Species Status Assessment Report for the Frecklebelly Madtom (*Noturus munitus*)

Version 1.2

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U.S. Fish and Wildlife Service
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SUMMARY OF VERSION UPDATES

The changes from version 1.0 (December 2019) and version 1.1 (March 2020) are minor and do not change the assessment of risk. The following changes were made:

1. Added Executive Summary
2. Added Acknowledgements
3. Corrected grammatical errors
4. Corrected formatting inconsistencies
5. Added missing page number from in-text citations
6. Clarified that modifications to Army Corps of Engineers' Water Control Manuals were not considered in future conditions scenarios

The changes from version 1.1 (March 2020) and version 1.2 (August 2020) are minor and do not change the assessment of risk. The following changes were made:

1. Corrected typographical errors
2. Removed disclaimer
3. Added climate change projections from the National Climate Change Viewer
4. Added conservation efforts
5. Provided additional explanation for use of eDNA data
6. Provided additional citations
7.

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EXECUTIVE SUMMARY

This report summarizes the results of a species status assessment (SSA) completed for the frecklebelly madtom, *Noturus munitus*, to assess the species' overall viability. The historical range for the species includes the Pearl River system in eastern Louisiana and southern Mississippi; the Tombigbee River in eastern Mississippi and western Alabama; the upper Alabama and Cahaba rivers in central Alabama; the Etowah River in northern Georgia; and the Conasauga River in northern Georgia and southeastern Tennessee. It is believed that this species was historically more widespread in the Mobile Bay drainage but was extirpated from large river habitats after the creation of numerous impoundments.

The intent of our analysis was to characterize viability of the frecklebelly madtom over time. To assess the species' viability, we used the three conservation biology principles of resiliency, representation, and redundancy. Specifically, we identified the species' ecological requirements for survival and reproduction at the individual, population, and species levels, and described the factors influencing viability of the frecklebelly madtom.

For the frecklebelly madtom to survive and reproduce, individuals need suitable habitat that supports essential life functions at all life stages. Three elements appear to be essential to the survival and reproductive of individuals: flowing water, stable substrate, and aquatic vegetation. For populations to be resilient, the needs of individuals (flowing water, substrate, and aquatic vegetation) must be met at a larger scale. Stream reaches with suitable habitat must be large enough to support an appropriate number of individuals to avoid issues associated with small population sizes, such as inbreeding depression. At the species level, the frecklebelly madtoms need a sufficient number and distribution of healthy populations to withstand environmental stochasticity (resiliency) and catastrophes (redundancy) and adapt to biological and physical changes in its environment (representation). Long-term viability will require resilient populations to persist into the future; for the frecklebelly madtom, this will mean maintaining good to high quality stream habitat.

We compiled all available scientific and commercial data in hopes to evaluate the changes in representation, resiliency, and redundancy from historical to the current time and to project those variables into the future. Home range sizes and movements for frecklebelly madtom are not well known and studies designed to clarify population level genetic structuring have not been implemented, so delineating biological populations is not possible. Thus, we delineated what we term "resilience units" for the species as an approximation of a population to assess resilience. Resilience units were delineated as aggregations of adjacent HUC10 watersheds that contained an observation of the frecklebelly madtom, either direct or eDNA, and are not disconnected by dams or other major habitat alterations that may present a barrier to movement. Using this methodology, we identified 16 resilience units (Table ES1) consisting of a total of 66 HUC10 watersheds across the range of the species.

Table ES1. Resilience units and representative units used in assessing viability of the frecklebelly madtom.

Resiliency Units	***Representation Units***
Bogue Chitto River *Pearl River*	Pearl River
East Fork Tombigbee *Sipsey River* *Luxapallila Creek* *Buttahatchee River* *Bull Mountain Creek* *Upper Tombigbee River (mainstem)*	Upper Tombigbee River
Alabama River	Alabama River
Cahaba River *Alabama River/Big Swamp*	Cahaba River
Conasauga River *Etowah River* *Coosawattee River*	Upper Coosa River
Lower Tombigbee River *Lower Alabama River*	Lower Tombigbee/Alabama River

Representation units were delineated in an effort to describe the breadth of known genetic, phenotypic, and ecological diversity within the species. There is evidence of differentiation of habitat use, morphology, and genetics for areas that the frecklebelly madtom occupies which are disconnected spatially. Furthermore, a recent study suggested the Pearl River, Tombigbee River, Cahaba River, Alabama River, and upper Coosa River drainage be managed as evolutionary significant units (ESUs) based on the species' genetic differentiation between these watersheds. Therefore, these basins were each considered as separate representation units. Additionally, environmental DNA from the frecklebelly madtom was recorded from lower reaches of the Tombigbee River and Alabama River. These areas are not disconnected by any known barriers and are considered an additional representation unit. Ultimately, six representation units were described (Table ES1). Representation units generally consist of multiple resiliency units.

We assessed current resiliency of frecklebelly madtom units by considering occurrence data throughout the species' range. We use occurrence data to estimate range extent and range geometry. These metrics can be useful for evaluating resiliency, as larger areas of occupied habitat and multiple occupied streams (more complex ranges) would be more robust to stochastic events (i.e., a single more localized event would be unlikely to negatively affect the entire population or unit if many and larger reaches of streams were occupied). Data was classified into time periods to assess temporal variation in the state of the knowledge of the species which can help to inform persistence through time. Furthermore, organizing the data by time period allows us to evaluate fluctuations of occurrences which may provide a signal of population declines. In order to better facilitate comparisons of current and future conditions, we categorized resiliency into four levels, as follows:

- High—population substantially contributes to overall species viability. Population occurrence data indicate a relatively high number of occurrences, number of occupied stream reaches and total length of occupied stream reaches is relatively high.
- Moderate—population contributes to overall species viability. Population occurrence data indicate persistence over time, though the total number of occurrences or occupied stream length may be low-moderate.
- Low—population is likely persisting, but does not contribute to overall species viability. Population occurrence data suggest substantial declines over time.
- Unknown—lack of direct observations; occurrence is only known from positive eDNA samples.
- Likely extirpated—population is likely not persisting, and thus is not contributing to overall species viability. Population occurrence data suggests the species has been

extirpated due to lack of recent observations and probable extirpation is documented in scientific literature.

Table ES2 shows the results of the current resilience assessment. Across the range, resilience of units is as follows: three high resilience; five moderate resilience; one low resilience; three unknown resilience (i.e. based only off of eDNA); and four likely extirpated. The resilience of these units is based on a categorical assessment of the population factors discussed above. Because extant units of the frecklebelly madtom are distributed relatively widely, and several of those units are classified as moderate or better resilience, it is highly unlikely that a catastrophic event would impact the entire species' range. Because of this, the frecklebelly madtom exhibit a moderate-high degree of redundancy, and that level of redundancy has stayed relatively stable over time. The species range is currently disjunct, thus there is a potential that representation has been reduced from historical levels. However, occurrences of the species show that it remains extant in four of the six delineated representation units, with the Cahaba and Upper Tombigbee units classified as moderate resilience (currently contributing to representation of the species), and the stronghold of the species located in the Pearl River where the unit is assessed as having high resilience, and occupies over 128 stream km, including mainstem and tributary habitats.

Table ES2. Current resilience for all analysis units for frecklebelly madtom. * refers to units that were assessed exclusively based on positive eDNA samples.

Representation Unit	Resiliency Unit	Resiliency Estimate
Pearl River	Pearl River	High
	Bogue Chitto	High
Upper Tombigbee	East Fork Tombigbee River	Moderate
	Upper Tombigbee River	Likely Extirpated (Millican et al. 2006, Shepard 2004, Bennett et al. 2008)
	Sipsey River	Moderate
	Luxapallila Creek	Moderate
	Buttahatchie River	High
	Bull Mountain Creek	Likely Extirpated (Shepard et al. 1997, Shepard 2004)
Alabama River	Alabama River	Likely Extirpated (Shepard et al. 1997, Bennett et al. 2008)
Cahaba River	Cahaba River	Moderate
	Alabama River-Big Swamp Creek	Likely Extirpated (Shepard et al. 1997, Bennett et al. 2008)
Upper Coosa River	Conasauga River	Low
	Etowah River	Moderate
	Coosawattee River	Unknown*
Lower Tombigbee/Alabama River	Lower Tombigbee River	Unknown*
	Lower Alabama River	Unknown*

To assess the future condition of frecklebelly madtom resilience units, we determined current stressors and their prevalence on the landscape and projected those factors (agriculture and developed land use) into the future under three different scenarios. Other threats such as construction of dams and impoundments, channelization, and novel industry or resumption of historical industries (pulp mills) were not included in our future conditions assessment due to the high amount of uncertainty regarding their implementation and operation in a future landscape. The three scenarios (low development, moderate development, and high development) capture the range of uncertainty in the changing human population footprint on the landscape, and how the frecklebelly madtom populations will respond to these changing conditions. All three scenarios were projected out to the year 2050 (i.e. 30 years). This time frame was based on input from species experts, and the fact that beyond 30 years, the ability to predict patterns of urbanization and agriculture, and how these land uses will interact with the frecklebelly madtom and its habitat diminishes.

