limited in the wild subpopulations.

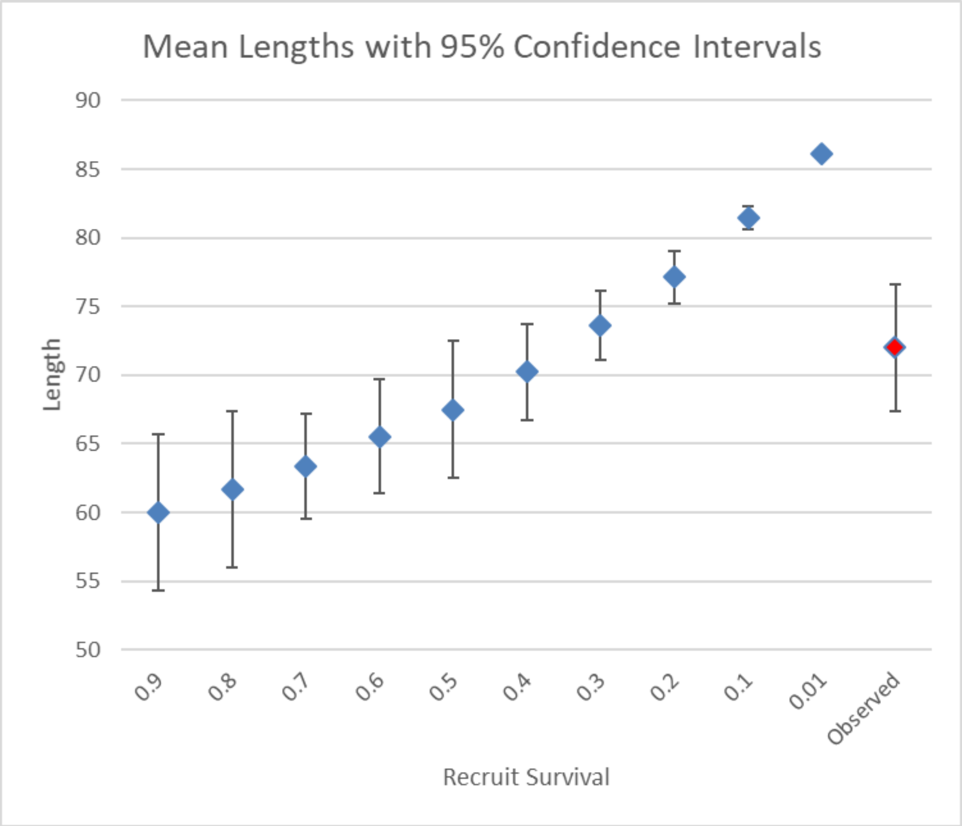


*Figure 4-3. Estimated recruitment survival of CCC with modeled size class distribution and mean length against the observed size class distribution. Source data: Fobian et al. 2017, Fobian 2018, and Buntin 2017.*

Later, we used these estimates of recruitment survival to explore the probability of CCC persisting into the future. We considered scenarios in which drought and habitat changed in the future. Additionally, we considered how propagation efforts may influence CCC's survival (Chapter 5).

### 4.2.3 Assumptions

- Suitable habitat is uniformly distributed throughout the occupied range and the CCC is uniformly distributed throughout.
- CCC can reproduce at densities as low as 0.0002 females per $m^2$ (2 females per river kilometer).
- Reproduction begins at year class 6.
- Juvenile and adult survival is similar and high (approximately 90%) in natural conditions.
- Survival after settlement is no greater than 50%.
- CCC produced approximately 9,543 infective glochidia per reproductive female.
- No additional natural mortality exists (no predation or disease).
- Population growth is density independent.
- Individual growth rates follow logistic curve.

### 4.2.4 Inputs

- Juvenile Survival
- Adult Survival
- Settlement survival (stochastic with beta distribution with an alpha parameter of 3 and beta parameter of 10)
- Beverton-Holt a: 0.7 (from literature)
- Beverton-Holt b: 0.0008 (adjusted to reflect a stable abundance range)

## 4.3 Summary of Current Conditions and Viability based on Resiliency, Representation, and Redundancy

### 4.3.1 Species Resiliency

The CCC and each subpopulation (East and West) needs to be able to withstand, or be resilient to, stochastic events or disturbances (*e.g.* drought, major storms and flooding, spills, or fluctuations in reproduction rates). To be resilient, the species and each subpopulation need to have an adequate number of individuals, cover a large enough area (multiple sites within a population or subpopulation) that a localized event does not eliminate a subpopulation, and have connectivity among sites within each subpopulation such that areas could be repopulated if local site extirpations were to occur. The results of our population model indicate that currently, the CCC subpopulations likely have reduced to little ability to recover from a severe stochastic event, and thus have very limited resiliency. It is also likely that the current observed size class distribution is indicative of recruitment failure (Strayer and Malcom 2012, p. 1783) across the CCC's range. Current demographics may already indicate the species is in an extinction debt, where one or both subpopulations are in a downward spiral from which they are unable to recover naturally (Haag 2012, pp. 384-385).

### 4.3.2 Species Representation

Representation reflects a species' adaptive capacity to changing environmental conditions over time and can be characterized by genetic and ecological diversity within and among populations. The CCC is represented by a single watershed (the BCC watershed). The two subpopulations within the BCC do not differ markedly in their genetic, morphology, ecology, or behavior. The one distinction between the two subpopulations is that Subpopulation East's drainage area is represented by two different physiographic provinces (Cumberland Plateau and Alabama Valley and Ridge), though all portions of its present range occurs within the Alabama Valley and Ridge, as does all portions of the present range of the Subpopulation West. Given that the CCC is so limited in range and individuals of each subpopulation do not vary markedly, the adaptive capacity of the species is likely very limited. Although historical data on the species is limited, we believe the species has likely always been a narrow endemic and that the current, limited adaptive capacity of the CCC is likely similar to that which the species had historically.

### 4.3.3 Species Redundancy

Similar to its adaptive capacity, redundancy for the CCC likely remains relatively unchanged from its historical state and is generally very limited. The CCC's redundancy is currently characterized by two subpopulations that exist within the species' narrow range. However, the relatively recent structuring of the species into two subpopulations likely does not largely provide a benefit to the species since it is a result of a human-caused inundation, the H. Neely Henry Reservoir, which creates a stretch of unsuitable habitat for the mussels and host fish. Indeed, we understand this unsuitable stretch of the species’ range as primarily having a negative impact on the species, as it is a cause of isolation and prevents genetic exchange and the opportunity of recolonization among the subpopulations. Therefore, while the species’ redundancy is characterized by having two subpopulations, the species’ distribution across its range likely provides the greatest protection against catastrophic events. However, since the range of the species is so limited, many catastrophic events, such as a severe drought event, that may impact an entire subpopulation, are likely to impact both subpopulations. Events such as a contaminant spill would be unlikely to affect both subpopulations, as they do not occur directly downstream of one another. However, if a subpopulation were to be extirpated as a result of such an event, natural recolonization would be near impossible given its isolation from its counterpart. Therefore, the CCC currently has limited redundancy to protect against catastrophic events.

# CHAPTER 5 – FUTURE CONDITIONS AND VIABILITY

We have considered what the CCC needs for viability and the current condition of those needs (Chapters 2 and 4), and we reviewed the factors that are driving the historical, current, and future conditions of the species (Chapter 3). We now consider what the species' future conditions are likely to be. We apply our future forecasts to the concepts of resiliency, redundancy, and representation to describe the future viability of the CCC.

## 5.1 Introduction to Projections and Scenarios

To assess the future condition of the CCC, we have forecasted what the CCC may have in terms of the 3Rs under three plausible future scenarios. As outlined in Chapters 3 and 4, climate events (drought), reduced habitat (sediment and water quality) availability and continued decline, and lack of natural recruitment were the primary factors identified as affecting the CCC in the future. Therefore, we projected how these factors would change over time in order to develop our future scenarios by subpopulation to assess propagation or no propagation and historical or enhanced severe drought probability by population at four time periods: years 2045, 2070, 2095, and 2120; or 25, 50, 75, and 100 years into the future. These time steps begin in year 2020, as this was the end of our current condition timeframe that extended through year 2019.

Our population model is meant to represent one subpopulation of CCC and for the purpose of this modeling exercise, we assume both subpopulations of CCC are equal in size. To summarize the overall subpopulation resiliency of the CCC in the future, we introduced both CCC subpopulations to various conditions (habitat degradation and drought frequency) and a propagation scenario that CCC may face.

To assess future conditions and probability of extinction, we used a simple age based population model initially developed to assess recruitment survival (Section 4.2) and we varied environmental stochasticity, habitat availability, and propagation alternatives under each plausible recruitment survival estimate. The models were run 100 times and extirpation was recorded at 25, 50, 75, and 100 years into the future per each iteration.

Demographic stochasticity was introduced in the population model in the first year class of our population model. No studies have been conducted on mussels that were able to estimate survival of wild freshwater mussels during settlement. However, observations in hatcheries indicated that approximately 50% of mussels survived in the first 50 days after excysting (Haag 2012, p. 220; Hanlon and Neves 2006, pp. 47-48). Because hatcheries are controlled environments, we consider a 50% survival estimate of first year-class mussels to overestimate survival of that year class in the wild. Therefore, we included survivorship of the first year class as a stochastic parameter that varied by year and was sampled from a beta distribution with an alpha parameter of 3 and beta parameter of 10. This ensured that survivorship of new recruits generally did not exceed 50%.

Environmental stochasticity was incorporated by considering the effects of severe droughts (PDSI < -3) on mussel populations. Drought conditions have a substantial effect of mussel populations, with declines in mussel abundances observed between 65-83% in small (<267 km$^2$)

watersheds (Table 3-2) (Haag and Warren 2008, p. 1170). Based on these observations, we incorporated survivorship of CCC during drought years as a fixed estimate of 26% (the median "survivorship" reported by Haag and Warren 2008, p. 1170) during years of severe drought. The probability that the entire simulated mussel population would be exposed to this level of survivorship in a particular year was approximated by calculating the percentage of years in which severe droughts (average annual PDSI ≤ -3) were recorded during the period of record (1895-2018) (Figure 4-4). Approximately 50% of the years between 1895 and 1999 exhibited drought conditions in the State of Alabama and severe drought (PDSI ≤ -3) occurred in approximately 6% of recorded years (NOAA 2020, unpaginated). Overall drought frequency did not increase in the years between 2000 and 2018, however, the frequency of years that exhibited severe drought conditions did increase (NOAA 2020, unpaginated). We assumed that the probability of a severe drought occurring in a particular year followed a binomial distribution (sequence of independent pass/fail or drought/no drought experiments). For the purpose of this model, we assumed a 6% (moderate) and 11% (enhanced) frequency of severe drought to represent two plausible severe drought frequency scenarios based on past drought data for the State of Alabama (Figure 4-4).

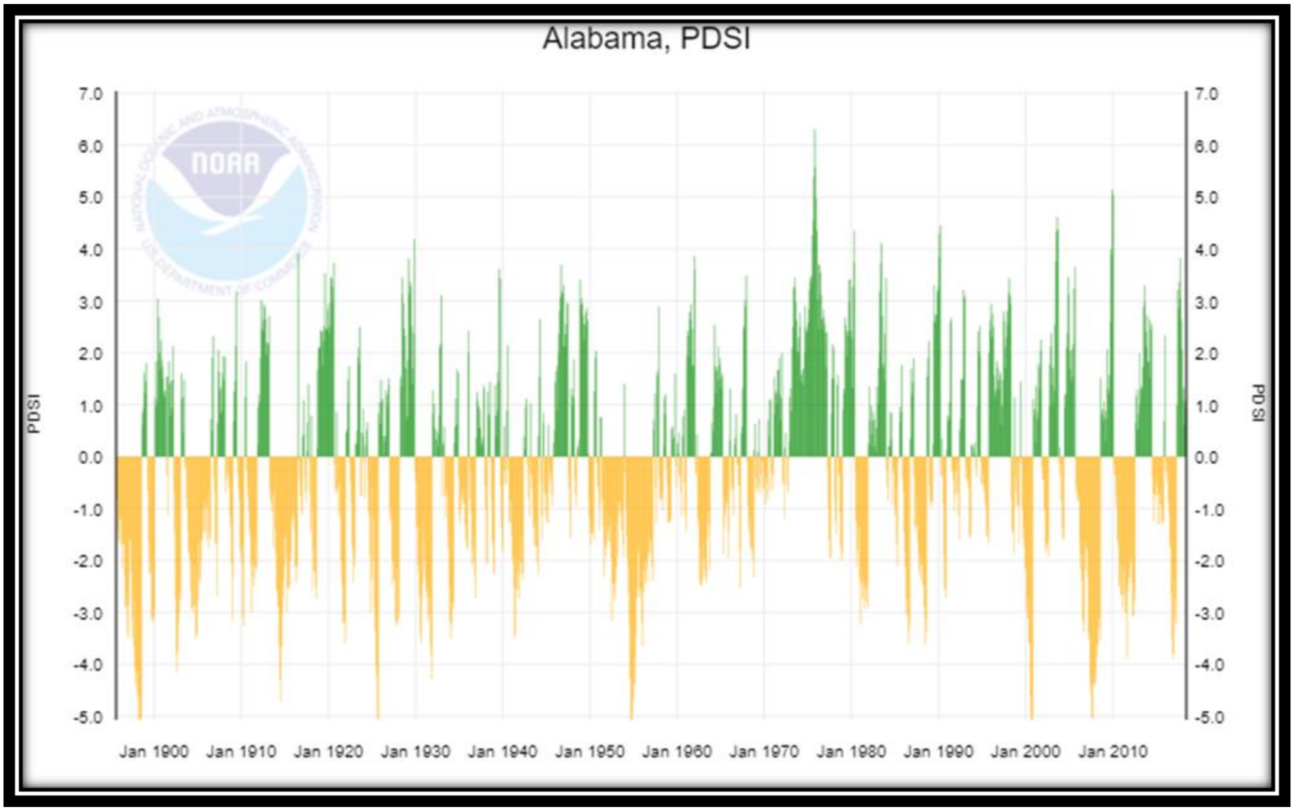


*Figure 4-4. Palmer Drought Severity Index for the State of Alabama for the period of record (1895-2018) (NOAA 2020, unpaginated).*

### 5.1.1 Population Model - Assumptions

- Suitable habitat is uniformly distributed throughout the occupied range and the CCC is uniformly distributed throughout.
- CCC can reproduce at densities as low as 0.0002 females per m$^2$ (2 females per river km).