We used projected trends in land use change from two models, the National Land Cover Database (NLCD), and the SLEUTH model (Slope, Land use, Excluded, Urban, Transportation and Hillshade; Jantz et al. 2010, entire). These large scale environmental variables are known to influence habitats of aquatic organisms (see Chapter 4). Future projections for agricultural land use were developed from NLCD data. We calculated a 15-year trend in agricultural land use change between 2001 and 2016 for each analysis unit using NLCD shapefiles. This 15-year trend was converted to an annual rate of change for each unit, and was used to assess changes in agricultural land use across analysis units and within riparian areas from the baseline current level. For our future development projections, we used the SLEUTH data sets from the year 2050 (closest to 30 years in the future), and examined development across analysis units and within riparian areas. For the low development scenario, we considered all areas predicted to be developed at a >90% probability; moderate development scenario considered all areas to be developed at a >50% probability; and the high development scenario considered all areas to be developed at a >10% probability. We consider the moderate development scenario to be the most likely scenario.

Resilience levels did not change substantially under the low development scenarios, but there were changes in the resilience of a few resilience units under the moderate and high development scenarios. (Table ES3). The Pearl River representative unit continues to be the stronghold for the species, as the resilience remains high for Bogue Chitto across all scenarios, and the Pearl River resilience unit maintains a moderate resilience across all scenarios. The Cahaba River is predicted to maintain its moderate resilience across all scenarios, contributing positively to the overall viability of the species. All extant resilience units in the Upper Tombigbee representative unit are anticipated to maintain moderate resilience, also contributing to the overall viability of the species. The Etowah River unit is predicted to become substantially more urbanized by 2050 under all scenarios. In the moderate and high development scenarios, resilience drops from moderate to low, making it potentially much more vulnerable to stochastic events and no longer contributing to viability. Finally, it is important to note that presence of frecklebelly madtom in the Coosawattee, Lower Tombigbee, and Lower Alabama resilience units is based on recent positive eDNA samples. There is much uncertainty in the assessment of resilience of these units without direct observation of the frecklebelly madtom. Future surveys should focus on determining the status of the species within these units, as this would help establish a baseline for current resiliency.

Redundancy is maintained in the low and moderate development scenarios, as there are no resilience units predicted to be likely extirpated by 2050. Because the frecklebelly madtom's range is relatively large, it is highly unlikely that any one catastrophic event would affect the entire species, although redundancy within the Upper Coosa representation unit is anticipated to be further reduced given the susceptibility of the Conasauga and Etowah populations to changes in future land use. Future representation is expected to remain consistent with current representation in the low development scenario with all known representative units (Pearl River, Upper Tombigbee River, Cahaba River, and upper Coosa River) persisting. It is important to conduct further surveys in the Alabama River, Lower Tombigbee-Alabama River, and Coosawattee units to confirm presence of the species because based on our current knowledge of these units, we cannot determine if they meaningfully contribute to representation currently or in the future. The upper Coosa River unit is expected to be vulnerable to extirpation under the moderate and high development scenarios. Loss of the upper Coosa River units could have profound effects on the future representation of the species because preliminary morphological data suggested this drainage may have the most distinctive populations, they occupy unique physiographic provinces, and they occupy unique local habitats.

Table ES3. Summary table of current and future resilience under 3 scenarios of frecklebelly madtom units in 2050. *Presence of frecklebelly madtom is inferred from positive eDNA samples in this assessment.

Representation Unit	Resiliency Unit	Current Resilience	Low Development	Moderate Development	High Development
Pearl River	Pearl River	High	Moderate	Moderate	Moderate
	Bogue Chitto	High	High	High	High
Upper Tombigbee	East Fork Tombigbee River	Moderate	Moderate	Moderate	Moderate
	Upper Tombigbee River	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
	Sipsey River	Moderate	Moderate	Moderate	Moderate
	Luxapallila Creek	Moderate	Moderate	Moderate	Moderate
	Buttahatchie River	High	Moderate	Moderate	Moderate
	Bull Mountain Creek	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Alabama River	Alabama River	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Cahaba River	Cahaba River	Moderate	Moderate	Moderate	Moderate
	Alabama River-Big Swamp Creek	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Upper Coosa River	Conasauga River	Low	Low	Low	Likely Extirpated
	Etowah River	Moderate	Moderate	Low	Low
	Coosawattee River	Unknown*	Unknown*	Unknown*	Unknown*
Lower Tombigbee/Alabama River	Lower Tombigbee River	Unknown*	Unknown*	Unknown*	Unknown*
	Lower Alabama River	Unknown*	Unknown*	Unknown*	Unknown*

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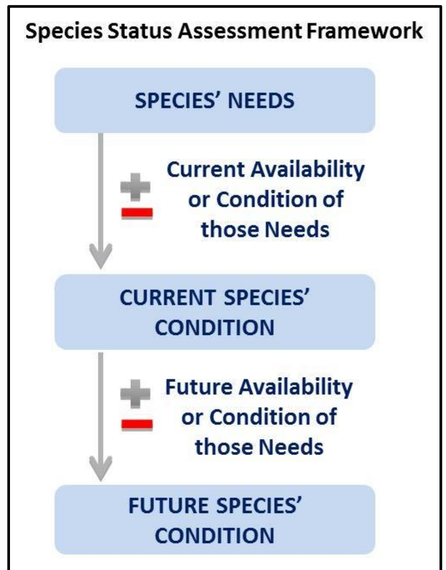
CHAPTER 1 – INTRODUCTION AND ANALYTICAL FRAMEWORK

The frecklebelly madtom (*Noturus munitus*) is a species of small catfish that inhabits the main channels and larger tributaries of large river systems and typically occurs over firm gravel substrates in swift flowing water. The species has a broad but disjunct distribution, with documented populations in the Pearl, Upper Tombigbee, Alabama, Cahaba, Etowah, and Conasauga river systems. We, the U.S. Fish and Wildlife Service (Service), were petitioned to list the frecklebelly madtom as an endangered species or threatened species under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531-1543) (Act), in 2010 as a part of the Petition to List 404 species in the Southeastern United States by the Center for Biological Diversity (Center for Biological Diversity 2010, p. 184). On September 27, 2011, the Service published a 90-day finding that the petition presented substantial scientific or commercial information indicating that listing may be warranted for 374 species, including the frecklebelly madtom (76 FR 59836, September 27, 2011). 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 frecklebelly madtom. Thus, we conducted a Species Status Assessment (SSA) to compile the best available data regarding the species' biology and factors that influence the species' viability. This 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 frecklebelly madtom and serves as the biological underpinning of the Service's forthcoming decision (12-month finding) on whether the species warrants protection under the Act.

The SSA framework (U.S. Fish and Wildlife Service (USFWS) 2016, p. 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 Endangered Species Act decision making, such as listing, recovery, Section 7, Section 10, and reclassification decisions (should the species warrant listing under the Act). 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 frecklebelly madtom. In addition, we forecast the possible response of the species to various future risk factors and environmental conditions to formulate a complete risk profile for the frecklebelly madtom.

The objective of this SSA is to thoroughly describe the viability of the frecklebelly madtom based on the best scientific and commercial information available. Through this description, we determine 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 a description of the ability of a species to sustain populations in the wild beyond a biologically meaningful timeframe. 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**, **representation**, and **redundancy** (USFWS 2016, p. entire).



Assessing the species level of viability is achieved by completing the above assessment framework. Credit: USFWS

- **Resiliency** describes the ability of a population to withstand stochastic disturbance. Stochastic events are those arising from random factors such as weather, flooding, or fire. 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 frecklebelly madtom, we used occurrence data within analysis units to assess resiliency.

- **Representation** describes the ability of the 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. Representative units based on recent genetic evidence were used to assess representation for the frecklebelly madtom.

- **Redundancy** describes the ability of a species to withstand catastrophic events. A catastrophic event is defined here as a rare, destructive event or episode that exceeds the typical random stochastic and environmental variation a population experiences. Redundancy is about spreading risk among populations, and thus, is assessed by characterizing the number of resilient populations across a species' range. The more resilient populations the species has, distributed over a larger area, the better the chances that the species can withstand catastrophic events. For the frecklebelly madtom, we used the distribution and resilience of analysis units to measure redundancy.

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

This SSA Report includes the following chapters:

1. Introduction;
2. Species Biology and Individual Needs. The life history of the species and resource needs of individuals;
3. Factors Influencing Viability. A description of likely causal mechanisms, and their relative degree of impact, on the status of the species;
4. Population and Species Needs and 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 frecklebelly madtom resiliency, representation, and redundancy.

This SSA Report provides a thorough assessment of the biology and natural history of the species and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the frecklebelly madtom. Importantly, this SSA Report does not result in, nor predetermine, any decisions by the Service under the Act. In the case of the frecklebelly madtom, the SSA Report does not determine whether the species warrants protections of the Act, or whether it should be proposed for listing as a threatened or endangered species under the Act. 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 frecklebelly madtom.

CHAPTER 2 – SPECIES BIOLOGY AND INDIVIDUAL NEEDS

In this chapter, we provide biological information about the frecklebelly madtom, including its taxonomic history, morphological description, historical and current distribution and range, and known life history. We then outline the resource needs of individuals.

2.1 Taxonomy

The frecklebelly madtom is in the genus *Noturus* in the family Ictaluridae. All species in this genus, referred to as madtoms, are diminutive and possess long and low adipose fins (Page and Burr 2011, p. 207). The first known collection of frecklebelly madtom was obtained from the Pearl River in Louisiana and Mississippi in 1950 (Suttkus and Taylor 1965, p. 169). The species was described from the Pearl River by Suttkus and Taylor (1965, p. 171). At that time, the only other known populations occupied the Cahaba and Upper Tombigbee rivers in Alabama and Mississippi. Populations were subsequently discovered in the Alabama, Etowah, and Conasauga rivers (Bryant et. al., 1979, unpaginated). Since the time of description, uncertainty regarding the taxonomic status of some populations of the frecklebelly madtom has arisen. In 1998, the name "Coosa madtom" (*Noturus sp. cf. N. munitus*) was coined to describe the madtoms previously identified as frecklebelly madtom in the Conasauga and Etowah rivers that were morphologically distinct from the frecklebelly madtom found elsewhere (Neely 2018 pp 1, Boschung and Mayden 2004 pp 347). This name continues to be used by ichthyologists and persists in the literature. Upon reanalyzing morphological and genetic data, considerable levels of genetic differentiation was observed between the Pearl, Tombigbee, Cahaba, and Coosa river populations; however, morphological variation was incongruent with genetic variation (Neely 2018, p. 10). These results "do not allow clear diagnosis of distinct species within *Noturus munitus*" (Neely 2018, p. 10). However, caution should be exercised when interpreting these results, and analysis of other genetic data may be more informative for assessing diversity within the frecklebelly madtom (Neely 2018, p. 2). We discuss genetic variation further in section 2*.5: Genetics.*

The full taxonomy is described below.

Kingdom—Animalia

Phylum—Chordata

Class—Actinopterygii

Order—Siluriformes

Family—Ictaluridae

Genus—*Noturus*

Subgenus—*Rabida*

Species—*Noturus munitus*

Common name—Frecklebelly Madtom

2.2 Species Description

The frecklebelly madtom is a small, stout catfish with recorded body sizes reaching to 99mm (3.9 in) (Ethnier and Starnes 1993, pp 324). It is a member of the subgenus *Rabida*, and is a sister species to the Northern madtom (*Noturus stigmosus*), and piebald madtom (*Noturus gladiator*).

Like other member of the subgenus *Rabida*, the frecklebelly madtom is distinctively marked with dark saddles, typically four for this species (Suttkus and Taylor 1965, pp. 171). This pattern helps to distinguish the frecklebelly madtom from other madtoms with which it co-occurs. The color of the frecklebelly madtom is a mixture of light yellows with brownish patches, which provides camouflage in its preferred habitats (Vincent 2019, unpaginated). It exhibits a lighter color with a combination of many scattered specks or freckles on the venter, which inspired its common name (Suttkus and Taylor 1965, p. 176).

The color variation on the species' fins can vary, but typically they are mottled or blotched (Etnier and Starnes 1993, p. 324). The distal portion of the dorsal fin displays a broad dark band and the caudal fin possesses two dark crescent-shaped bands (one near the middle and one at the distal edge) (Florida Museum 2017, unpaginated, Boschung and Mayden 2004, pp. 346-347). A dark blotch on the adipose fin is a continuation of the third dorsal saddle (Boschung and Mayden 2004, pp. 346-347). The caudal fin is straight or slightly rounded with 54 or fewer rays and nearly separate from the adipose fin (Suttkus and Taylor 1965, p. 175). Like all madtoms, the frecklebelly madtom is armed with venomous pectoral and dorsal spines used to defend against predation. The pectoral spines have up to ten serrae (spike-like projections) on the posterior edge and numerous serrae on the anterior edge (Boschung and Mayden 2004, pp. 346-347). Like all catfishes in the family Ictaluridae, the frecklebelly madtom has barbels around the mouth that act as sensory organs.

2.3 Range and Distribution

The frecklebelly madtom occurs within the states of Alabama, Georgia, Louisiana, Mississippi, and Tennessee. It has a disjunct distribution across the Mobile Basin and Pearl River drainage, with populations in the Pearl River and Bogue Chitto River in the Pearl River drainage and the Upper Tombigbee, Alabama, Cahaba, Etowah, and Conasauga river systems in the Mobile River Basin (Figure 2.1; Piller et al. 2004, p. 1004; Bennett et al. 2010, pp. 507-508).

Throughout its range, the frecklebelly madtom primarily occupies rivers within the Gulf Coastal Plain physiographic province; however, it occurs in the Ridge and Valley physiographic province in the Conasauga River and Piedmont Upland physiographic provinces in the Etowah River (Mettee et al. 1996, pp. 408-409). Physiographic provinces are regions divided into distinctive geographic areas based on physical geography, such as topography, soil type, and geologic history (Fenneman 1928, pp. 266-272). The Piedmont province contains lowlands (plains) and highlands (plateaus) with isolated mountains, and in Georgia, the elevation reaches up to 480 meters (1,500 feet) (Fennemann 1928, p. 293); the Ridge and Valley province contain a longitudinal series of valleys (lowlands) and ridges (mountains) through the Appalachians (Fennemann 1928, p. 296).

The historical range for the species includes the Pearl River system, eastern Louisiana and southern Mississippi; Tombigbee River, eastern Mississippi and western Alabama; upper Alabama and Cahaba rivers, central Alabama; Etowah River, northern Georgia; Conasauga River, northern Georgia and southeastern Tennessee (Bennett et al. 2008, pp. 464-467). It is believed that this species was historically more widespread in the Mobile Bay drainage but was extirpated from large river habitats after the creation of numerous impoundments (Bennett et al. 2010, p. 508).

The frecklebelly madtom has been documented in 53 HUC10 watersheds across its range in Louisiana, Mississippi, Alabama, Georgia, and Tennessee, but has only been documented in 29 (55%) these of watersheds within the last decade (Albanese et al. 2018, p. 38; Fig. 2.2). The current range for the species includes: Pearl River drainage (Bogue Chitto River, Pearl River and tributaries downstream of Ross Barnett Reservoir in Jackson, MS); upper Tombigbee River drainage (East Fork, Buttahatchee River, lower Luxapallila Creek, Sipsey River); Alabama and Cahaba river drainages (lower Cahaba River, approximately downstream of Centreville, AL); Etowah River system (Etowah River upstream of Alatoona Reservoir);and the Conasauga River system (middle Conasauga River) (Bennett *et al*. 2010, p. 508). Recent surveys for the species have analyzed water samples for environmental DNA or eDNA (DNA that is shed from an organism, typically during its life). These surveys have reported frecklebelly madtom eDNA occurring in the Alabama River, lower Tombigbee River in Alabama and the Coosawattee River in Georgia (Freeman and Bumpers 2018, entire; Janosik and Whitaker 2018, entire, Rider et al. 2018, entire). These results suggest that the species persists in portions of its hypothesized historical range and expands our knowledge of its range into previously undocumented river reaches in the Tombigbee and Alabama rivers and the Coosawattee River. However, considerable uncertainty (arising from false positives, false negatives, DNA contamination, origin and fate of organismal sources of eDNA, etc.) can persist with this type of information (Cristescu and Hebert 2018 pp. 216-224) and methods need to be implemented to account for that uncertainty (Ficetola et al. 2015, pp. 551-554; Roussel et al. 2015, pp. 824-825; Wilson et al 2016, pp. 25-28; Cristescu and Hebert 2018 p. 224) For this assessment, we use eDNA data as evidence to support the hypothesis that the probability of the species being present in a particular river is greater than zero. We present a current known range for the species informed by occurrence data and eDNA. We only report rivers that have explicitly been identified to have evidence of eDNA or species observations as part of the range of the frecklebelly madtom. We hope to encourage additional discussion and research efforts from the scientific community on the potential populations that, until 2018, have not been reported as part of the documented range of the species in the lower Tombigbee, lower Alabama, and Coosawattee rivers.

The frecklebelly madtom can be abundant in appropriate habitat, and large collections (>300 individuals) have been made prior to habitat alteration in the Tombigbee River (Bennett et al. 2008, supplement). The species was thought to have declined in portions of its range since the mid-1960s due habitat degradation (Bennett et al. 2010, p. 508), however more recent surveys have indicated some populations are relatively stable.