- Reproduction begins at year class 6.
- Juvenile and adult survival is similar and high (approximately 90%) in natural conditions.
- Survival after settlement is no greater than 50%.
- CCC produced approximately 9,543 infective glochidia per reproductive female.
- Survival during severe droughts affects all members of the population equally and the survival rate during severe droughts is 26%
- No additional natural mortality exists (no predation or disease).
- Population growth is density independent.
- Individual growth rates follow logistic curve.
- Abundance is related to habitat availability

### 5.1.2 Population Model - Inputs

- Juvenile Survival
- Adult Survival
- Settlement survival (stochastic with beta distribution with an alpha parameter of 3 and beta parameter of 10)
- Beverton-Holt a: 0.7 (from literature)
- Beverton-Holt b: 0.0008 (adjusted to reflect a stable abundance range)
- Drought probabilities: 6% and 11%
- Drought survival: 26%
- Habitat parameter: adjust the Beverton-Holt b parameter to reflect approximately half of our original estimates (see Section 4.2.3 for the model assumptions)
- Propagation parameter: 500 animals of the first year-class per year for the duration of our time horizon

## 5.2 Projections

### 5.2.1 Drought

Drought conditions are reasonably certain to occur into the future; and with climate change, more intense droughts are expected to occur, especially in sub-tropical areas (Elizza and Zaki, 2011, p. 252). The Southeastern United States has been projected to experience more frequent occurrences of summer precipitation variability that equates to enhanced flood/drought intensity (Li *et al.* 2013, pp. 340, 351). Warmer temperatures can amplify the impacts of drought (Center for Climate and Energy Solutions 2019, https://www.c2es.org/content/drought-and-climate-change/). The CMIP5 shows hydrological modeling estimates of global drought variability, and captures regional variation in drought frequency (Wuebbles *et al.* 2014, pp. 578-579). The figures below show the future CHIP5 projections of temperature and precipitation (Figure 5-1 and Figure 5-2).

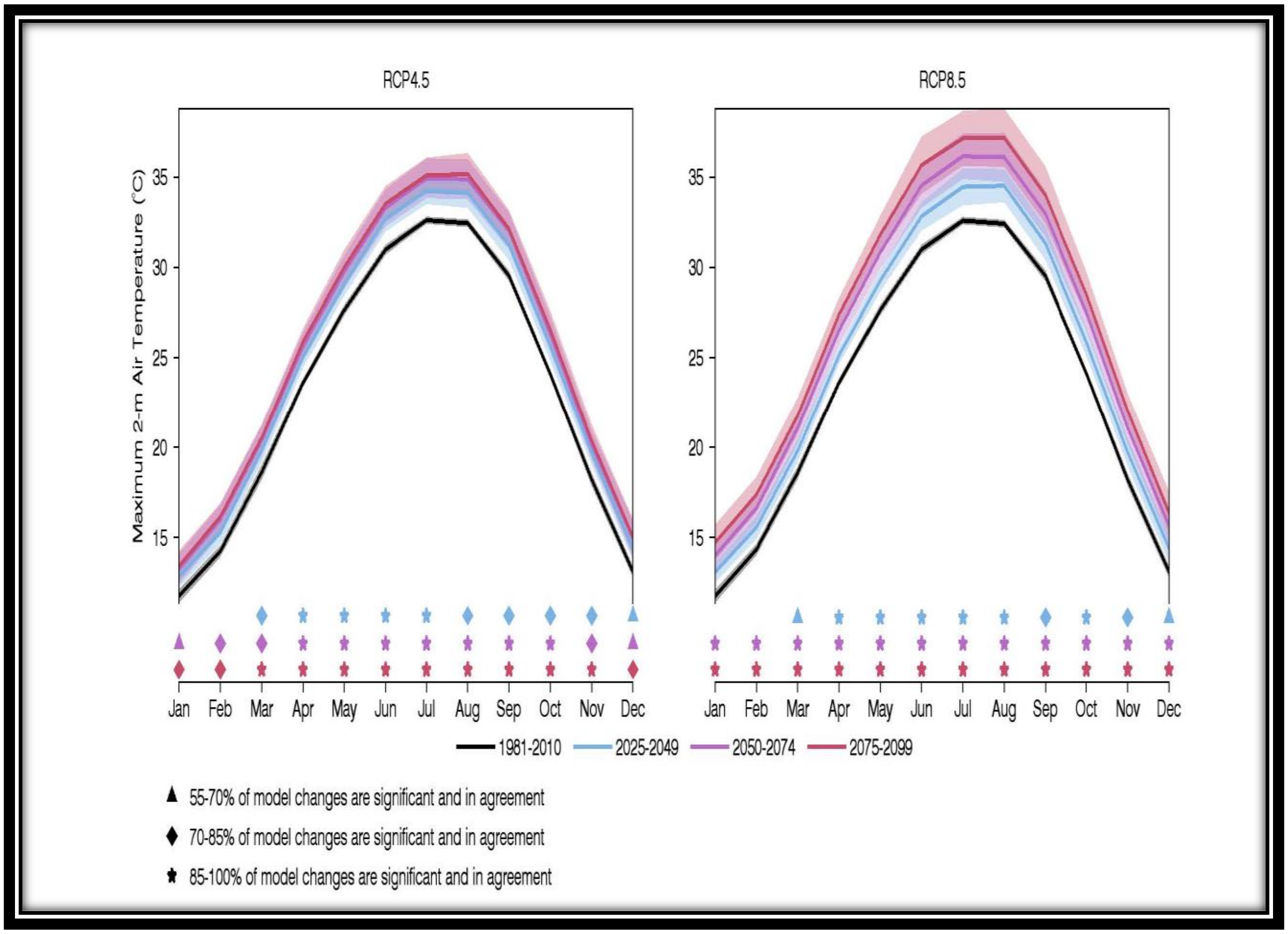


*Figure 5-1. Change in monthly averages of maximum 2-m (2 meters above ground) air temperature for four time periods (historical and future scenarios) based off of RCP 4.5 (left) and RCP 8.5 (right) simulations for St. Clair County, Alabama. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes. Triangle, diamond and square symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A two-sided Students t-test is used to establish significance ($p \leq 0.05$). Source: Alder and Hostetler 2013, NCCV USGS.*

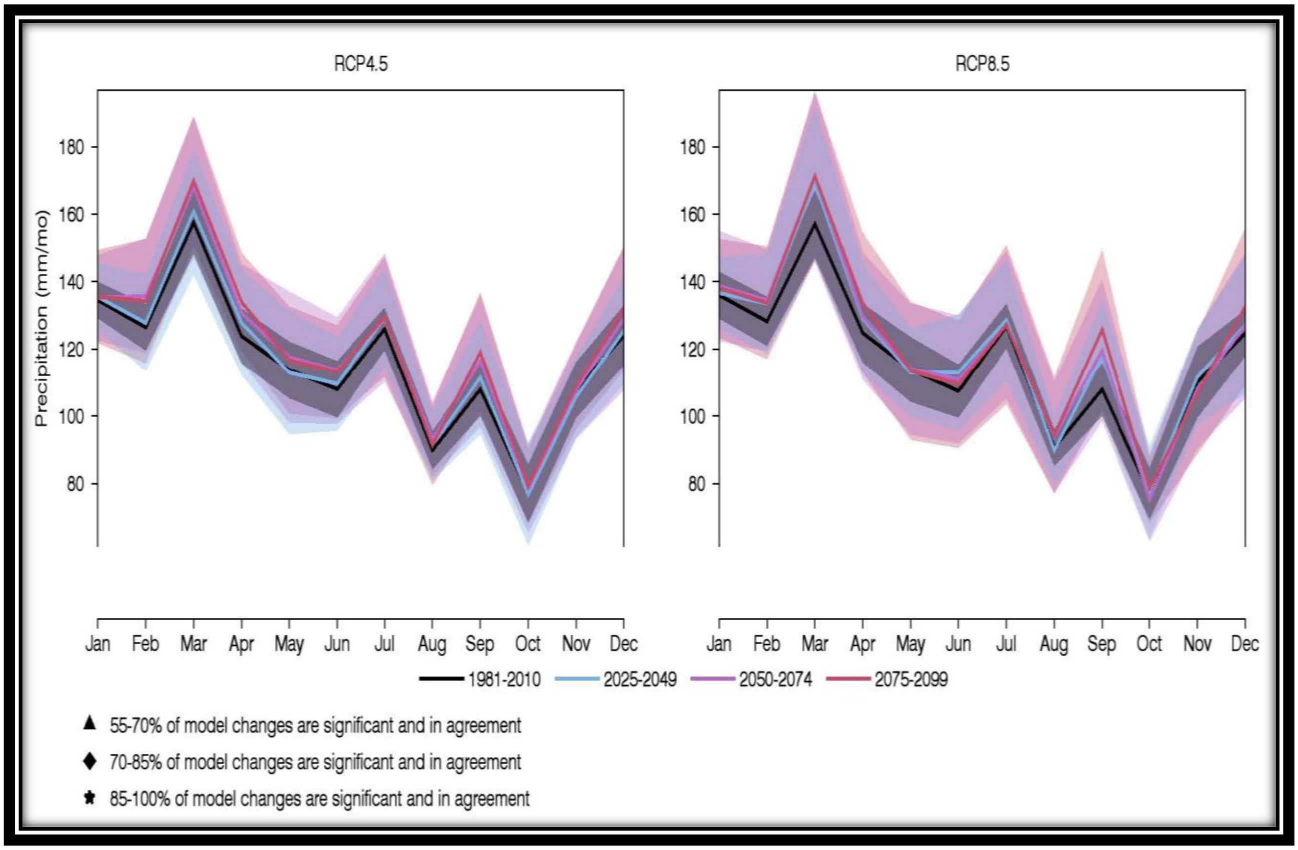


*Figure 5-2. Change in monthly averages of precipitation for four time periods (historical and future scenarios) based off of RCP 4.5 (left) and RCP 8.5 (right) simulations for St. Clair County, Alabama. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes. Triangle, diamond and square symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A two-sided Students t-test is used to establish significance (p ≤ 0.05). Source: Alder and Hostetler 2013, NCCV USGS.*

Higher temperatures increase the water-holding capacity of the atmosphere and thus increase potential evapotranspiration, as such global warming not only raises temperatures, but also enhances drying near the surface, and is captured by the PDSI; and the increased risk of drought duration, severity, and extent are the consequence (Dai *et al.* 2004, p. 1129).

Drought severity has been recorded for Alabama since 1895 (NOAA 2020, unpaginated), and has a substantial effect of mussel populations, with declines in mussel abundances observed between 65-83% in small (<267 km$^2$) watersheds (Table 3-2) (Haag and Warren 2008, p 1170). Approximately 50% of the years between 1895 and 1999 exhibited drought conditions in the State of Alabama and severe drought (PDSI ≤ -3) occurred in approximately 6% of recorded years (NOAA 2020, unpaginated). Overall drought frequency did not increase in the years between 2000 and 2018, however, the rate or incidence of severe drought has increased since the beginning of this century (*e.g.*, 2000 and 2007) (NOAA 2020, unpaginated). Given the uncertainty in the proportion of years that will face severe drought conditions in the future, we developed two scenarios with varying probabilities of severe drought conditions: one scenario assumes the probability of severe droughts continue at the rate observed historically (6%) and a second scenario assumes the probability of severe droughts continues at the rate more similar to that seen in recent years (11%).

### 5.2.2 Habitat Changes

Habitat quality degradation is reasonably certain to occur into the future given the stressors already occurring on the landscape: agriculture, urban development, construction activities, unpaved roads, and forestry activities, and predicted growth (Wynn *et al.* 2016, pp. 50-52) (Appendix A). Recent habitat assessments by ADEM and GSA indicate approximately half of the habitat available for CCC is already impaired (ADEM 2005a, entire; ADEM 2005b, entire, and Wynn *et al.* 2016, p. 17) and unlikely suitable for the CCC per surveyor observations (T. Fobian pers. comm. 2019). Therefore, to assess habitat alteration in our simulated mussel population, we adjusted the Beverton-Holt b parameter to reflect a reduced carrying capacity (approximately one-half of our original estimate, see Section 4.2.2). We did not evaluate a continued change in this amount of suitable habitat for the CCC because it is difficult to estimate habitat declines by year. However, it is reasonably certain that habitat will continue to degrade. Therefore, our models overestimate abundances of the CCC into the future and likely projects a higher chance of a subpopulation remaining extant.