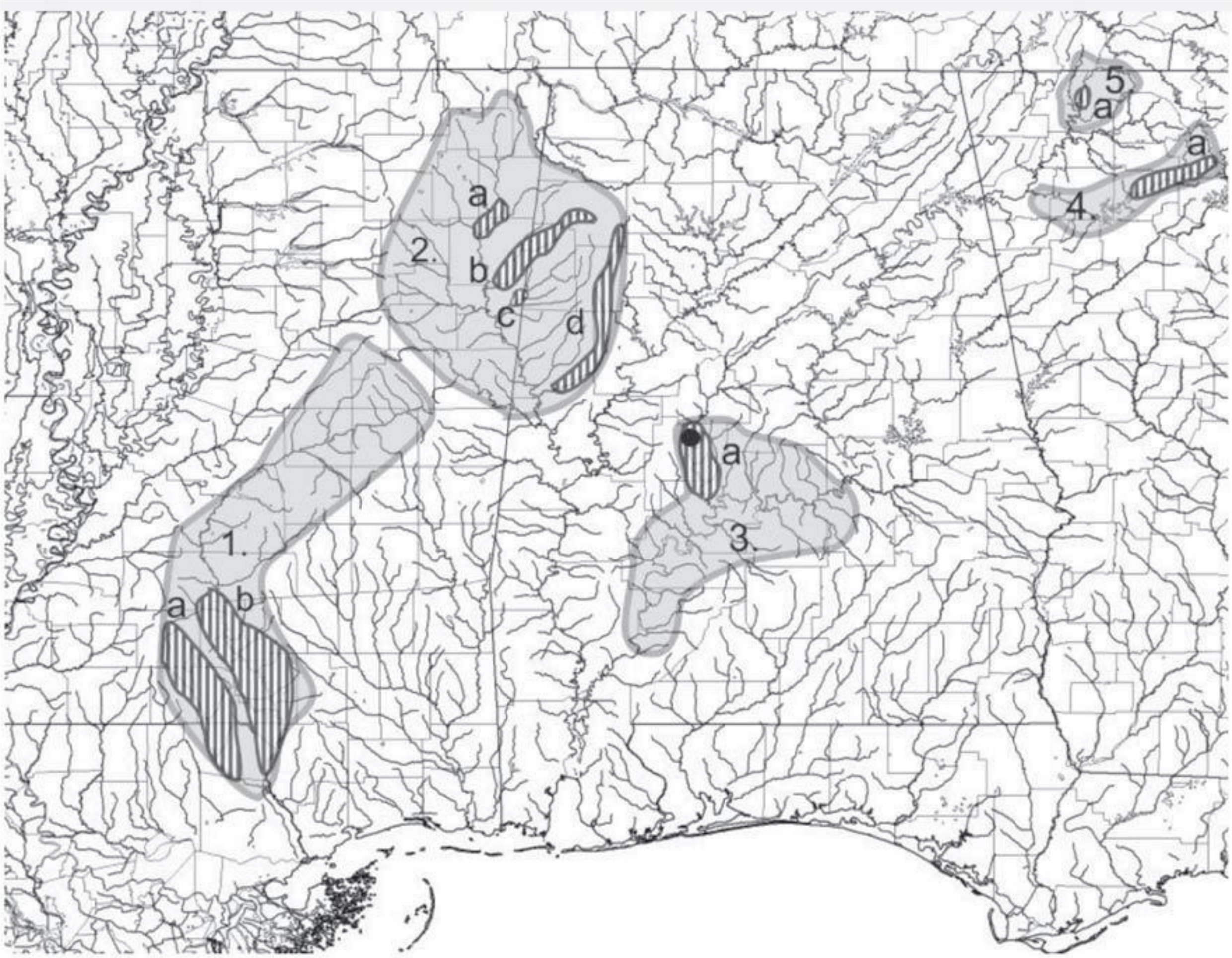


Figure 2.1. *From Bennett et al. 2010 (p. 508).* Current and historical distribution of *N. munitus*. Gray shading represents a hypothesized historical range. Hatching represents current distribution. 1. Pearl River drainage—a) Bogue Chitto River, b) lower Pearl River and tributaries; 2. upper Tombigbee River drainage—a) East Fork, b) Buttahatchee River, c) lower Luxapallila Creek, d) Sipsey River; 3. Alabama and Cahaba river drainages—a) lower Cahaba River; 4. Etowah River system—a) upper Etowah River; 5. Conasauga River system—a) middle Conasauga River.

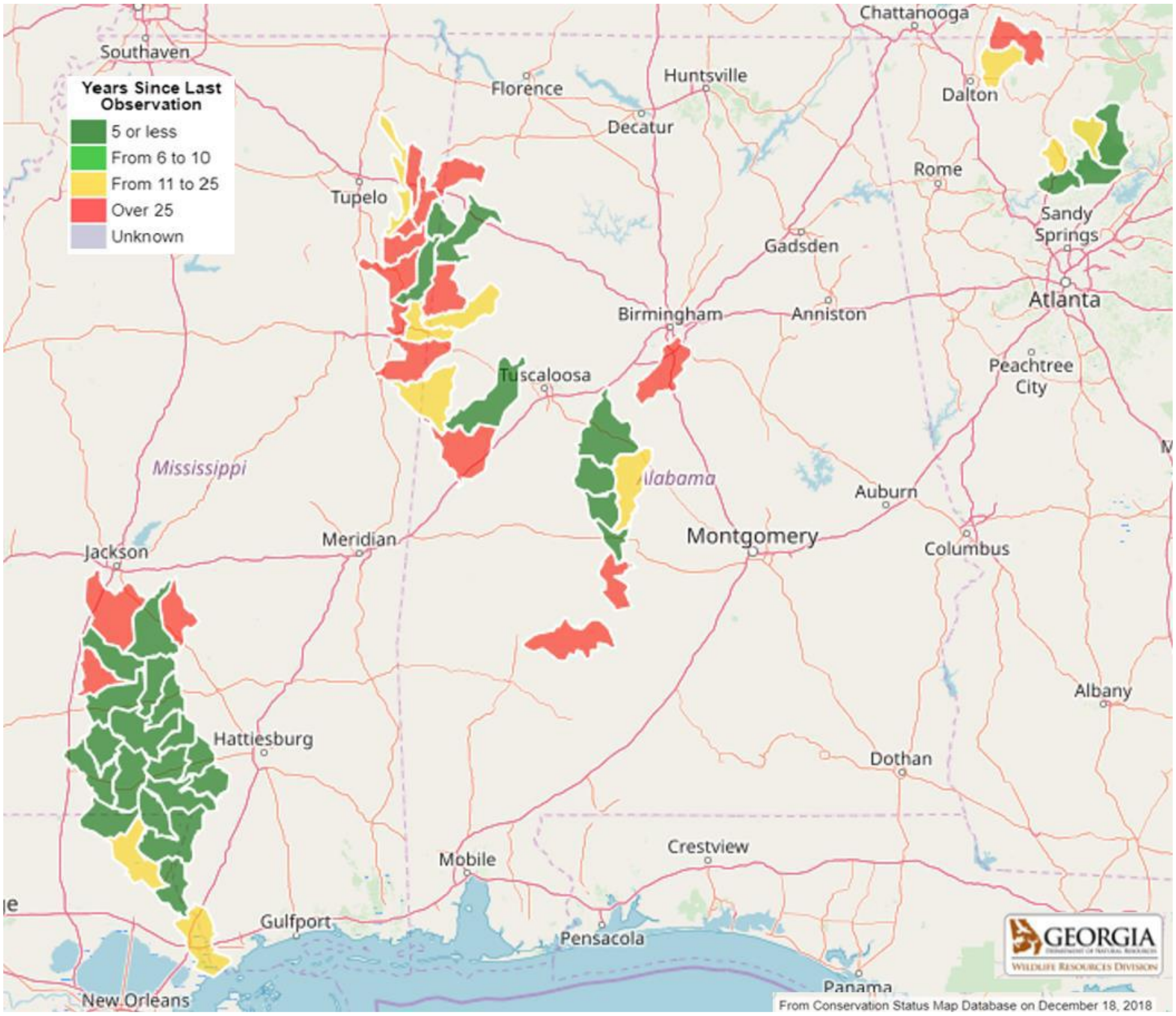


Fig. 2.2. *From Albanese et al. 2018.* Global range of the Frecklebelly Madtom in Georgia, Tennessee, Alabama, and Mississippi. Note: This map reflects data acquired through Fall 2018.

2.4 Life History

The life span of the frecklebelly madtom is reported to be up to five years (Metee et al. 1996, pp. 408-409). The species is likely nocturnal, and for the most part is only active during the night. Trauth et al. (1981, entire) examined aspects of reproductive development and population structure in Mississippi, and Miller (1984, entire) conducted a detailed study of the diet in a population of frecklebelly madtom from the Tombigbee River system. However, the species' patchy distribution, combined with its nocturnal habits, and preference for difficult-to-sample large-river gravel shoals, has contributed to the lack of detailed life-history information for the species (Bennet et al. 2008, p. 459). A detailed life-history study was conducted in earnest in

2010 (Bennett et al. 2010, entire). Below, we discuss the current knowledge of life history characteristics for the species, including reproduction, diet, and age and sex ratios.

2.4.1 Reproduction

There is a lack of information and studies on the breeding behaviors of the frecklebelly madtom. Nesting biology and habitat has yet to be determined for frecklebelly madtoms, although data could potentially be inferred from closely related taxa.

Reproduction is thought to occur between June and July (Trauth et al. 1981, p. 66). The female produces 50-70 eggs, which are released all at one time (Trauth et al. 1981, p. 66). The frecklebelly madtom is reproductively mature in the second summer after birth, similar to other madtom species (Burr and Stoeckel 1999, p. 65).

Nesting sites for madtoms are typically cavities under natural material (rocks, logs, empty mussel shells) or human litter (inside cans or bottles, under boards). Madtoms construct cavities on the bottoms of streams by moving substrate using their heads to push gravel, or their mouths to carry gravel and pebble (Vincent 2018, unpaginated). Both males and females may construct nesting cavities (Burr and Stoeckel 1999, p. 69). A single male guards nests in least, elegant, smoky, and potentially frecklebelly madtoms (Mayden and Walsh 1984, p. 357; Dinkins and Shute 1996, pp. 56-58). Guardian males have empty stomachs, suggesting that they do not feed during nest guarding, which can last as long as 3 weeks (Dinkins and Shute 1996, pp. 56-58). In a study conducted on the Cahaba River, no nests of frecklebelly madtoms were observed. However, seasonal differences in sex ratios suggested that males likely moved to more difficult to sample habitat in pools to create and defend nests, while females remain more evenly dispersed among a variety of habitats (Bennett et al. 2010 p. 517; Burr and Stoeckel 1999, p. 65; Clugston and Cooper 1960, pp. 11-12).

Fecundity in madtoms is among the lowest for North American freshwater fishes due to their small size, relatively large egg size, and high level of parental care given to the fertilized eggs (embryos) and larvae (Dinkins and Shute 1996, pp. 58-60; Burr and Stoeckel 1999, pp. 66-67). Fecundity for the frecklebelly madtom has been reported at 100-140 ova per female in the Tombigbee River (Etnier and Starnes 1993, p. 324; Trauth et al. 1981 p. 66) and 50-175 yolk follicles (Boshcung and Mayden 2004, pp. 346-347). Absolute fecundity and mean relative fecundity were calculated to be 119.4 and 30.6, respectively in the Cahaba River. Regardless of the metric reported, the frecklebelly madtom is considered highly fecund for a madtom and among the highest fecundity known for its subgenus, *Rabida* (Bennett et al. 2010, p. 507).

Propagation trials on the frecklebelly madtom were conducted by the Private John Allen National Fish Hatchery in Tupelo, MS. Their research found that spawning began on May 30, 2019 when water temperatures ranged from 25 ℃ to 26.6 ℃ on a diel cycle and ended on August 16, 2019 when temperatures ranged from 25.6 ℃ to 30 ℃. The male and female would pair up in a shelter and keep all other fish from entering. The male would move gravel from inside the shelter to block the hole. After spawning was completed the female would leave the shelter and the male would stay to guard the eggs. The individual eggs measured 3 mm in diameter. The fry hatched between 4 and 6 days post fertilization. From May 30, 2019 until August 16, 2019 there were 8 different spawning events that produced an egg mass. The number of eggs ranged from 44 to 189 depending on the size of the female. Only four of the eight batches of eggs produced fry and only two of those batches produce fry that completely developed. With water temperature ranging from 25.6 ℃ to 30 ℃, it took the fry 8 days to completely absorb their yolk sac. Once the fry reached 7 days after hatch they began to feed on cut up frozen bloodworms.

2.4.2 Diet

Diet for the frecklebelly madtom is similar to those for other madtom species. The species is an opportunistic insectivore feeding on a variety of aquatic insect larvae (Miller 1984, p. 9). Data from Bennett et al. (2010, p. 516) for frecklebelly madtom diet are similar to results from Miller's (1984, pp. 9-14) study on a Tombigbee River population which found only slight changes in prey taxa through time and between sexes. Seasonal changes found in diet probably reflect differences in prey availability (Miller 1984, p. 11).

The primary food source for the species appears to be aquatic insects, including caddisflies, mayflies, blackflies, and midges. There appears to be seasonal shifts in food preference between the sexes, with males typically preferring caddisflies in the fall months, and the females preferring midges during the same time (Miller 1984, p. 10). Seasonal changes, prey availability, and breeding behavior may alter the feeding characteristics of the species (Miller 1984, p. 11).

Diet analysis from Bennett et al. (2010, p. 513) revealed a few patterns. Baetidae (mayfly) nymphs (31%), Hydropsychidae (caddisfly) larvae (20%), and Simuliidae (blackfly) larvae (20%) composed the highest volume of food for frecklebelly madtom. Baetidae nymphs made up 56% of the diet volume in spring, but only 14–22% in other seasons. Simuliidae larvae made up 38% of the diet volume in fall, but only 1–17% in other seasons. Isonychiidae (mayfly) nymphs appeared in the diet only in spring and fall, and Perlodidae (stonefly) larvae were found only in summer. Small madtoms seem to have a heavier reliance on Chironomidae (midge) (3% of diet volume versus 1% in large individuals), whereas larger individuals consume a greater diversity of prey items. There appear to be a few differences in food preference between the sexes, where gut content analysis revealed that males preferentially utilized Simuliidae (32%) and Isonychiidae (7%). Females consumed a larger total volume than an equal number of males.

2.4.3 Age and Sex Ratios

Bennett et al. (2010, pp. 514-516) examined length-frequency histograms and were able to distinguish three size classes in his study population of the frecklebelly madtom: a young-of-the-year age class, with a mode length of 29 mm (17–31 mm), a second year age class represented by the mode length of 53 mm (49–66 mm); and an third year age class represented by individuals greater than or equal to 58 mm. The young of the year age class exhibited rapid growth; therefore, a first year age class was difficult to define. Subsequent length-frequency analysis from the Etowah River and Tombigbee River, suggests the presence of four age classes in each system, and it appears that sexual maturity is not reached until age two, at around 45-50 mm standard length (Neely 2018, p. 11).

Unequal sex ratios have been reported for frecklebelly madtoms. Different sex ratios in summer (2 females to 1 male) versus fall (1:1), as well as lack of adults in summer have been observed (Bennett et al. 2010, pp. 514-516). These observations are thought to have been an artifact of sampling bias due to male madtoms moving to deeper pools to prepare nesting sites, where wade sampling is more difficult, while females remain more evenly distributed among various habitat types (Bennett et al. 2010, pp. 514-516, Clugston and Cooper 1960, pp. 11-12). Another potential explanation for the observed female biased sex ratio could be higher mortality rates for males. However, this is unlikely, due to the fact that males make up a greater portion of larger size classes (Bennett et al. 2010, pp. 514-516, Clugston and Cooper 1960, pp. 11-12; Mayden and Walsh 1984, p. 363).

2.5 Genetics

Frecklebelly madtom morphological, meristic, and mitochondrial DNA (mtDNA) sequence data were gathered between 1997-2001 from across their range (Neely 2018, p. 1). Preliminary data suggested there was considerable morphological variation across the species range, but the populations in the Coosa River drainage above the Fall Line were the most distinctive population (Neely 2018, p. 1). A subsequent review of a mtDNA data set found that while populations exhibited a degree of genetic differentiations, morphological differentiation was incongruent with genetic differentiation (Neely 2018, p. 2). Through this reanalysis of the existing morphological and genetic datasets, Neely (2018, entire) summarized genetic and morphological variation across the Pearl, Tombigbee, Cahaba, and upper Coosa (Etowah River) drainages. Pearl and Mobile basin populations exhibited the strongest genetic divergence, followed by Tombigbee and Alabama River (Cahaba and Coosa) populations. The Cahaba and Coosa populations exhibited the lowest genetic differentiation and could not be reliably diagnosed based on morphology or meristics. The analysis of mtDNA helps to clarify some uncertainty regarding the taxonomic status of the frecklebelly madtom across its range; however, additional genetic data is required to better inform management decisions for the species. Neely cautions that microsatellite or Single Nucleotide Polymorphisms (SNPs), might provide different perspectives on genetic diversity within the species (Neely 2018, p. 2). Analyzing SNPs and microsatellite data would reveal patterns of gene flow and isolation of the populations and would be necessary to understand adaptive ability of frecklebelly madtom and inform management actions such as population translocation, reintroduction, and augmentation. Therefore, Neely recommended that at a minimum, each population considered in his analysis should be managed as a separate evolutionary significant unit or ESU (Neely 2018, p. 10).

2.6 Resource Needs and Habitat

Primary habitat for frecklebelly madtom is associated with fast moving streams often associated with rivers and their tributaries, with substrate consisting of various sizes of gravel (Suttkus and Taylor 1965, pp. 177-178; Mettee et al. 1996, p. 409; Vincent, 2019, unpaginated). Cover is an important habitat factor for the species, as it provides for concealment against predators

(Vincent, 2019, unpaginated), foraging habitat, and nesting habitat. Areas providing firm gravel substrates, such as small pebbles and rocks, are preferred, thus muddy waterways and still streams are not desirable habitat for this species (Suttkus and Taylor 1965, pp. 177; Taylor 1969, pp. 183; Mettee et al. 1996, p. 409; Piller et al. 2004, p. 1004). The presence or absence of coarse and stable gravel substrate is an important indicator of the occurrence of other madtom species. Simonson and Neves (1992, pp. 117-118) showed that the orangefin madtom *N. gilberti* occurred at localities with abundant gravel and cobble substrates, but was absent at sites dominated by silt or sand substrates. Gravel also is an important predictor for the occurrence of Ozark madtom *N. albater* (Mayden et al. 1980, p. 336) the mountain madtom *N. eleutherus* (Starnes and Starnes 1985, p. 333), and the pygmy madtom *N. stanauli* (Etnier and Jenkins 1980, pp. 17-22). However, results from surveys for the frecklebelly madtom in Alabama, Louisiana, and Mississippi suggest that the species will utilize streams dominated with sand substrates if suitable cover such as large woody debris is present (Wagner *pers. comm.* 2019).

Aquatic vegetation appears to be an important habitat element for the frecklebelly madtom in some parts of its range. This species is often associated with permanent gravel shoals and riffles, and often found in or near aquatic vegetation, in small to large flowing streams and rivers (Taylor 1969, p. 183; Bennett et al. 2008, p. 459). Individuals occur in clumps of river weed (*Podostemon*) and under large, flat rocks (Taylor 1969, p. 183). In the upper Etowah and Conasauga rivers, frecklebelly madtoms have been collected in moderate to swift current over boulders, rubble, cobble, and coarse gravel and around concentrations of river weed.

CHAPTER 3 – SPECIES NEEDS FOR VIABILITY

In order to assess the current and future condition of the species it is necessary to identify the individual, population, and species needs (Figure 3.1). As defined earlier, resiliency is the ability to withstand disturbances and is associated with population abundance and demography, genetic diversity, growth rate, and habitat quality (Shaffer and Stein 2000, pp. 305-310). In this chapter, we consider the frecklebelly madtom's ecological needs at the individual, population and species level, and discuss these needs in relation to resiliency, redundancy, and representation.