Some of the primary influences on habitat quality degradation in the BCC Watershed are associated with urban growth (Figure 3-3). It is anticipated that the availability of suitable habitat will continue to decline as human populations and subsequent urban development continues to grow. The human population in the southern United States has grown at an average rate of 38.3% since 2010, making it the fastest growing region in the country (U.S. Census 2020). As a result, urbanization has been identified as a stressor to this species and its habitat. Growth will continue at a rapid pace within Birmingham and the surrounding areas. Therefore, development and urban sprawl is expected to expand and influence areas that previously were unaffected by urbanization. Rapid growth in the Birmingham area and across the southeastern U.S. as a whole is expected to be a major driver of change and an important consideration when evaluating future viability of the CCC. We used the SLEUTH (Slope, Land use, Excluded area, Urban area, Transportation, Hillside area) model to consider how land use across BCC is predicted to change and develop.

The SLEUTH model, simulates patterns of urban expansion that are consistent with spatial observations of past urban growth and transportation networks, including the sprawling, fragmented, “leapfrog” development that has been dominant in the southeastern United States. (Terando *et al.* 2014, p. 2). The extent of urbanized areas has been predicted to increase across the southeastern United States by approximately 100 - 192 % based on the “business-as-usual” (BAU) scenario (Figure 5-3) that expects future development to match current development rates (Terando *et al.* 2014, p. 1). We use this range of percent change in urbanization to develop our future scenarios described below.

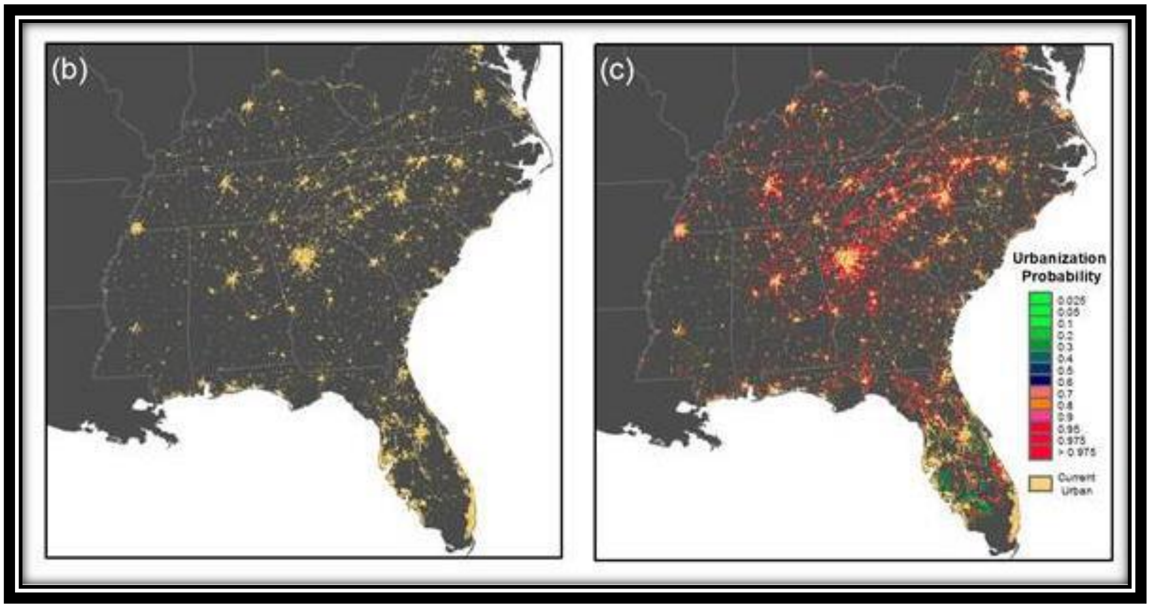


*Figure 5-3. a) "Business-as-usual" scenario for the Southeast United States where red indicates urban extent (Terando et al. 2014, p. 3); b) is the initial urban land cover as of 2009; and c) is the projected urban land cover in 2060.*

The corridor between Gadsden and Birmingham, Alabama is expected to urbanize according to the SLEUTH model and will apply pressure to the CCC in both BCC subpopulations (Figure 5-4 and 5-5). The areas surrounding Springville, Ashville, Steele, and Gadsden will experience further development which will negatively affect water quality and habitat quality within BCC.

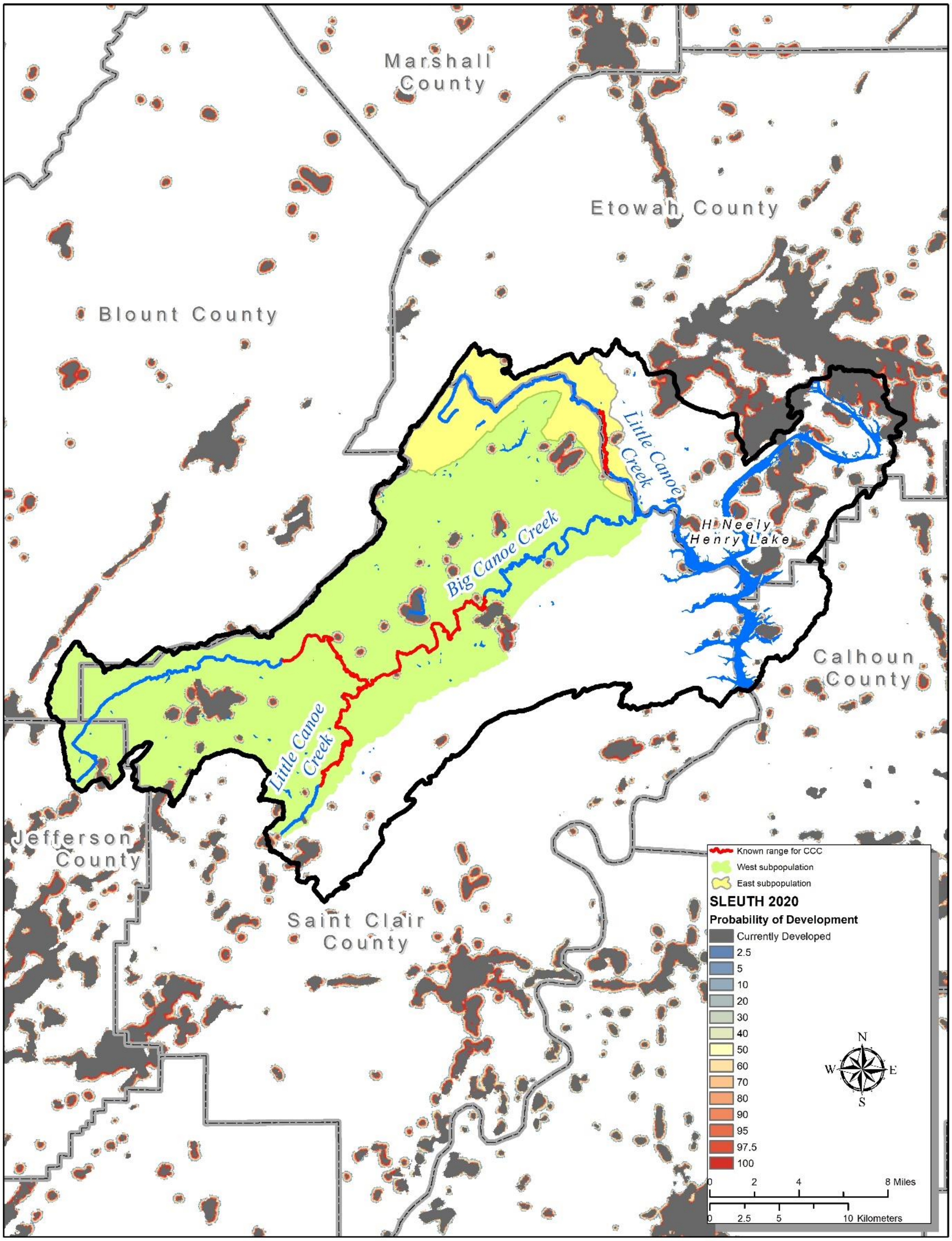


*Figure 5-4. SLEUTH Model projection of 2020 in the BCC area.*

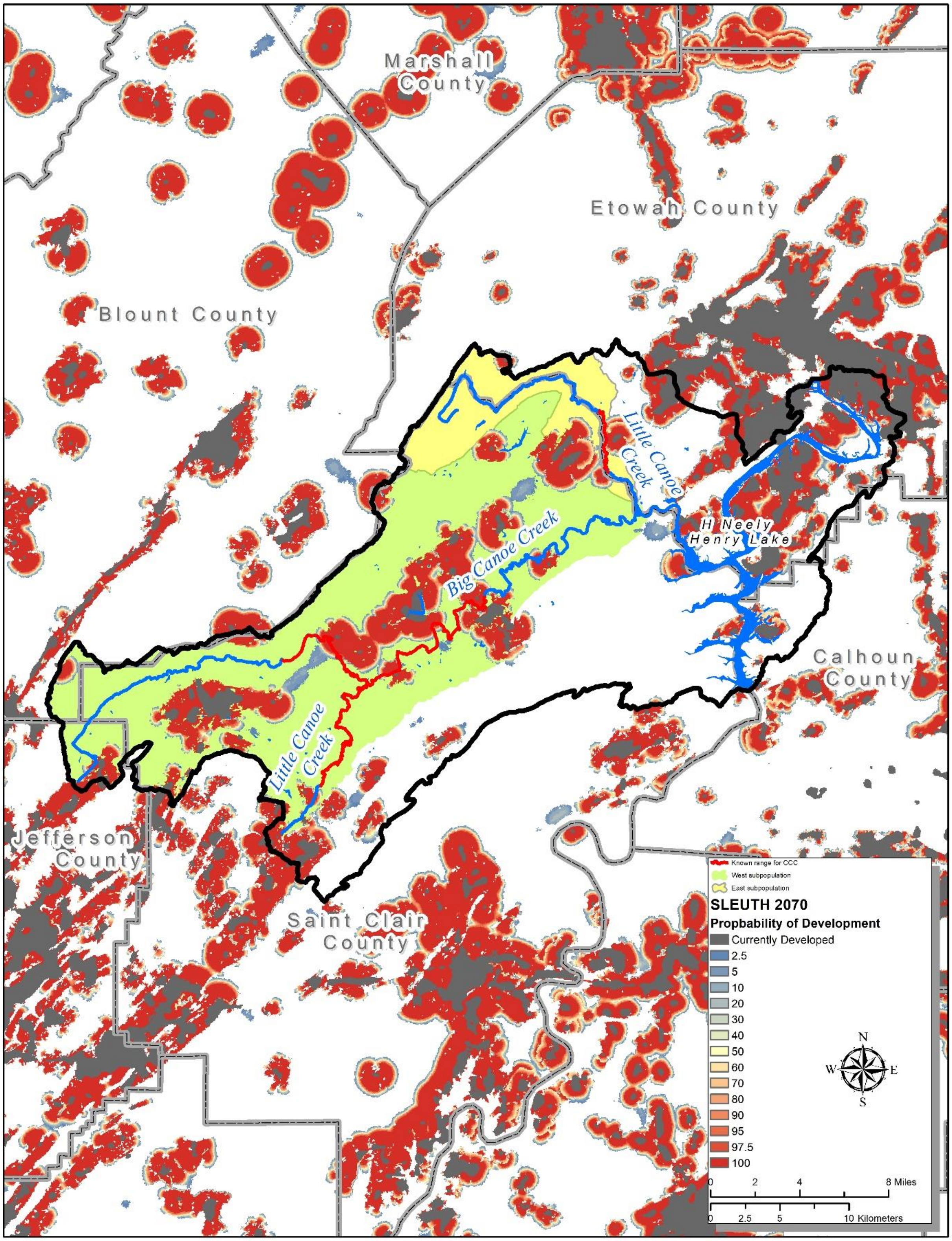


*Figure 5-5. SLEUTH Model projection of 2070 in the BCC area.*

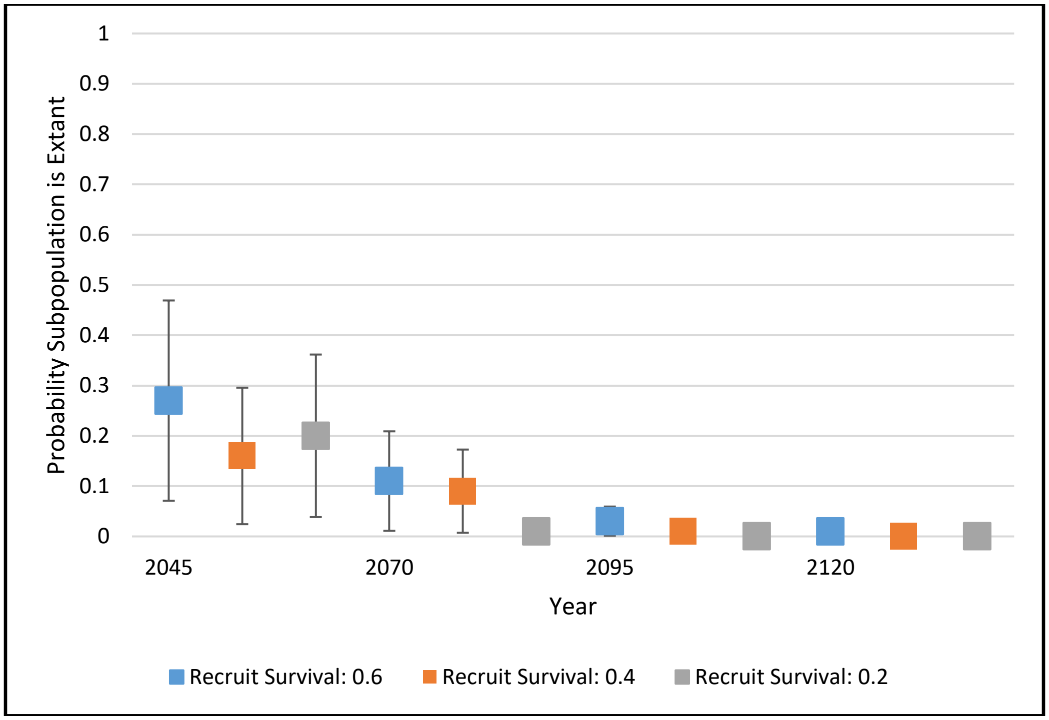
### 5.2.3 Propagation

Active propagation of CCC has been identified by both the Mobile River Basin Mollusk Restoration Committee (represented by multiple state, federal, and non-governmental natural resource organizations) and the State of Alabama as likely to be required in order to recover this species (MRBMRC 2010, p. 26; Shelton-Nix 2017, p. 69). The AABC began conducting host trials on CCC in 2019 and will continue this work into 2020 (P. Johnson pers. comm. 2019; Fobian 2019, entire). At this time, this current work is only to help identify gaps in our knowledge of CCC life history and to develop culture methods for this species, and a long term plan for CCC has not been developed. However, implementation of successful propagation techniques will be required in the future to successfully recruit and augment the subpopulations of CCC in BCC. Likewise, future conservation efforts should also focus on removing barriers and conserving or restoring habitat and water quality, as an important component of any propagation/augmentation plan or natural recruitment scenario.