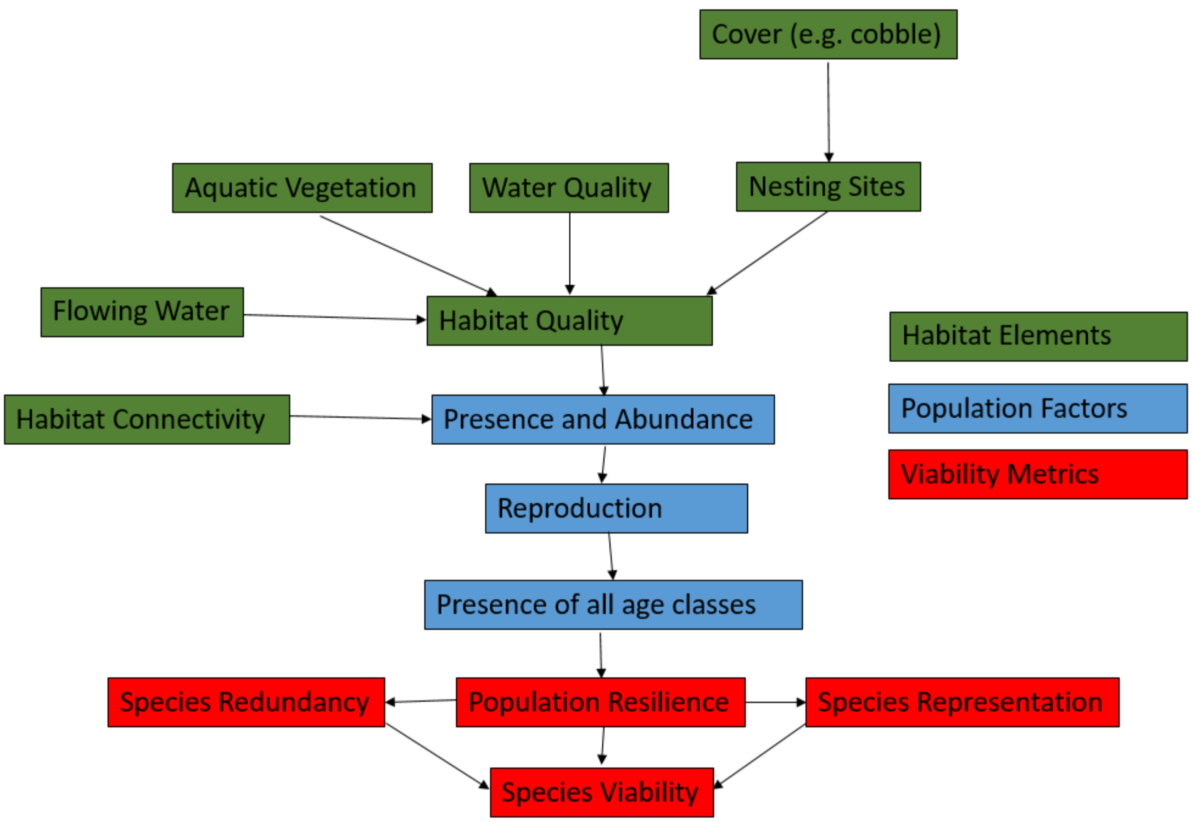


Figure 3.1. Influences diagram depicting the habitat elements and population factors that influence frecklebelly madtom viability.

3.1 Individual Level

For the frecklebelly madtom to survive and reproduce, individuals need suitable habitat that supports essential life functions at all life stages. Three elements appear to be essential to the survival and reproductive of individuals, as discussed in Section 2.6: flowing water, stable substrates, and aquatic vegetation.

3.2 Population Needs

For populations to be resilient, the needs of individuals (flowing water, gravel substrate, and aquatic vegetation) must be met at a larger scale. Stream reaches with suitable habitat must be large enough to support a large enough reservoir of potential mates for frecklebelly madtom to breed with while avoiding issues associated with small population sizes, such as inbreeding depression.

3.3 Species Needs

For the species to be viable, there must be adequate redundancy (suitable number, distribution, and connectivity of populations to allow the species to withstand catastrophic events) and representation (genetic and environmental diversity to allow the species to adapt to changing environmental conditions). Redundancy improves with increasing numbers of populations (natural or reintroduced) distributed across the species range, and connectivity (either natural or human-facilitated) allows connected populations to "rescue" each other after catastrophes. Representation improves with the persistence of populations spread across the range of genetic and/or ecological diversity within the species. Long-term viability will require resilient populations to persist into the future; for the frecklebelly madtom, this will mean maintaining quality stream habitat to support many redundant populations across the species range.

CHAPTER 4 – FACTORS INFLUENCING VIABILITY

Of the 29 described *Noturus* species, more than 50% are considered vulnerable, imperiled, or extinct, and many of the undescribed forms are likely in need of conservation action due to small ranges and increasing anthropogenic threats (Jelks et al. 2008, entire). The frecklebelly madtom is potentially threatened by several factors including impoundments, channelization, gravel mining, altered flow regimes, agriculture, and logging (Mettee et al. 1996, p. 409; Shephard et al. 1996, p. 3; Piller et al. 2004, pp. 1010-1011; Bennett et al. 2008, pp. 469-470). Jelks et al. (2008, p. 395) describes the species as vulnerable because of the present or threatened destruction, modification, or reduction of habitat or range. The following chapter provides a summary of the factors that are affecting or could be affecting the current and future condition of the frecklebelly madtom throughout some or all of its range.

4.1 Water Quality

The frecklebelly madtom, like other benthic species, is sensitive to poor water quality (Warren et al. 1997, p. 125) and needs clean, flowing water to survive, thus water quality degradation is considered a threat to the species. Changes in water chemistry and flow patterns, resulting in a decrease in water quality and quantity have detrimental effects on madtom ecology because they can render aquatic habitat unsuitable for occupancy.

Inputs of point (point source discharge from particular pipes, discharges, etc.) and nonpoint (diffuse land surface runoff) source pollution across the range are numerous and widespread. Point source pollution can be generated from inadequately treated effluent from industrial plants, sanitary landfills, sewage treatment plants, active surface mining, drain fields from individual private homes, and others (Service 2000, pp. 14-15). In the Pearl River drainage there are multiple paper mills that may pose a threat of point source pollution (Piller et al. 2015, p. 2435). A black liquor release from a paper mill in August 2011 negatively impacted fish species abundances and richness in downstream reaches of the Pearl River, though upstream reaches of the Pearl River and its tributaries were not impacted and likely acted as refugia leading to a short, non-pervasive perturbation that only lasted a few days (Piller et al. 2015, p. 2440). Never the less, such events can have profound effects on aquatic communities.

Nonpoint pollution originates from agricultural activities, poultry and cattle feedlots, abandoned mine runoff, construction, silviculture, failing septic tanks, and contaminated runoff from urban areas (Deutsch et al. 1990, entire; Service 2000, pp. 14-15). These sources contribute pollution to streams via sediments, heavy metals, fertilizers, herbicides, pesticides, animal wastes, septic tank and gray water leakage, and oils and greases. Water quality and native aquatic fauna decline as a result of this pollution, as result of nitrification, decreases in dissolved oxygen concentration, increases in acidity and conductivity, or directly introduction of toxicants. These alterations likely have direct (e.g. decreased survival and/or reproduction) and indirect (e.g. loss, degradation, and fragmentation of habitat) effects. For aquatic species, submergent vegetation provides critical spawning habitat for adults, refugia from predators, and habitat for prey of all life stages (Jude and Pappas 1992, pp. 666-667), and degraded water quality and high algal biomass that result from pollutant inputs, cause loss of these critical submergent plant species (Chow-Fraser et al.1998, pp. 38-39), that are vital habitat for fish like the frecklebelly madtom.

Human-caused increases in sediment are particularly troublesome, and are likely a factor in local declines of the species. The frecklebelly madtom is intolerant of excessive sedimentation (Shepard 2004, p. 221), and its habitat requirements make it vulnerable to practices which disturb substrate integrity. The species is restricted to habitat with pea-sized gravel, cobble, or slab-rocks substrates not embedded by large amounts of silt (Bennett et al. 2008, p. 467; Bennett et al. 2010, p. 510), although it has been found to occupy some sandy streams. Degradation from sedimentation, physical habitat disturbance, and contaminants threaten the habitat and water quality on which the frecklebelly madtom depends. Sedimentation from an array of land uses (e.g. urbanization, agriculture, channel maintenance activities) could negatively affect the species by reducing growth rates, disease tolerance, and gill function; reducing spawning habitat, reproductive success, and egg (embryo), larva, and juvenile development; reducing food availability through reductions in prey; reducing foraging efficiency; and reducing shelter. Sedimentation is a concern in some of the watersheds the species occupies, and a substantial threat to the frecklebelly madtom.

A wide range of current activities and land uses can lead to sedimentation within streams that can include: agricultural practices, construction activities, stormwater runoff, unpaved roads, forestry activities, utility crossings, and mining. Fine sediments are not only input into streams during presently ongoing activities, historical land use practices may have substantially altered hydrological and geological processes such that sediments continue to be input into streams for several decades after those activities cease (Harding et al. 1998, p. 14846).

The negative effects of increased sedimentation are well understood for aquatic species (Newcombe and MacDonald 1991, p.72; Burkhead et al. 1997, p 411; Burkhead and Jelks 2001, p. 964). Sedimentation can affect fish species by degrading physical habitat used for foraging, sheltering and spawning (Burkhead and Jelks 2001, p. 964; Sutherland 2005, p. 90), alter food webs and stream productivity (Schofield et al. 2004, p. 907), force altered behaviors (Sweka and Hartman 2003, p. 346), and even have sub-lethal effects and mortality on individual fish (Sutherland 2005, p. 94; Wenger and Freeman 2007, p. 7). Chronic exposure to sediment has been shown to have negative impacts to fish gills, causing gill damage, stress, and may reduce growth rates (Sutherland and Meyer 2007, p. 401). The frecklebelly madtom may experience detrimental effects of sedimentation in the form of gill damage, decreased availability of suitable spawning habitats, and reduced spawning success as a result of fine sediments smothering and killing eggs.

Water quality for frecklebelly madtom is impacted by three processes that warrant further discussion: channel modification (i.e. dredging and channelization), urbanization, and agriculture.

4.1.1 Channel Modification

Dredging and channelization have led to loss of aquatic habitat in the Southeast (Neeves et al. 1997, p. 71). Dredging and channelization projects are extensive throughout the region for flood control, navigation, sand and gravel mining, and conversion of wetlands into croplands (Neves et al. 1997, p. 71; Herrig and Shute 2002, pp. 542-543). Many rivers are continually dredged to maintain a channel for shipping traffic. Dredging and channelization modify and destroy habitat for aquatic species by destabilizing the substrate, increasing erosion and siltation, removing woody debris, decreasing habitat heterogeneity, and stirring up contaminants which settle onto the substrate (Williams et al. 1993, pp. 7-8; Buckner et al. 2002, entire; Bennett et al. 2008, pp. 467-468). Channelization can also lead to head cutting, which causes further erosion and sedimentation (Hartfield 1993, pp. 131-141). Dredging removes woody debris which provides cover and nest locations for many fish species, including the frecklebelly madtom (Bennett et al. 2008, pp. 467-468).

The frecklebelly madtom was apparently eliminated from much of the main-stem of the Tombigbee River after the construction of the Tennessee-Tombigbee (Tenn-Tom) Waterway. Tributaries to the upper Tombigbee River have also been affected by channel modification of the Tenn-Tom Waterway due to head cutting and other geomorphic and flow modifications (Raborn and Schramm 2003, pp. 289-301; Roberts et al. 2007, pp. 250-256; Tipton et al. 2004, pp. 49-61), and a reduced number of tributaries maintain necessary habitat for frecklebelly madtom in this system (Sipsey and Buttahatchee rivers, East Fork of the Tombigbee River, and Luxapallila Creek; Millican et al. 2006, p. 84; Shepard 2004, pp. 220-222; Shepard et al. 1997, pp. 3-4). In the Cahaba River, although frecklebelly madtom abundances seem to have remained stable throughout the modification periods in surrounding drainages, channel geomorphology and substrate is likely being affected by head cutting due to impoundment of the Alabama River, similar to changes occurring in the upper Tombigbee River (Bennett et al. 2008, p. 468).

The Cahaba River, Conasauga River, and some tributaries to the upper Tombigbee River are the only remaining waters within the range of the frecklebelly madtom that have escaped large-scale human modification through damming or channelization (Bennet et al. 2008, p. 468). However, populations in the Conasauga River are greatly reduced from their former extent and perhaps extirpated in the drainage, having been heavily impacted by poor land-use practices in the surrounding watershed (Shepard 2004, pp. 220-222; Shepard et al. 1997, pp. 22-24) and the species has not been seen in the drainage since 2000 (Albanese et al. 2018, pp. 38-39; Freeman et al. 2017, p. 425).

4.1.2 Agriculture

Agricultural practices such as traditional farming, feedlot operations, and associated land use practices can contribute pollutants to rivers. These practices can also degrade habitat by eroding stream banks, which results in alterations to stream hydrology and geomorphology. Nutrients, bacteria, pesticides, and other organic compounds are generally found in higher concentrations in areas affected by agricultural than forested areas. Contaminants associated with agriculture (e.g., fertilizers, pesticides, herbicides, and animal waste) can cause degradation of water quality and habitats through instream oxygen deficiencies, excess nutrification, and excessive algal growths, with a related alteration in fish community composition (Petersen et al. 1999, p. 6).

Areas within the current range of the frecklebelly madtom that are predominantly agricultural, are potentially threatened by nonpoint source sediment and agrochemical discharges altering the physical and chemical characteristics of its habitat, thus potentially impeding its ability to feed, seek shelter from predators, and successfully reproduce. Etnier and Jenkins (1980) suggested that madtoms, which are heavily dependent on chemoreception (detection of chemicals) for survival, are susceptible to human-induced disturbances, such as organic chemical and sediment inputs, because the olfactory (sense of smell) "noise" these pollutants produce could interfere with a madtom's ability to obtain food, coordinate behavioral patterns, and otherwise monitor its environment.

Agricultural practices such as use of glyphosate-based herbicides for weed control and animal waste for soil amendment are becoming common in many regions, and pose threats to biotic diversity in freshwater systems. Over the past two decades, these practices have corresponded with marked declines in populations of fish and mussel species in the Upper Conasauga River watershed in Georgia/Tennessee (Freeman et al. 2017, p. 419). A study in this watershed showed that nutrient enrichment of streams was widespread with nitrate and phosphorus exceeding levels associated with eutrophication, and hormone concentrations in sediments were often above those shown to cause endocrine disruption in fish, possibly reflecting widespread application of poultry litter and manure (Lasier et al. 2016, entire). Researchers postulate that species declines observed in the Conasauga watershed may be at least partially due to hormones, as well as excess nutrients and herbicide surfactants (Freeman et al. 2017, p. 429).

Estrogens, a hormone and type of endocrine disruptor that can be found in poultry litter, have been identified as a threat to aquatic fauna in the Conasauga River system (Jacobs 2015, entire). Increased levels of estrogens have been found to have numerous effects on fishes including: intersex individuals and testicular oocytes (Yonkos et al. 2010, p. 2338), decreased competitive behavior (Martinovic et al. 2007, p. 275), decreased sperm concentrations and decreased sperm mobility, and delayed spermatogenesis (Aravindakshan et al. 2004, p. 161). All of these effects lead to decreases in spawning success and potentially population collapse within short time frames (Kidd et al. 2007). In a recent study of endocrine disruptors on fishes in the Conasauga

River, approximately 7.5% of male fishes surveyed were found to have testicular oocytes (Jacobs 2015, p. 39). Studies have not been conducted to clarify the effects of endocrine disruptors on madtoms; however, instances of intersex, testicular oocytes, and decreased reproductive health attributed to higher concentrations of endocrine disruptors has been observed in benthic species such as blackbanded (*Percina nigrofasciata*), speckled (*Etheostma stigmaeum*), rainbow (*Etheostma caeruleum*), and greenside (*Etheostma blenniodes*) darters (Jacobs et al 2015, p. 65; Tetreault et al. 2011, p. 287; Fuzzen et al. 2015, p. 111) as well as species of fish in the Centrarchidae family.

4.1.3 Development

Urbanization is a significant source of water quality degradation that can reduce the survival of aquatic organisms, including the frecklebelly madtom. Urban development can stress aquatic systems in a variety of ways, including increasing the frequency and magnitude of high flows in streams, increasing sedimentation and nutrient loads, increasing contamination and toxicity, decreasing the diversity of fish, aquatic insects, plants, and amphibians, and changing stream morphology and water chemistry (Coles et al. 2012, entire; CWP 2003; entire). Sources and risks of an acute or catastrophic contamination event, such as a leak from an underground storage tank or a hazardous materials spill on a highway, increase as urbanization increases.

Several studies have examined the negative impacts of urbanization on endemic fish assemblages. In the Etowah Basin, Georgia, models indicated that urbanization lowered fish species richness and density, and led to predictable changes in species composition, where darters and sculpin, cyprinids, and endemic species declined along the urban gradient, but centrarchids persisted and became the dominant group (Walters et al. 2005, pp. 10-11). In Maryland, habitat degradation from urban development was determined to be the most important threat limiting the distributions of the rarest fish species (Stranko et al. 2010, p. 603). In the Alameda Creek Watershed, near San Francisco, California, researchers observed significant changes in fish community composition and a decrease in native species richness at urbanized sites, and increased urbanization was associated with changes in the fish community (Cervantes-Yoshida et al. 2015, pp. 7-9).

Currently, larger population centers, such as the cities of Atlanta, GA, Jackson, MS, and Birmingham, AL, contribute substantial runoff to the watersheds occupied by the frecklebelly madtom. Urbanization is predicted to increase in several areas across the range of the frecklebelly madtom. In Georgia, the frecklebelly madtom is restricted to the mainstem Etowah River, and all of the watersheds upstream of Lake Allatoona are expected to experience additional urbanization (Albanese et al. 2018, p. 39). Conservation concerns in the Etowah River system have focused on potential effects of this predicted urban growth on imperiled fishes (Burkhead et al. 1997, pp. 959-968; Wenger et al. 2010, pp. 11-21), and previous analyses show negative correlations between occurrence of native fishes and increases in impervious cover associated with urban development (Wenger et al. 2008, p. 1260). However, Freeman et al. (2017, pp. 427-428) found that no fish species sampled in the Etowah River system had diminished estimated occupancy over time, and frecklebelly madtom were estimated to occur at all sites sampled (n = 10). When comparing dynamics between the Conasauga (lower frecklebelly madtom occupancy over time) to the Etowah (no change in occupancy over time), the authors hypothesize that pollutants from agricultural land use may be a primary factor driving lowered occupancy in the Conasauga system (Freeman et al 2017, pp. 430).