## 5.3 Scenarios

The results of the population model, summarized below, indicate the probability of a subpopulation remaining extant under three future scenarios 25, 50, 75, and 100 years in the future.

### 5.3.1 Scenario 1: Static habitat availability with a moderate probability of severe drought (6%) and no propagation of the species



| Year | Recruitment Survival Coefficient | Probability of Subpopulation Remaining Extant | Variance |
|---|---|---|---|
| 2045 | 0.6 | 0.27 | 0.20 |
| | 0.4 | 0.16 | 0.14 |
| | 0.2 | 0.20 | 0.16 |
| 2070 | 0.6 | 0.11 | 0.10 |
| | 0.4 | 0.09 | 0.08 |
| | 0.2 | 0.01 | 0.01 |
| 2095 | 0.6 | 0.03 | 0.03 |
| | 0.4 | 0.01 | 0.01 |
| | 0.2 | 0 | 0 |
| 2120 | 0.6 | 0.01 | 0.01 |
| | 0.4 | 0 | 0 |
| | 0.2 | 0 | 0 |

*Figure 5-6. Probability of subpopulation remaining extant (graph and table) given the conditions of Scenario 1 at year 2045, 2070, 2095, and 2120 into the future within a range of three probable recruitment survival estimates.*

In Scenario 1 (Figure 5-6), the population model assumes a static amount of suitable habitat is uniformly distributed throughout the range of the CCC, but is reduced by adjusting the model carrying capacity by half to reflect a more realistic estimate of habitat alteration as documented by recent habitat assessments (ADEM 2005a, entire; ADEM 2005b, entire, and Wynn *et al.* 2016, p. 17). This level of habitat alteration more likely reflects what is available to CCC as suitable, and is also supported by the numerous null surveys within the range of the CCC (Figure 2-6 and 2-7) and surveyor observations (T. Fobian pers. comm. 2019). It is likely suitable habitat for the CCC will continue to degrade based on predicted development (Figure 5-5) and climate change (Figure 5-1 and 5-2), however from a modeling standpoint these declines are hard to ascertain, so by reflecting static suitable habitat, we are likely underestimating the degree to which CCC is likely to remain extant. We also assume severe drought (PDSI ≤ -3) will continue to occur at a 6% frequency during the modelled years, similar to the frequency observed in Alabama between years 1895 and 1999. Each severe drought event that is run by the model will incorporate a survival rate of 26% for CCC, similar to the survival experience by a related taxon (Warrior pigtoe) in the Sipsey Fork drainage during the severe drought of 2000 (Table 3-3). The drought of 2000 had a mean annual PDSI of -3.01, and had similar recorded drought levels to BCC (Figure 3-4). It also hard to anticipate a frequency at which severe drought occur, but we do know that climate change is predicted to result in increases in annual maximum air temperatures and precipitation in BCC (Figures 5-1 and 5-2) and result in more intense droughts (Elizza and Zaki, 2011, p. 252; Li *et al.* 2013, pp. 340, 351).

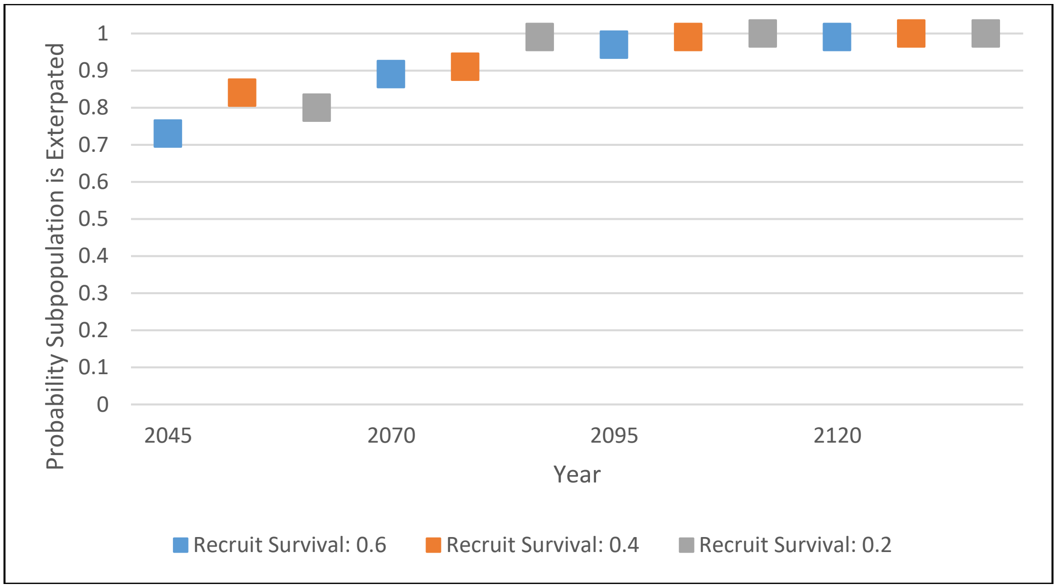
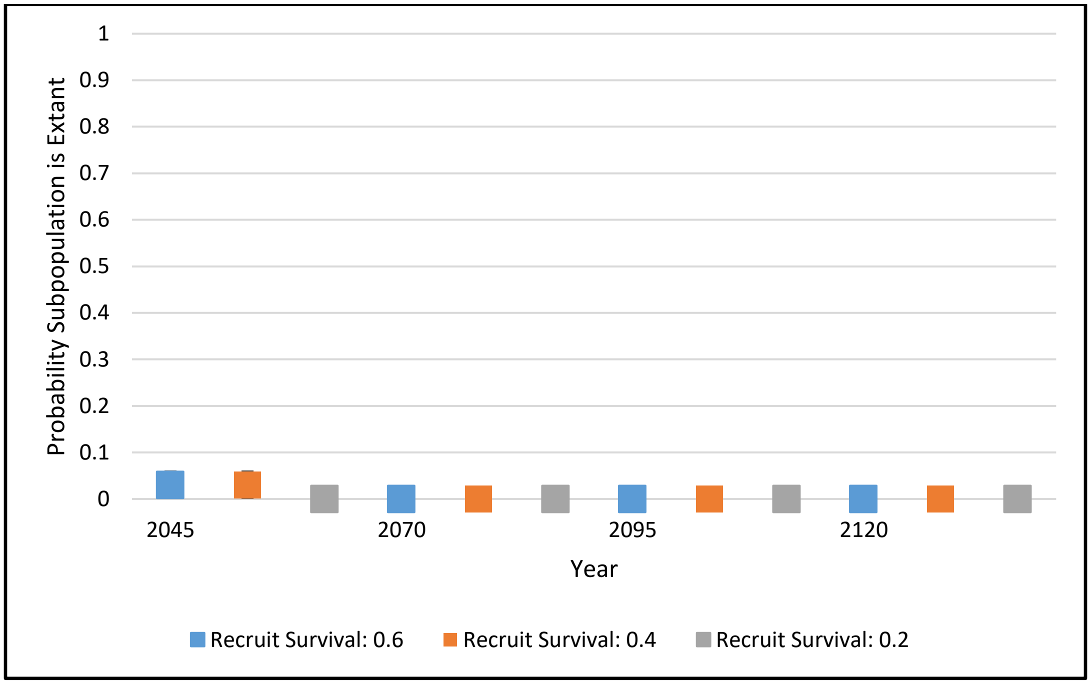


*Figure 5-7. Probability of subpopulation becoming extirpated given the conditions of Scenario 1 at year 2045, 2070, 2095, and 2120 into the future within a range of three probable recruitment survival estimates.*

In summary, under Scenario 1, both subpopulations are likely to be affected by drought in a similar fashion due to close geographic proximity. So, we assume the model output could equally be applied to either subpopulations of CCC. When the model ran at moderate probability of severe drought (6%) and at three different recruitment survival coefficients (0.2, 0.4, and 0.6), the model estimated mean probability of either subpopulation remaining extant (Figure 5-6). Given current demographics of CCC in both subpopulations and the probability of this scenario resulting extirpation (Figure 5-7), resiliency of each subpopulation is critically low. Extinction of the species as a whole is also likely to highly likely (30-100%) across all future time periods evaluated (Table 5-1).

### 5.3.2 Scenario 2: Static habitat availability with enhanced probability severe drought (11%) and no propagation of the species



| Year | Recruitment Survival Coefficient | Probability of Subpopulation Remaining Extant | Variance |
|---|---|---|---|
| 2045 | 0.6<br>0.4<br>0.2 | 0.03<br>0.03<br>0 | 0.03<br>0.03<br>0 |
| 2070 | 0.6<br>0.4<br>0.2 | 0<br>0<br>0 | 0<br>0<br>0 |
| 2095 | 0.6<br>0.4<br>0.2 | 0<br>0<br>0 | 0<br>0<br>0 |
| 2120 | 0.6<br>0.4<br>0.2 | 0<br>0<br>0 | 0<br>0<br>0 |

*Figure 5-8. Probability of subpopulation remaining extant (graph and table) given the conditions of Scenario 2 at year 2045, 2070, 2095, and 2120 into the future within a range of three probable recruitment survival estimates.*

In Scenario 2 (Figure 5-8), the population model assumes a static amount of suitable habitat is uniformly distributed throughout the range of the CCC, but is reduced by adjusting the model carrying capacity by half to reflect a more realistic estimate of habitat alteration as documented by recent habitat assessments (ADEM 2005a, entire; ADEM 2005b, entire, and Wynn *et al.* 2016, p. 17). This level of habitat alteration more likely reflects what is available to CCC as suitable, and is also supported by the numerous null surveys within the range of the CCC (Figures 2-5 and 2-6) and surveyor observations (T. Fobian pers. comm. 2019). It is likely suitable habitat for the CCC will continue to degrade based on predicted development (Figure 5-5) and climate change (Figures 5-1 and 5-2), however from a modeling standpoint these declines are hard to ascertain, so by reflecting static suitable habitat, we are likely underestimating the degree to which CCC is likely to remain extant. We also assume severe drought (PDSI ≤ -3) will continue to occur at an 11% frequency during the modelled years, similar to the frequency observed in Alabama between years 2000 to 2018. Each severe drought event that is run by the model will incorporate a survival rate of 26% for CCC, similar to the survival experience by a related taxon (Warrior pigtoe) in the Sipsey Fork drainage during the severe drought of 2000 (Table 3-3). The drought of 2000 had a mean annual PDSI of -3.01, and had similar recorded drought levels to BCC (Figure 3-4). It also hard to anticipate a frequency at which severe drought occur, but we do know that climate change is predicted to result in increases in annual maximum air temperatures and precipitation in BCC (Figures 5-1 and 5-2) and result in more intense droughts (Elizza and Zaki, 2011, p. 252; Li *et al.* 2013, pp. 340, 351).

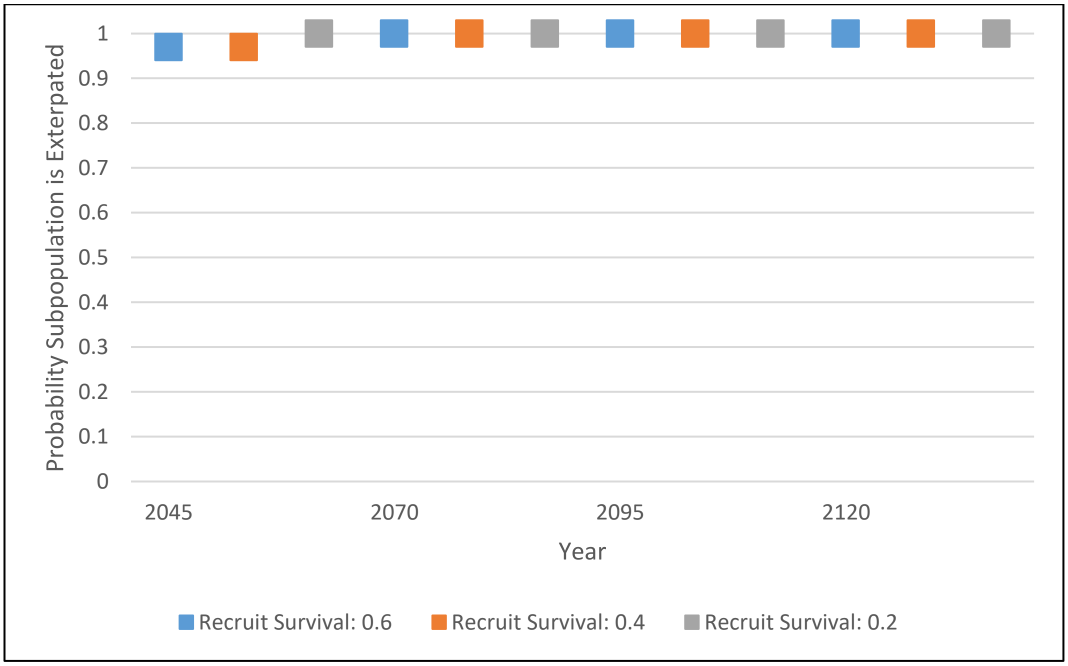


*Figure 5-9. Probability of subpopulation becoming extirpated given the conditions of Scenario 2 at year 2045, 2070, 2095, and 2120 into the future within a range of three probable recruitment survival estimates.*

In summary, based on Scenario 2, both subpopulations are likely to be affected by drought in a similar fashion due to close geographic proximity. So, we assume the model output could be applied to either subpopulations of CCC. When the model ran at enhanced probability of severe drought (11%) and at three different recruitment survival coefficients (0.2, 0.4, and 0.6), the model estimated mean probability of either subpopulation remaining extant (Figure 5-8). Given current demographics of CCC in both subpopulations and the probability of this future scenario resulting extirpation (Figure 5-9), resiliency of each subpopulation is critically low. Extinction of the species as a whole is also highly likely (94-100%) across all future time periods evaluated (Table 5-1).

### 5.3.3 Scenario 3: Static habitat availability with enhanced probability of severe drought and propagation of the species

When propagation of the CCC is implemented and 500 animals of the year one class are released every year into the future to offset recruitment mortality, the probability of a subpopulation remaining extant is 100% for every year considered in our future conditions analysis. We did not assess propagation of the CCC at moderate probabilities (6%) of severe drought because it is reasonable to infer that if propagation is able to ensure the CCC remains extant under enhanced drought probabilities (11%), it will also ensure the CCC remains extant when the probability of severe drought is reduced.

Under Scenario 3, both subpopulations are likely to be affected by drought in a similar fashion due to close geographic proximity. Both Scenario 1 and 2, demonstrated critically low resiliency. However, while Scenario 3 is modeled against an enhanced probability of severe drought, this scenario anticipates active conservation through propagation. Propagation assumes assisted recruitment with CCC that will by adding 500 recruits to the range of the species per year. Resiliency is increased to the level that 100% of the model replicates resulted in an extant subpopulation. If active conservation through propagation is maintained on the CCC, extinction of the species is unlikely across all future time periods evaluated (Table 5-1).

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

*Table 5-1. Summary of the probability of extirpation of one CCC subpopulation and both CCC subpopulations (i.e., species extinction) given future scenarios. Time periods of 2045, 2070, 2095, and 2120 were used for the three future scenarios.*

| Year | Recruitment Survival Coefficient | Probability of Subpopulation Extirpation Scenario 1 | Probability of Species Extinction Scenario 1 | Probability of Subpopulation Extirpation Scenario 2 | Probability of Species Extinction Scenario 2 | Probability of Species Extinction Scenario 3 |
|---|---|---|---|---|---|---|
| 2045 | 0.6 | 0.73 | 0.53 | 0.97 | 0.94 | 0 |
| | 0.4 | 0.84 | 0.71 | 0.97 | 0.94 | 0 |
| | 0.2 | 0.80 | 0.64 | 1 | 1 | 0 |
| 2070 | 0.6 | 0.89 | 0.79 | 1 | 1 | 0 |
| | 0.4 | 0.91 | 0.83 | 1 | 1 | 0 |
| | 0.2 | 0.99 | 0.98 | 1 | 1 | 0 |
| 2095 | 0.6 | 0.97 | 0.94 | 1 | 1 | 0 |
| | 0.4 | 0.99 | 0.98 | 1 | 1 | 0 |
| | 0.2 | 1 | 1 | 1 | 1 | 0 |
| 2120 | 0.6 | 0.99 | 0.98 | 1 | 1 | 0 |
| | 0.4 | 1 | 1 | 1 | 1 | 0 |
| | 0.2 | 1 | 1 | 1 | 1 | 0 |

### 5.4.1 Future Species Resiliency

Both subpopulations of CCC shows critically limited ability to withstand, or be resilient to, stochastic events or disturbances into the future (*e.g*. drought, major storms and flooding, spills, or fluctuations in reproduction rates). The model scenarios show that unless active conservation is introduced in the way of CCC propagation/augmentation, this species is extremely vulnerable to drought, and thus has very limited resiliency. This model, while showing the dire circumstances facing the CCC in the future, presents a conservative estimate of the probability of extinction this species faces in the future. Regardless, the model indicated a high to extremely high probability of species extinction (Table 5-1) when introduced to future drought scenarios (Scenario 1 and 2) where species propagation (Scenario 3) was not considered, across all years projections (25-100 years).

### 5.4.2 Future Species Representation

Being a narrow endemic occurring within only a single watershed (drainage area of 583 km$^2$), the CCC has limited adaptive capacity. We subdivided this single population into two smaller subpopulations based on limited connectivity, but the two subpopulations are not known to differ genetically, morphologically, ecologically, or behaviorally. Subpopulation East HUC 12 is located across two physiographic provinces (Cumberland Plateau and Alabama Valley and Ridge), though the occupied range of both subpopulations are limited to the Alabama Valley and Ridge. It is extremely likely that extirpation of either or both subpopulations will occur in the future (Table 5-1) and what little representation exists within the CCC will be reduced under all scenarios and time periods unless active propagation is conducted.

### 5.4.3 Future Species Redundancy

It is extremely likely that extirpation of either or both subpopulations will occur in the future (Table 5-1) and what little redundancy exists within the CCC will be reduced under all scenarios and time periods unless actively propagation is conducted. The CCC's redundancy is currently characterized by two subpopulations that exist within the species' narrow range. However, susceptibility of both populations to localized stochastic events (*e.g.*, spills, new point source discharges) that reduce resiliency or cause extirpation and/or continued, large scale habitat degradation (*e.g.*, urban growth/urbanization, see Figure 3-3 and 5-5) there is a high likelihood that redundancy will greatly reduce in the future. Furthermore, as seen in our modelling exercise, the species is unable to withstand probable increase in catastrophic events (Table 5-1).

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# Appendix A

## Evaluating Causes and Effects for Canoe Creek Clubshell Species Status Assessment

| **THEME: Sedimentation** | | | | |
|---|---|---|---|---|
| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| **SOURCE(S)** | *What are the ultimate actions causing the stressor?* | Agriculture, livestock, mining, construction activities, stormwater runoff, unpaved roads, forestry activities, utility crossings, and dredging. | **Highly confident** that these are the primary sources of sedimentation for the CCC. | Wynn *et al.* 2016, pp. 45-52, Brim Box and Mossa 1999, pp. 99-117; Watters 2000, p. 266 |
| **- Activity(ies)** | *What is actually happening on the ground as a result of the action? I.e., what are the specifics of the source?* | **Agriculture** - field tillage (exposed ground) and cattle pasturing or access to creek; **construction activities** - commercial and residential (urban) development (clearing and grading); **stormwater runoff** - lack of appropriate Best Management Practices (BMPs) and increased in amount of impermeable surfaces; **unpaved roads** - lack of appropriate BMPs, roadside vegetation, or properly installed drainage ditches or outlets; **forestry activities** - land clearing and improperly installed forestry BMPs or suitable buffers; **utility crossings** - improperly vegetated utility ROW, trenching, construction BMPs; and **dredging** - resuspending sediments. | **Highly confident** that these actions are occurring within the BCC watershed. | Wynn *et al.* 2016, pp. 50-52; Brim Box and Mossa 1999, p 99, 100, 103 |
| **STRESSOR(S)** | *What are the changes in environmental conditions on the ground that may be affecting the species?* | **Deposited and suspended sediments degrade/remove habitat and decrease survival of CCC.** Deposited sediments - bury suitable habitat (clean gravel shoals), fill interstitial spaces, reduce pool volume and fish (host) cover, destabilize stream channels, interferes with mussel feeding (pedal and filter feeding), mussels unable to emerge with increasing sediment depth, disrupts host fish-mussel relationship; Suspended sediments - Interferes with mussel feeding (clogs gills) and respiration, disrupts host fish mussel relationship (reduction in fish population, reduced viability of mantle lures or | **High confidence** in the relationship between sedimentation and freshwater mussels, in general. **Moderately confident** that these effects apply equally to the CCC. | Haag 2012, p 359-365; Brim Box and Mossa 1999, p. 100; Gascho Landis *et al.* 2013, p. 76; Beussink 2007, pp. 17-22 |

| **THEME: Sedimentation** | | | | |
|---|---|---|---|---|
| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| | | displays, disrupts ability of conglutinates to adhere to substrate, and can effect fertilization and reproductive success. | | |
| **- Exposure of Stressor(s)** | *When and where does the stressor overlap with the resource (life history and habitat needs)?* | Larval (glochidia), juvenile, and adult CCC. | **Moderately** confident that the CCC is exposed to sedimentation throughout the year (varying degrees of sedimentation), and **highly** confident that sedimentation is exacerbated during periods of high flows. | Wynn *et al.* 2016, p 9-10, 50-52; Brim Box and Mossa 1999, p. 99 |
| **- Immediacy of Stressor(s)** | *Are the stressors happening past, present, and/or future? What's the timing and frequency?* | **Historical**: Historical sources of sedimentation include agriculture, construction activities, stormwater runoff, unpaved roads, forestry activities, utility crossings, and dredging. **Present**: Current sources of sedimentation include agriculture, construction activities, stormwater runoff, unpaved roads, forestry activities, utility crossings, and dredging. **Future**: Future sources of sedimentation will likely include agriculture (may be reduced by conversion of land to other uses, *e.g.*, development), construction activities, stormwater runoff, unpaved roads (may be reduced by conversion to pavement), forestry activities (reduced by enhanced forestry BMPs), utility crossings, and dredging. | **Historical: Highly confident**<br>**Current: Highly confident**<br>**Future: Moderately confident** that these activities will continue at some level into the future within BCC watershed. | Wynn *et al.* 2016, p 9-10, 50-52 |
| **Affected Resource(s)** | *What are the resources that are needed by the species that are being affected by this stressor?* | Water quality, habitat (substrate) quality, and host fish survival/habitat. | **Moderately confident** that sediment is affecting these resources needed by the CCC. | Henley *et al.* 2000, p. 132; Brim Box and Mossa 1999, 101-102; Beussink 2007, pp. 17-22 |

**THEME: Sedimentation**

| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
|---|---|---|---|---|
| **Response to Stressors: RESOURCES** | *What are the effects on resources?* | Degraded habitat and water quality. | **Highly confident** that sediment is affecting habitat and water quality within BCC. | Brim Box and Mossa 1999, p. 99-102, Wynn *et al.* 2016, p. 37-40, 51, 53 |
| **Response to Stressors: INDIVIDUALS** | *What is the effect on individuals of the species to the stressor? (May be by life stage)* | Depressed growth rates, impaired respiration, feeding, and reproductive success of CCC and host fish and reduced fitness and survival of CCC and host fish. | **Highly confident** that sediment if affecting life functions of mussels in general, **moderately confident** that sediment if affecting CCC. There is extensive literature on the impacts of sedimentation on mussel health. | Henley *et al.* 2000, p. 130-131; Brim Box and Mossa 1999, p. 99-102; Beussink 2007, pp. 17-22 |
| **POPULATION & SPECIES RESPONSES** | *How do population effects translate to population and species-level responses?*<br>*What is the magnitude of this stressor in terms of species viability?* | Lower or loss of recruitment can result from impaired habitat quality. Juvenile mussels are considered especially vulnerable to smothering by sedimentation. Adult CCC may also die depending on the severity of the impairment. Repeated year class loss will result in population loss. | **Highly confident** that sediment affects mussel populations in general, **moderately confident** that sediment if affecting CCC. | Haag 2012 p 363; Brim Box and Mossa 1999, p. 109; Beussink 2007, pp. 17-22 |
| **Responses to Stressors: POPULATIONS [RESILIENCY]** | *What are the effects on population characteristics (lower reproductive rates, etc.)?* | These stressors can cause decreased reproductive and growth rates and population abundance. | **Highly confident** that sediment can negatively affect mussel reproduction, growth, and abundance in general, **moderately confident** that sediment similarly affects CCC. | Gascho Landis *et al.* 2013, p. 76; Brim Box and Mossa 1999, p. 99-102; Beussink 2007, pp. 17-22 |
| **SCOPE** | *What's the geographic extent of the stressor relative to the range of* | Sedimentation is a stressor that effects the complete range of the CCC to some degree. Wynn *et al.* (2016, p. 51) noted sediment impairment in the following Big Canoe Creek subwatersheds as impaired by | **Highly confident** that sediment is affecting habitat and water quality throughout the BCC. Wynn *et al.* (2016, | Wynn *et al.* 2016, p 51 |

| **THEME: Sedimentation** | | | | |
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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| | *the species/populations?* | sedimentation: Lower Big Canoe Creek, Little Canoe Creek (east), Gulf Creek, Muckleroy Creek, Middle Big Canoe, and Little Canoe Creek (west). | entire) documents several contributors to sedimentation with BCC. | |
| **Responses to Stressors: - REDUNDANCY** | *What are the expected future changes to the number of populations and their distribution on the landscape?* | The robustness of these populations could be impacted by impaired recruitment. In extreme cases of sedimentation, individual mussel beds could be extirpated. Resiliency of the CCC subpopulations is impacted by sedimentation because it causes decreased survival and abundance of populations. Future redundancy could decrease if a subpopulation is extirpated. | **Highly confident** that sedimentation can negatively affect mussel populations in general and their distribution on the landscape, **moderately confident** that sedimentation can similarly affect CCC. | Gascho Landis *et al.* 2013, p. 76; Brim Box and Mossa 1999, p. 99-101; Beussink 2007, pp. 17-22 |
| **- REPRESENTATION** | *What changes to the genetic or ecology diversity in the species might occur?* | Being a narrow endemic with minimal genetic and ecological diversity, sedimentation is not likely having a notable impact on the representation of the species. Given the limited genetic and ecological diversity among the two subpopulations, and the range-wide impacts of sedimentation, little to no reduction in overall representation has occurred or will likely occur in the future. | **Moderately confident** that sediment impacts to one subpopulation will likely be experienced within the other subpopulation when related to climate events (due to proximity), **low confidence** if sedimentation events are related to localized events. | Wynn *et al.* 2016, p 51 |
| **SUMMARY** | *What is overall impact of sedimentation on the viability of the species?* | Excessive sedimentation can reduce life history needs of CCC. This includes depressed growth rates, impaired respiration, feeding, and reproductive success of CCC and host fish and reduced fitness and survival of CCC and host fish; and as such can reduce the Resiliency, Redundancy, and Representation of CCC. | **Highly confident** | See previous citations |

| THEME: Water Quality | | | | |
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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| **SOURCE(S)** | *What are the ultimate actions causing the stressor?* | Changes in water quality parameters such as dissolved oxygen, increased temperature, and contaminants. Sources of these changes include: **Low dissolved oxygen** relative to the needs of the species. High amounts of nutrients, such as **nitrogen and phosphorus**, in streams can stimulate excessive plant growth, which in turn can reduce dissolved oxygen levels when dead plant material decomposes. **Increased temperature**: Drought and increased air temperature due to climate change. **Contaminants**: Point sources, such as spills and wastewater treatment plants, and non-point sources, such as agriculture. These sources contribute organic compounds, heavy metals, pesticides, herbicides, and a wide variety of newly emerging contaminants to the aquatic environment. Sources of **ammonia** include agricultural activities (animal feedlots and nitrogenous fertilizers), municipal wastewater treatment plants, and industrial waste, as well as precipitation and natural processes (decomposition of organic nitrogen). | **Highly confident that these are the sources of water quality impairment for the CCC in the BCC watershed.** | Bringolf *et al.* 2007, p. 2090-2091; Bringolf *et al.* 2010, 1315-13-17; Diamond *et al.* 2002, p. 7; Havlik 1987 (entire), Markich 2017, pp. 1432-1434; Milam *et al.* 2005, pp. 167-172; Naimo 1995 (entire); Valenti *et al.* 2006, pp. 2514-2517; Wang *et al.* 2007, pp. 2052-2055; Newton *et al.* 2003 (entire); Bartsch *et al.* 2003, pp. 566; Augspurger *et al.* 2003, p. 2,571, 2569; Gibson *et al.* 2018, pp. 245-248; Pandolfo *et al.* 2010, pp. 961-967; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **- Activity(ies)** | *What is actually happening on the ground as a result of the action? I.e., what are the specifics of the source?* | Agricultural runoff (pesticides, herbicides, fertilizers, animal waste), urban runoff (pesticides, herbicides, fertilizers, hydrocarbons, heated discharge) wastewater treatment plants, spills, industrial discharges. | **Highly confident** that these actions are occurring within the BCC watershed. | Diamond *et al.* 2002, p. 7; Pandolfo *et al.* 2010, pp. 961-967; Gibson *et al.* 2018, pp. 245-248; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **STRESSOR(S)** | *What are the changes in environmental conditions on the ground that may be affecting the species?* | Eutrophication and acute or chronic toxicity. **Low dissolved oxygen**: Juveniles are particularly susceptible to low dissolved oxygen levels, although adult | **Moderately confident** that these stressors are having some level of impact to CCC within BCC. | Bringolf *et al.* 2007, p. 2090-2091; Bringolf *et al.* 2010, 1315-13-17; Diamond *et al.* 2002, p. 7; Haag and Warren 2008, pp. 1175-1176; |

| **THEME: Water Quality** | | | | |
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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| | | metabolism levels are lower in areas of lower dissolved oxygen. Juveniles will reduce feeding behavior between 2 - 4 mg/L, and mortality has been shown to occur at levels below 1.3 mg/L. *Pleurobema* showed increased mortality at dissolved oxygen levels below 5 mg/L when associated with drought. **Increased temperature**: Glochidial release may be associated with water temperature; increased stream temperature may cause the timing of release to change. Depending the degree of change in temperature, this could cause species/host interactions to be out of sync. However, mussel species can have very different reactions to increased temperature depending on their thermal tolerance. A water temperature increase of several degrees appears unlikely to affect the species on its own. Instead, increased water temperature can exacerbate other water quality problems, such as the effects of contaminants. **Chemical contaminants**: The release of pollutants into streams from point and nonpoint sources have immediate impacts on water quality conditions and may make environments unsuitable for habitation by mussels. Early life stages of freshwater mussels are some of the most sensitive organisms of all species to ammonia and copper, with mortality occurring at levels lower than current EPA criteria. Additionally, sublethal effects of contaminants over time can result in | (Glochidial and juvenile life stages of mussel (in general) have shown higher sensitivities many of these pollutants than adult life stages.) | Havlik 1987 (entire), Markich 2017, pp. 1432-1434; Milam *et al.* 2005, pp. 167-172; Naimo 1995 (entire); Valenti *et al.* 2006, pp. 2514-2517; Wang *et al.* 2007, pp. 2052-2055; Newton *et al.* 2003 (entire); Bartsch *et al.* 2003, pp. 566; Augspurger *et al.* 2003, p. 2,571, 2569; Gibson *et al.* 2018, pp. 245-248; Pandolfo *et al.* 2010, pp. 961-967; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |

| THEME: Water Quality | | | | |
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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| | | reduced filtration efficiency, reduced growth, decreased reproduction, changes in enzyme activity, and behavioral changes to all mussel life stages. Even wastewater discharges with low ammonia levels have been shown to negatively affect mussel populations. **While impacts to mussels are noted above, their host fish can also have also suffer impacts from these stressors to water quality.** | | |
| **- Exposure of Stressor(s)** | *When and where does the stressor overlap with the resource (life history and habitat needs)?* | CCC at all life stages are likely exposed to some level of pollution at all times. Juvenile mussels are likely to be more susceptible to contaminants, especially those that concentrate in interstitial water and encountered during pedal feeding. Adult CCC may also die depending on the severity of the impairment. Point source inputs may have a more toxic influence during low flows or drought due to reduced dilution (ratio of pollutant vs volume of stream discharge) and higher temperatures. Agricultural contaminants (herbicides, pesticides, and fertilizers) are likely applied during spring or fall plantings and could result in higher concentrations during these times. Non-point source pollution may be more intensified during rain or high flow events when more non-point source runoff enters the stream. Ammonia warrants priority attention for its effects on mussels. Documented toxic effects of ammonia on freshwater bivalves include reduced survival, reduced growth, and reduced reproduction. | **High** (early life stages) - multiple studies; **Moderate** (Adult Life Stages) | Augspurger *et al.* 2003, p. 2,575; Mummert *et al.* 2003, p. 2,522; Wang *et al.* 2007, pp. 2052-2055; Gibson *et al.* 2018, pp. 245-248; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |

| THEME: Water Quality | | | | |
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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| **- Immediacy of Stressor(s)** | *Are the stressors happening past, present, and/or future? What's the timing and frequency?* | Contaminants have been and will continue to threaten the CCC throughout its range. Current state regulations regarding pollutants are designed to be protective of aquatic organisms; however, unionids may be more susceptible to some pollutants than the test organisms commonly used in bioassays. Historical: Less government regulation on point source discharges and pesticide and herbicide applications. Present: While regulation have become more stringent and toxicity and environmental consequences of contaminants are better understood, the use of many pesticides/herbicides are more common place. The increase in the amount of impermeable surfaces will increase hydrocarbon inputs and urban runoff. Point source discharges (wastewater and NPDES discharges) are also increasing with urbanization of the area. Future: Human encroachment is expected to increase and point and non-point source contaminants are expected to increase as well. | **Moderately** confident stressors are occurring within the BCC watershed, and **somewhat confident** these stressors will continue to increase in response to human growth and development and their associated antroprogentic stressors. | ADEM (GIS data); Augspurger *et al.* 2007, pp. 2,025–2,028; Gibson 2015, p. 90; Gibson *et al.* 2018, pp. 239-248 |
| **Affected Resource(s)** | *What are the resources that are needed by the species that are being affected by this stressor?* | Water quality, habitat quality, and host fish survival/habitat. | **Moderately** confident | Havlik and Marking 1987 (entire);<br>Carpenter *et al.* 1998 (entire);<br>Wynn *et al.* 2016 (entire) |
| **Response to Stressors: RESOURCES** | *What are the effects on resources?* | Water quality, habitat quality, and host fish survival/habitat are all reduced as a result of these stressors. | **Moderately** confident | Carpenter *et al.* 1998 (entire);<br>Wynn *et al.* 2016 (entire) |
| **Response to Stressors: INDIVIDUALS** | *What is the effect on individuals of the species to the stressor? (May be by life stage)* | Contaminants can have chronic or acute effects or mortality on CCC, depending on the contaminant and concentration. (See discussion regarding water quality (D.O. | **Moderately** confident | Bringolf *et al.* 2007, p. 2090-2091;<br>Bringolf *et al.* 2010, 1315-13-17;<br>Diamond *et al.* 2002, p. 7; Havlik 1987 (entire), Markich 2017, pp. |

**THEME: Water Quality**

| Factors | *Analysis* | | Confidence / Uncertainty | Supporting Information |
|---|---|---|---|---|
| | | and temperature) and contaminants in stressors row above). | | 1432-1434; Milam *et al.* 2005, pp. 167-172; Naimo 1995 (entire); Valenti *et al.* 2006, pp. 2514-2517; Wang *et al.* 2007, pp. 2052-2055; Newton *et al.* 2003 (entire); Bartsch *et al.* 2003, pp. 566; Augspurger *et al.* 2003, p. 2,571, 2569; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **POPULATION & SPECIES RESPONSES** | *How do population effects translate to population and species-level responses?*<br>*What is the magnitude of this stressor in terms of species viability?* | Lower or loss of recruitment can result from impaired habitat quality. Direct toxicity on the CCC could also affect population abundance. Repeated year class loss will result in population loss. | **Moderately** confident | Bringolf *et al.* 2007, p. 2090-2091; Bringolf *et al.* 2010, 1315-13-17; Diamond *et al.* 2002, p. 7; Havlik 1987 (entire), Markich 2017, pp. 1432-1434; Milam *et al.* 2005, pp. 167-172; Naimo 1995 (entire); Valenti *et al.* 2006, pp. 2514-2517; Wang *et al.* 2007, pp. 2052-2055; Newton *et al.* 2003 (entire); Bartsch *et al.* 2003, pp. 566; Augspurger *et al.* 2003, p. 2,571, 2569; Gibson *et al.* 2018, pp. 245-248; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **Responses to Stressors: POPULATIONS [RESILIENCY]** | *What are the effects on population characteristics (lower reproductive rates, etc.)?* | Lower reproductive rates, survival, and fitness. Lowered reproduction and survival can, in turn, reduce the overall abundance of the subpopulations. | **Moderately** confident | Bringolf *et al.* 2007, p. 2090-2091; Bringolf *et al.* 2010, 1315-13-17; Diamond *et al.* 2002, p. 7; Havlik 1987 (entire), Markich 2017, pp. 1432-1434; Milam *et al.* 2005, pp. 167-172; Naimo 1995 (entire); Valenti *et al.* 2006, pp. 2514-2517; Wang *et al.* 2007, pp. 2052-2055; Newton *et al.* 2003 (entire); |

| THEME: Water Quality | | | | |
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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| | | | | Bartsch *et al.* 2003, pp. 566; Augspurger *et al.* 2003, p. 2,571, 2569; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **SCOPE** | *What's the geographic extent of the stressor relative to the range of the species/populations?* | Contaminants is a stressor that effects the complete range of the CCC to some degree. | **Moderately** confident | ADEM GIS data; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **Responses to Stressors:**<br>**- REDUNDANCY** | *What are the expected future changes to the number of populations and their distribution on the landscape?* | The robustness of these populations could be impacted by impaired recruitment and reduced adult fitness. In extreme cases of water quality, individual mussel beds could be extirpated. Resiliency of the CCC subpopulations is impacted by water quality because it causes decreased survival and abundance of populations. Future redundancy could decrease if a subpopulation is extirpated. | **Moderately** confident | ADEM GIS data; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **- REPRESENTATION** | *What changes to the genetic or ecology diversity in the species might occur?* | Excessive water quality issues can reduce life history needs of CCC. This includes depressed growth rates, impaired respiration, feeding, and reproductive success of CCC and host fish and reduced fitness and survival of CCC and host fish; and as such can reduce the Resiliency, Redundancy, and Representation of CCC. | **Moderately** confident that water impacts to one subpopulation will likely be experienced within the other subpopulation when related to climate events (due to close proximity), **low** confidence if it is a water quality point source event. | ADEM GIS data; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |

| **THEME: Climate Events** | | | | |
|---|---|---|---|---|
| **Factors** | ***Analysis*** | | **Confidence/Uncertainty** | **Supporting Information** |
| **SOURCE(S)** | *What are the ultimate actions causing the stressor?* | Climate change, drought, and floods. | **Highly confident** that these are the primary climate events affecting the CCC in BCC. | Haag and Warren 2008 (entire); Golladay *et al.* 2004, pp. 499-504; Hastie *et al.* 2001, 111-114; Hastie *et al.* 2003, 40-45; Pandolfo *et al.* 2010, pp. 961-967; Pandolfo *et al.* 2012, pp. 71-75; Eissa and Zaki 2011, p. 252; Pederson *et al.* 2012 (entire); NOAA 2020 (unpaginated); NDMC 2019 (unpaginated); USGS 2016a (entire); USGS 2016b (entire) |
| **- Activity(ies)** | *What is actually happening on the ground as a result of the action? Ie, what are the specifics of the source?* | Drought can be responsible for dewatering of occupied habitat. Impaired water quality (temperature, DO) and not enough flow/water for wastewater or other point source discharge dissemination. Floods can cause excessive erosion and can destabilize banks and bed materials. Floods can also lead to increases in sedimentation and suspended solids. Climate change can affect the frequency of drought and floods, as well as alter normal temperature regimes. | **Highly confident** | Haag and Warren 2008 (entire); Golladay *et al.* 2004, pp. 499-504; Hastie *et al.* 2001, 111-114; Hastie *et al.* 2003, 40-45; Pandolfo *et al.* 2010, pp. 961-967; Pandolfo *et al.* 2012, pp. 71-75; Pederson *et al.* 2012 (entire); NOAA 2020 (unpaginated); NDMC 2019 (unpaginated); USGS 2016a (entire); USGS 2016b (entire) |
| **STRESSOR(S)** | *What are the changes in environmental conditions on the ground that may be affecting the species?* | Drought can lead to dewatering of habitat, changes to water quality (DO, temperature), and can isolate CCC and make it more vulnerable to predation. Flood or extreme flows from flooding can modify habitat, dislodge CCC from the substrate and deposit them in new, possibly unsuitable habitat. Thermal tolerance may be impacted by climate events | **Highly confident** | Golladay *et al.* 2004, p. 501; Haag and Warren 2008, p. 1176; USGS 2016a (entire); USGS 2016b (entire); Pederson *et al.* 2012 (entire); Eissa and Zaki 2011, p. 252; NOAA 2020 (unpaginated); NDMC 2019 (unpaginated); USGS 2016a (entire); USGS 2016b (entire) |

| **THEME: Climate Events** | | | | |
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| **Factors** | ***Analysis*** | | **Confidence/Uncertainty** | **Supporting Information** |
| | | and alter normal life functions (spawning, respiration, etc.) of the CCC. Climate change will result in more intense floods and droughts. | | |
| **- Exposure of Stressor(s)** | *When and where does the stressor overlap with the resource (life history and habitat needs)?* | The stressors would have a direct impact on the habitat of the CCC. These climate events could occur at any time and effect all life stages. However, effects could be exacerbated during spawning (late spring-early summer) and have disproportionate impact on early life stages, resulting in reduced or loss of year classes. Effects could also be exacerbated during the hottest or coldest periods. Host fish thermal tolerance and normal life functions may also be impacted by climate events. | **Moderately confident** | Haag and Warren 2008 (entire); Golladay *et al.* 2004, pp. 499-504; Hastie *et al.* 2001, 111-114; Hastie *et al.* 2003, 40-45; Pandolfo *et al.* 2010, pp. 961-967; Pandolfo *et al.* 2012, pp. 71-75; NOAA 2020 (unpaginated); NDMC 2019 (unpaginated); USGS 2016a (entire); USGS 2016b (entire) |
| **- Immediacy of Stressor(s)** | *Are the stressors happening past, present, and/or future? What's the timing and frequency?* | These stressors could occur at any time, but could increase in intensity in the future with the effects of global warming. | **Moderately confident** | Trenberth *et al.* 2013, p. 17; Hastie *et al.* 2003, 40-45; Pandolfo *et al.* 2012, pp. 71-75; Pederson *et al.* 2012 (entire); NOAA 2020 (unpaginated); NDMC 2019 (unpaginated); |
| **Affected Resource(s)** | *What are the resources that are needed by the species that are being affected by this stressor?* | CCC habitat components, host fish interactions, and water quality. | **Moderately confident** | Haag and Warren 2008 (entire); Golladay *et al.* 2004, pp. 499-504; Hastie *et al.* 2001, 111-114; Hastie *et al.* 2003, 40-45; Pandolfo *et al.* 2010, pp. 961-967; Pandolfo *et al.* 2012, p. 75 |
| **Response to Stressors: RESOURCES** | *What are the effects on resources?* | Dewatered or unstable habitat, dislodged woody debris or vegetation, impaired water quality, increased or decreased water velocities, temperature changes. | **Moderately confident** | Haag and Warren 2008 (entire); Golladay *et al.* 2004, pp. 499-504; Hastie *et al.* 2001, 111-114; Hastie *et al.* 2003, 40-45; Pandolfo *et al.* 2010, pp. 961- |

**THEME: Climate Events**

| Factors | *Analysis* | | Confidence/Uncertainty | Supporting Information |
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| | | | | 967; Pandolfo *et al.* 2012, pp. 71-75; NOAA 2020 (unpaginated); NDMC 2019 (unpaginated); USGS 2016a (entire); USGS 2016b (entire) |
| **Response to Stressors: INDIVIDUALS** | *What is the effect on individuals of the species to the stressor? (May be by life stage)* | Extreme climate events are likely to decrease fitness of CCC by interfering with feeding, sheltering, and reproduction. Physiological stress or death to individuals or populations already stressed by habitat alteration. Mussels in the Sipsey Fork (within 50 miles of BCC) were documented as being highly sensitive to the secondary effects of drought during the drought of 2000. This was likely due to the low levels of dissolved oxygen caused by low flow, warm temperatures, and high biological oxygen demand—in addition to the direct drying of their habitat (Haag and Warren 2008, p. 1165). Also, extreme floods can dislodge and displace mussels and can negatively affect reproduction (gametes and disrupt host fish/glochidial interactions) if they coincide with the spawn. | **Moderately confident** that these stressors will impact the CCC. | Haag and Warren 2008, p. 1170-1176; Hastie *et al.* 2001, 111-114; Hastie *et al.* 2003, 40-45; Galloday *et al.* 2004, p. 501; Pandolfo *et al.* 2010, pp. 961-967; Pandolfo *et al.* 2012, pp. 71-75; NOAA 2020 (unpaginated); NDMC 2019 (unpaginated); USGS 2016a (entire); USGS 2016b (entire) |
| **POPULATION & SPECIES RESPONSES** | *How do population effects translate to population and species-level responses?*<br>*What is the magnitude of this stressor in terms of species viability?* | Lower or loss of recruitment can result from extreme climate events. Chronic or acute exposures could lower fitness or lead to direct mortality. Repeated year class loss or adult loss will result in population loss. Haag and Warren (2008) documented streams that remained | **Moderately confident** that these stressors will impact the CCC subpopulations within BCC. | Haag and Warren 2008, p. 1170-1176; Hastie *et al.* 2001, 111-114; Hastie *et al.* 2003, 40-45; Galloday *et al.* 2004, p. 501; Pandolfo *et al.* 2010, pp. 961-967; Pandolfo *et al.* 2012, pp. 71-76 |

| THEME: Climate Events | | | | |
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| **Factors** | ***Analysis*** | | **Confidence/Uncertainty** | **Supporting Information** |
| | | flowing during the drought showed no declines in mussel numbers, but streams that stopped flowing experienced severe reductions in mussel abundance regardless of the extent to which the streambed was dewatered. The subpopulations within the headwaters of BCC might be more vulnerable during drought. | | |
| **Responses to Stressors: POPULATIONS [RESILIENCY]** | *What are the effects on population characteristics (lower reproductive rates, etc.)?* | These stressors can cause decreased reproductive rates and subpopulation abundance. | **Moderately confident** that these stressors will impact resiliency by affecting reproduction | Haag and Warren 2008, p. 1170-1176; Hastie *et al.* 2001, 111-114; Hastie *et al.* 2003, 40-45; Galloday *et al.* 2004, p. 501; Pandolfo *et al.* 2010, pp. 961-967; Pandolfo *et al.* 2012, pp. 71-77 |
| **SCOPE** | *What's the geographic extent of the stressor relative to the range of the species/populations?* | Being a narrow endemic species, these stressors could potentially affect the entire range of the CCC. | **Highly confident** that if one subpopulation is impacted by a climate event then the other will also be impacted due to close proximity within BCC. | Pederson *et al.* 2012 (entire); NOAA 2020 (unpaginated); NDMC 2019 (unpaginated); USGS 2016b (entire) |
| **Responses to Stressors: - REDUNDANCY** | *What are the expected future changes to the number of populations and their distribution on the landscape?* | Being a narrow endemic with minimal genetic and ecological diversity, climate events are not likely having a notable impact on the representation of the species. Given the limited genetic and ecological diversity among the two subpopulations, and the range-wide impacts of climate, little to no reduction in overall representation has occurred or will likely occur in the future. | **Highly confident** that climate events can negatively affect mussel populations in general, **moderately confident** that climate events can similarly affect CCC. | Pederson *et al.* 2012 (entire); NOAA 2020 (unpaginated); NDMC 2019 (unpaginated); USGS 2016a (entire); USGS 2016b (entire) |
| **- REPRESENTATION** | *What changes to the genetic or ecology diversity in the species might occur?* | Being a narrow endemic, little change in representation is expected. | **Moderately confident** that climate events that impact one subpopulation will likely be experienced within the other | Pederson *et al.* 2012, (entire); NOAA 2020 (unpaginated); NDMC 2019 (unpaginated); |

## THEME: Climate Events

| Factors | *Analysis* | | Confidence/Uncertainty | Supporting Information |
|---|---|---|---|---|
| | | | subpopulation (due to close proximity). | USGS 2016a (entire); USGS 2016b (entire) |

## THEME: Development/Urbanization

| Factors | *Analysis* | | Confidence / Uncertainty | Supporting Information |
|---|---|---|---|---|
| **SOURCE(S)** | *What are the ultimate actions causing the stressor?* | Human growth with the watershed and the increase of construction of residential and commercial developments has occurred portions of BCC watershed. As a result, stormwater discharges, construction activities, increased wastewater discharges, increased residential fertilizer/herbicide usage, conversion of forest and agriculture fields to development, have resulted. **Wynn *et al.* 2016 lists the following Big Canoe Creek subwatersheds as impaired by urban development: Muckleroy Creek, Little Canoe Creek (west), and Upper Big Canoe Creek.** | **Highly confident** that these are the primary stressors of urbanization are occurring within BCC watershed. | Carpenter *et al.* 1998, p. 559-566; Giddings *et al.* 2009, pp. 1-9; Wynn *et al.* 2016, pp. 11-21, 51, 53; Brim Box and Mossa 1999, p 103 |
| **- Activity(ies)** | *What is actually happening on the ground as a result of the action? Ie, what are the specifics of the source?* | Lands are converted into impermeable surfaces, drainage systems are installed, bank erosion and bed scouring result, point source and non-point source discharges increase with development, and contaminant loads will increase within Big Canoe Creek. Wynn *et al.* 2016 (p. 51) states that the most vulnerable area for urban development in the watershed is Springville and the Ala. Hwy 174 corridor adjacent to upper Little Canoe Creek (west). The Little Canoe Creek (west) watershed around Springville is a mixture of rural and urban | **Highly confident** that these actions are occurring within the BCC watershed and in areas where CCC occur. | Carpenter *et al.* 1998, p. 559-566; Giddings *et al.* 2009, pp. 1-9; Wynn *et al.* 2016, pp. 11-21, 51, 53; Brim Box and Mossa 1999, p 103; EDPA 2019 (entire); GECIDA 2015 (entire) |

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| Factors | *Analysis* | | Confidence / Uncertainty | Supporting Information |
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| | | landscapes and the many small farms and pastures are quickly being converted to neighborhoods and shopping areas as the human population expands from Jefferson County. A Little Canoe Creek Mega Site has been developed, along Little Canoe Creek (east), Etowah County. This will likely be a large scale (1100 acres) industrial site when a prospective client is found. | | |
| **STRESSOR(S)** | *What are the changes in environmental conditions on the ground that may be affecting the species?* | Water and habitat quality will degrade with these added inputs to the watershed. See the corresponding discussion within the sedimentation and water quality section. | **Moderately confident** that these stressors are water quality, sediment quality, are temperature are stressors that result from development and urbanization. | Carpenter *et al.* 1998, p. 559-566; Giddings *et al.* 2009, pp. 1-9; Brim Box and Mossa 1999, p 102; Gillies *et al.* 2003, p. 413 |
| **- Exposure of Stressor(s)** | *When and where does the stressor overlap with the resource (life history and habitat needs)?* | CCC are likely exposed to some level of pollution resulting from urban development at all times. Point source inputs may have a more toxic influence during low flows or drought due to reduced dilution (ratio of pollutant vs volume of stream discharge). Residential develop contaminants such as herbicides, pesticides, and lawn fertilizers are likely applied during spring, summer, and fall months. Non-point source pollution may be more intensified during rain or high flow events when more non-point source runoff enters the stream. | **Moderately confident** that these stressors are having some level of effect on CCC within BCC. | Carpenter *et al.* 1998, p. 559-566; Augspurger *et al.* 2003, p. 2,575; Mummert *et al.* 2003, p. 2,522; Wang *et al.* 2007, pp. 2052-2055; Gibson *et al.* 2018, pp. 245-248; Wynn *et al.* 2016, pp. 11-21, 51, 53; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **- Immediacy of Stressor(s)** | *Are the stressors happening past, present, and/or future? What's the timing and frequency?* | Urbanization has and will continue to threaten the CCC throughout its range as urban sprawl continues from Birmingham and Gadsden. Development is likely to increase in the future as the Little Canoe Creek Mega Site near Gadsden has been developed and is actively trying to find | Historical: **Moderately confident** Current: **Highly confident** Future: **Highly confident** that these activities will continue at some level into the future within BCC watershed. | Carpenter *et al.* 1998, p. 559-566; Giddings *et al.* 2009, pp. 1-9; Wynn *et al.* 2016, pp. 11-21, 51, 53; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire); |

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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| | | large scale industrial clients. This mega site is located on LCC (east) just immediately upstream of known CCC locations. We anticipate urbanization and development will worsen in the future and forests and fields will likely be converted into developed areas. | | EDPA 2019 (entire); GECIDA 2015 (entire) |
| **Affected Resource(s)** | *What are the resources that are needed by the species that are being affected by this stressor?* | Water quality, habitat (substrate) quality, and host fish survival/habitat. | **Moderately confident** that these stressors are having some level of effect on CCC within BCC. | Giddings *et al.* 2009, pp. 1-9; Wynn *et al.* 2016, pp. 11-21, 51, 53 |
| **Response to Stressors: RESOURCES** | *What are the effects on resources?* | Water quality, habitat quality, and host fish survival/habitat are all reduced as a result of these stressors. | **Highly confident** that these stressors are having some level of effect on CCC within BCC. | Giddings *et al.* 2009, pp. 1-9; Wynn *et al.* 2016, pp. 51, 53 |
| **Response to Stressors: INDIVIDUALS** | *What is the effect on individuals of the species to the stressor? (May be by life stage)* | Urbanization and development can have negative effects on water and habitat quality that will directly affect the fitness of the species. See Water Quality and Sedimentation tables for more information on impacts to individual CCCs caused by decreased water quality and increased sedimentation. | **Moderately confident** that these stressors are having some level of effect on CCC within BCC. | Gillies *et al.* 2003, pp. 415-420; Wynn *et al.* 2016, pp. 11-21, 51, 53 |
| **POPULATION & SPECIES RESPONSES** | *How do population effects translate to population and species-level responses?*<br>*What is the magnitude of this stressor in terms of species viability?* | Lower or loss of recruitment can result from impaired habitat and/or water quality resulting from urban development. Repeated year class loss will result in possible extirpation. | **Moderately confident** that these stressors are having some level of effect on CCC subpopulations within BCC. | Carpenter *et al.* 1998, p. 559-566; Augspurger *et al.* 2003, p. 2,575; Mummert *et al.* 2003, p. 2,522; Wang *et al.* 2007, pp. 2052-2055; Gibson *et al.* 2018, pp. 245-248; Wynn *et al.* 2016, pp. 11-21, 51, 53; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **Responses to Stressors:** | *What are the effects on population characteristics* | These stressors can cause decreased reproductive rates and population abundance. | **Moderately confident** that these stressors are having some level of effect on CCC within BCC. | Carpenter *et al.* 1998, p. 559-566; Augspurger *et al.* 2003, p. 2,575; Mummert *et* |

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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| **POPULATIONS [RESILIENCY]** | *(lower reproductive rates, etc.)?* | | | *al.* 2003, p. 2,522; Wang *et al.* 2007, pp. 2052-2055; Gibson *et al.* 2018, pp. 245-248; Wynn *et al.* 2016, pp. 11-21, 51, 53; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **SCOPE** | *What's the geographic extent of the stressor relative to the range of the species/populations?* | Urban development is more focused in certain areas of BCC, but could potentially affect the entire range of the CCC to some degree. Wynn *et al.* 2016 lists the following BCC subwatersheds as impaired by urban development: Muckleroy Creek, Little Canoe Creek (west), and Upper Big Canoe Creek. | **Moderately confident** that urban development will likely be experienced within both subpopulations. However, Wynn *et al.* 2016 (p. 51) states that the most vulnerable area for urban development in the watershed is Springville and the Ala. Hwy 174 corridor adjacent to upper Little Canoe Creek (west). | ADEM GIS data; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **Responses to Stressors:<br>- REDUNDANCY** | *What are the expected future changes to the number of populations and their distribution on the landscape?* | The robustness of these populations could be impacted by impaired recruitment and reduced adult fitness. In extreme cases of water quality and sediment impairment from urbanization, individual mussel beds could be extirpated. Resiliency of the CCC subpopulations is impacted by urbanization because it causes decreased survival and abundance of populations. Future redundancy could decrease if a subpopulation is extirpated. | **Moderately confident** | ADEM GIS data; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |
| **-REPRESENTATION** | *What changes to the genetic or ecology diversity in the species might occur?* | Excessive sedimentation and water quality impacts from urbanization can reduce life history needs of CCC. This includes depressed growth rates, impaired respiration, feeding, and reproductive success of CCC and host fish and reduced fitness and survival of CCC and host fish; | **Moderately confident** | ADEM GIS data; Wynn *et al.* 2016, 11-21; ADEM 2005 (entire); ADEM 2010 (entire); Chitwood 2019 (entire) |

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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| | | and as such can reduce the Resiliency, Redundancy, and Representation of CCC. | | |

| THEME: Connectivity | | | | |
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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| **SOURCE(S)** | *What are the ultimate actions causing the stressor?* | **Dams, perched culverts, and reservoirs.** The backwaters of H. Neely Henry Reservoir backs up into lower Big Canoe Creek past the mouth of Little Canoe Creek (east). Construction of H. Neely Henry Dam, completed by the Alabama Power Company in 1966, resulted in the loss of most of the mussel fauna and riverine habitat in the lower 12.5 km of BCC. A small mill dam "Goodwin Mill" was recently removed from the upper Little Canoe Creek (west) reestablishing connectivity in a portion of CCC range. Following the removal of the dam in 2013, this reach began to restore itself to a higher quality stream habitat. Additionally, there is potential for a pump storage reservoir to be built in the future in the Blount Mountain area for a pump storage hydroelectric facility. Land was originally purchased in the early 1980s, but there are no current plans for construction per APC. | **Highly confident** that these are, have been, or could be the primary sources of reduced connectivity for the CCC. | Wynn *et al.* 2016, pp. 41-48; Fobian *et al.* 2017, p. 4; APC 1985, p. 1, Watters 2000, p. 262; Gangloff *et al.* 2011, p. 1107; Gangloff *et al.* 2006, 53 |
| **- Activity(ies)** | *What is actually happening on the ground as a result of the action? Ie, what are the specifics of the source?* | Dams and reservoirs altered the thermal and sediment regime, channel morphology, and host fish dispersal. Perched culverts also contribute to scour and erosion, and provide a barrier to host fish dispersal. The lotic ecosystem within lower Big Canoe Creek was converted into a more lentic ecosystem by the creation of H. Neely Henry Lake and historically at Goodwin's Mill dam. Following the removal of Goodwin's Mill Dam in 2013, this reach began to restore itself to a higher quality stream habitat. While perched culverts have been identified in the watershed as barriers to fish movement, they are primarily concentrated in the smaller tributaries to BCC or both Little Canoe creeks. | **Moderately confident** that these stressors are having some level of effect on CCC within BCC. | Wynn *et al.* 2016, pp. 41-48; Fobian *et al.* 2017, p. 4; APC 1985, p. 1, Watters 2000, p. 262; Gangloff *et al.* 2011, p. 1107; Gangloff *et al.* 2006, 54 |
| **STRESSOR(S)** | *What are the changes in environmental conditions on the ground that may be affecting the species?* | A more lentic environment provides less suitable habitat (essential habitat components) for the CCC, which are only known from moving water, and could also limit host fish dispersal. Impoundments reduce | **Somewhat confident** | Watters 2000, p 263-265; Wynn *et al.* 2016, pp. 47-48 |

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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| | | that amount of habitat heterogeneity and as water velocity decreases, sediment settles out into the old river channel (sediment trap). Stream reaches become isolated by dams and/or perched crossing structures. This is often a problem for rare species because gene flow has become interrupted, ultimately leading to degraded genetic fitness and the decline of small, localized populations. | | |
| **- Exposure of Stressor(s)** | *When and where does the stressor overlap with the resource (life history and habitat needs)?* | Impoundments can permanently alter mussel habitat as long as they are present. Wynn *et al.* (2016) noted improvement in the quality of stream habitat after the removal of Goodwin's Mill Dam in 2013. The presence of perched culverts in tributary streams are likely to restrict host fish movement into these areas. | **Somewhat confident** | Watters 2000, p 263-265; Wynn *et al.* 2016, pp. 41, 47-49 |
| **- Immediacy of Stressor(s)** | *Are the stressors happening past, present, and/or future? What's the timing and frequency?* | The impoundment by H. Neely Henry in 1965 is expected to persist into the future and will continue to impact the lower BCC watershed. Construction of H. Neely Henry Dam, completed by the Alabama Power Company in 1966, resulted in the loss of most of the mussel fauna and riverine habitat in the lower 12.5 km of BCC. The perched culverts in the BCC tributaries are likely to persist into the future, but have the potential to be corrected as opportunities present themselves. The Goodwin's Mill Dam was removed in 2013 and connectivity restored, while improvement to mussel habitat are anticipated. | **Somewhat confident** | Fobian *et al.* 2017, p. 6; Gangloff *et al.* 2006, 53; Wynn *et al.* 2016, pp. 41, 47-49 |
| **Affected Resource(s)** | *What are the resources that are needed by the species that are being affected by this stressor?* | Geomorphically stable stream channel and banks; flow regime; water quality; habitat loss and fragmentation; and fish hosts. | **Moderately confident** | Watters 2000, p 263-264; Williams *et al.* 2008, p. 506; Brim Box and Mossa 1999, pp. 103-104 |
| **Response to Stressors: RESOURCES** | *What are the effects on resources?* | Decrease in water velocity, sediment deposition, thermal changes (water), changes to primary productivity, diminished or no recruitment, changes in fish community (host fish), etc... | **Moderately confident** | Watters 2000, p 261-269 |
| **Response to Stressors: INDIVIDUALS** | *What is the effect on individuals of the species to* | Smothering of juvenile or adult mussels, reduction in reproductive success, and reduced food base. | **Somewhat confident** | Watters 2000, p 261-270 |

| THEME: Connectivity | | | | |
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| **Factors** | ***Analysis*** | | **Confidence / Uncertainty** | **Supporting Information** |
| | *the stressor? (May be by life stage)* | | | |
| **POPULATION & SPECIES RESPONSES** | *How do population effects translate to population and species-level responses? What is the magnitude of this stressor in terms of species viability?* | Lower or loss of recruitment can result from impaired habitat and/or water quality resulting from inundation, loss of connectivity, and altered flow/temperature regime. This stressor can result in genetic isolation and possible extirpation because isolated subpopulations cannot be readily reestablished by a neighboring subpopulation. | **Somewhat confident** | Fobian *et al.* 2017, p. 4; Watters 2000, p 261-270 |
| **Responses to Stressors: POPULATIONS [RESILIENCY]** | *What are the effects on population characteristics (lower reproductive rates, etc.)?* | These stressors can cause decreased genetic flow, reproductive rates, and population abundance. | **Somewhat confident** | Watters 2000, p 261-270 |
| **SCOPE** | *What's the geographic extent of the stressor relative to the range of the species/populations?* | This stressor is limited to the lower Big Canoe Creek, but can isolate the eastern portion from the western portion of it range within the BCC watershed. Goodwin's Mill Dam is no longer of concern in the LCC (west) due to its removal. Perched culverts could be an issue in smaller tributaries, but we don't have any distribution data within the smaller tributaries. | **Somewhat confident** | Wynn *et al.* 2016, pp. 41-48; Fobian *et al.* 2017, p. 4; APC 1985, p. 1, Watters 2000, p. 262; Gangloff *et al.* 2011, p. 1107; Gangloff *et al.* 2006, 53 |
| **Responses to Stressors: - REDUNDANCY** | *What are the expected future changes to the number of populations and their distribution on the landscape?* | Connectivity and genetic exchange within the BBC watershed is reduced as the inundated portions lower BCC can be a barrier to host fish movement. | **Somewhat confident** | Wynn *et al.* 2016, pp. 41-48; Fobian *et al.* 2017, p. 4; APC 1985, p. 1, Watters 2000, p. 262; Gangloff *et al.* 2011, p. 1107; Gangloff *et al.* 2006, 54 |
| **- REPRESENTATION** | *What changes to the genetic or ecology diversity in the species might occur?* | Already being a narrow endemic, little change in representation is expected. | **Somewhat confident** | Wynn *et al.* 2016, pp. 41-48; Fobian *et al.* 2017, p. 4; Gangloff *et al.* 2006, 55 |