4.2 Impoundments

Impoundment of rivers is a primary threat to aquatic species in the southeast (Benz and Collins 1997, p. 22-23, 63, 91, 205, 273, 291, 397, 399, 401-406, 446); Buckner et al. 2002, 10-11). Dams modify habitat conditions and aquatic communities both upstream and downstream of an impoundment (Winston et al. 1991, pp. 103-104; Mulholland and Lenat 1992, pp. 193-231; Soballe et al. 1992, pp. 421-474). Upstream of dams, habitat is flooded and in-channel conditions change from flowing to still water, with increased depth, decreased levels of dissolved oxygen, and increased sedimentation. Sedimentation alters substrate conditions by filling in interstitial spaces between rocks which provide habitat for many species (Neves et al. 1997, p. 63-64), including the frecklebelly madtom. Downstream of dams, flow regime fluctuates with resulting fluctuations in water temperature and dissolved oxygen levels, the substrate is scoured, and downstream tributaries are eroded (Neves et al. 1997, p. 63-64; Schuster 1997, p. 273; Buckner et al. 2002, p. 11). Negative “tailwater” effects on habitat can extend many kilometers downstream (Neves et al. 1997, p. 63). Dams fragment habitat for aquatic species by blocking corridors for migration and dispersal, resulting in population isolation and heightened susceptibility to extinction (Neves et al. 1997, p.63-63). Dams also preclude the ability of aquatic organisms to escape from polluted waters and accidental spills (Buckner et al. 2002, p. 10).

Damming of streams and springs is extensive throughout the southeast (Etnier 1997, 88-89; Morse et al. 1997, 22-23; Shute et al. 1997, 458-459. Shute et al. (1997, p. 458) report that “few Southeastern streams are spared from impoundment”. Morse et al. (1997) report that many streams have both small ponds in their headwaters and large reservoirs in their lower reaches. Small streams on private lands are regularly dammed to create ponds for cattle, irrigation, recreation, and fishing, with significant ecological effects due to the sheer abundance of these structures (Morse et al. 1997, 22-23). Buckner et al. (2002, p. 11) report that small headwater streams are increasingly being dammed in the southeast to supply water for municipalities. Etnier (1997, p. 89) reports that many southeastern springs have also been inundated by impoundments.

Dams are known to have caused the extirpation and extinction of many southeastern species, and existing and proposed dams pose an ongoing threat to many aquatic species (Folkerts 1997, p. 11; Neves et al. 1997, p. 63; USFWS 2000, p. 15; Buckner et al. 2002, p. 11). Dams are a primary cause of imperilment for freshwater fish. Etnier (1997, p. 91) found that impoundment and alteration of flow regime is responsible for 32 percent of fish imperilment in the southeast.

The construction of ten lock and dam structures on the Tenn-Tom Waterway, which artificially connects the Tennessee River to the Gulf of Mexico, led to the extirpation of many species from the main river channel, including the frecklebelly madtom (Bennett et al. 2008, p. 467). The frecklebelly madtom has been considered extirpated from the Alabama River, likely due the construction of three dams in the late 1960s and early 1970s (Bennett et al. 2008, p. 467). Bennett et al. (2008, p. 470) claims construction of one dam on the Etowah River, "likely affected" the frecklebelly madtom, and because this species is dependent on large-river gravel shoal habitat, it is “vulnerable to river modifications that will likely continue into the foreseeable future”.

Piller et al. (2004, p. 1007, 1010) reported a precipitous decline in the frecklebelly madtom population in the Pearl River after 1964, coinciding with many human-induced river modifications. They concluded that the Pearl River experienced numerous human caused disturbances since the 1950s, and it is difficult to attribute the decline of the frecklebelly madtom to any one of these factors. Rather, it is likely that all of the disturbances contributed to the widespread problem of geomorphic instability in the river, and this in turn is depressing populations of gravel-dependent species such as the frecklebelly madtom. However, it seems the

Pearl River populations have rebounded, as recent collections found a high rate of presence at historic localities (83%) and a high average abundance and average catch per unit effort (Wagner et al. 2018, p. 16). Patterns of decline have also been seen in the Alabama and Tombigbee rivers, with few collections after 1970 producing specimens, in contrast to the Cahaba River collections, in which the species seems to have remained fairly common (Bennett et al. 2008, p. 467).

4.3 Invasive Species

It is estimated that 42% of Federally Threatened or Endangered species are significantly impacted by nonnative nuisance species across the nation and nuisance species are significantly impeding recovery efforts for them in some way (NCANSMPC 2015, pp.8-9). There are many areas across the Southeastern United States where aquatic invasive species have invaded aquatic communities; are competing with native species for food, light, or breeding and nesting areas; and are impacting biodiversity.

When an invasive species is introduced it may have many advantages over native species, such as easy adaptation to varying environments and a high tolerance of living conditions that allows it to thrive in its nonnative range. There may not be natural predators to keep the invasive species in check; therefore, it can potentially live longer and reproduce more often, further reducing the biodiversity in the system. The native species may become an easy food source for invasive species, or the invasive species may carry diseases that wipe out populations of native species.

Invasive crayfishes have been suspected in the decline of native species, including the endangered Watercress Darter (Fluker et al. 2009, p. 193) and other madtom species, including the endangered Chucky Madtom (USFWS 2018, pp. 12-13) and the Mountain Madtom (Harris et al. in press, entire). Specific impacts to madtom species from invasive crayfish include competition for habitat and direct predation, especially early life stages (USFWS 2018, p. 13). In addition to overlapping diets (i.e. mainly macroinvertebrates), crayfish and madtoms require cavities for spawning and protection from predators, thus when habitat becomes limited, crayfish can have particularly detrimental impacts (Harris et al. in press, p. 4).

Hydrilla is an aquatic plant that alters stream habitat, decreases flows, and contributes to sediment buildup in streams (NCANSMPC 2015, p.57). High sedimentation can cause suffocation and reduce stream flow necessary for madtom survival. Hydrilla is present in several watersheds where the frecklebelly madtom occurs. The dense growth is likely to alter the flow in these systems and cause sediment buildup, which could potentially alter the habitat for the frecklebelly madtom.

While data are lacking on invasive crayfish or Hydrilla, they could potentially have negative impacts to frecklebelly madtom, and the spread of these invasive species is expected to increase in the future.

4.4 Climate Change

In the southeast United States, several climate change models have projected more frequent drought, more extreme heat (resulting in increases in air and water temperatures), increased heavy precipitation events (e.g., flooding), more intense storms (e.g., frequency of major hurricanes increases), and rising sea level and accompanying storm surge (IPCC 2013, entire). When taking into account future climate projections for temperature and precipitation where frecklebelly madtom occurs, warming is expected to be greatest in the summer, which is predicted to increase drought frequency, while annual mean precipitation is expected to increase slightly, leading to a slight increase in flooding events (Figures 3.1 and 3.2) (IPCC 2013, entire; Alder and Hostetler 2013, unpaginated; USGS 2020, unpaginated). Changes in climate may affect ecosystem processes and communities by altering the abiotic conditions experienced by biotic assemblages resulting in potential effects on community composition and individual species interactions (DeWan et al. 2010, p. 7). These changes have the potential to impact the frecklebelly madtom and its habitat.

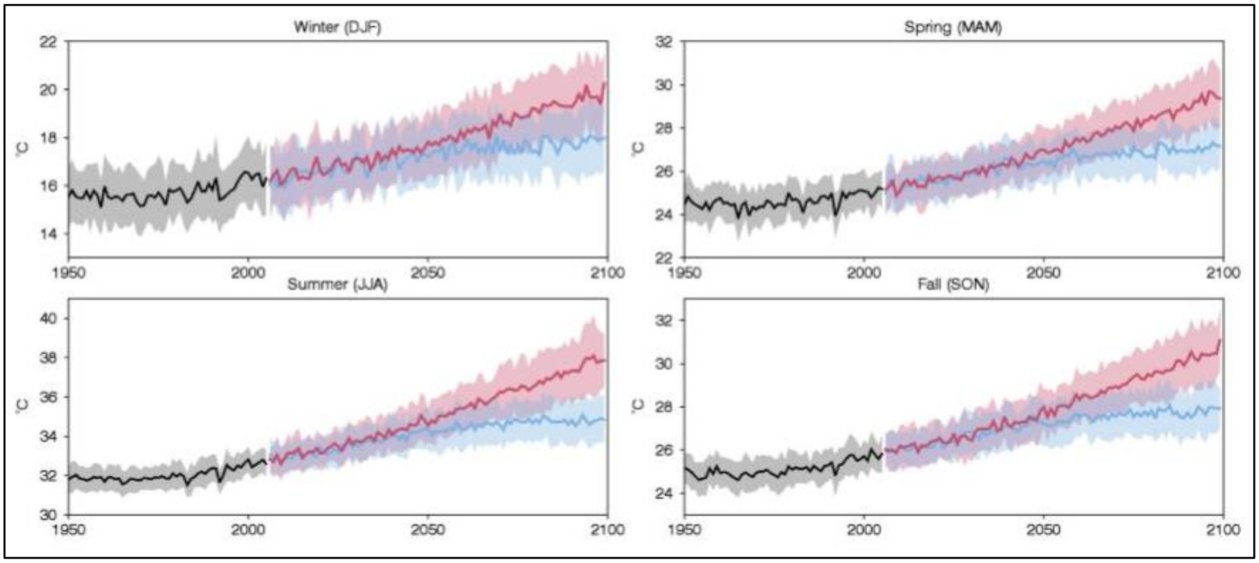


Figure 3.1. Time series of the seasonal average of maximum air temperature in the South Atlantic region with historical (black), RCP4.5 projection (blue), and RCP8.5 projection (red). “The historical period ends in 2005 and the future periods begin in 2006. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes.” Source: USGS National Climate Change Viewer (Credit: Alder and Hostetler 2013, unpaginated; Hostetler and Adler 2016, entire; Thrasher *et al.* 2013, entire).

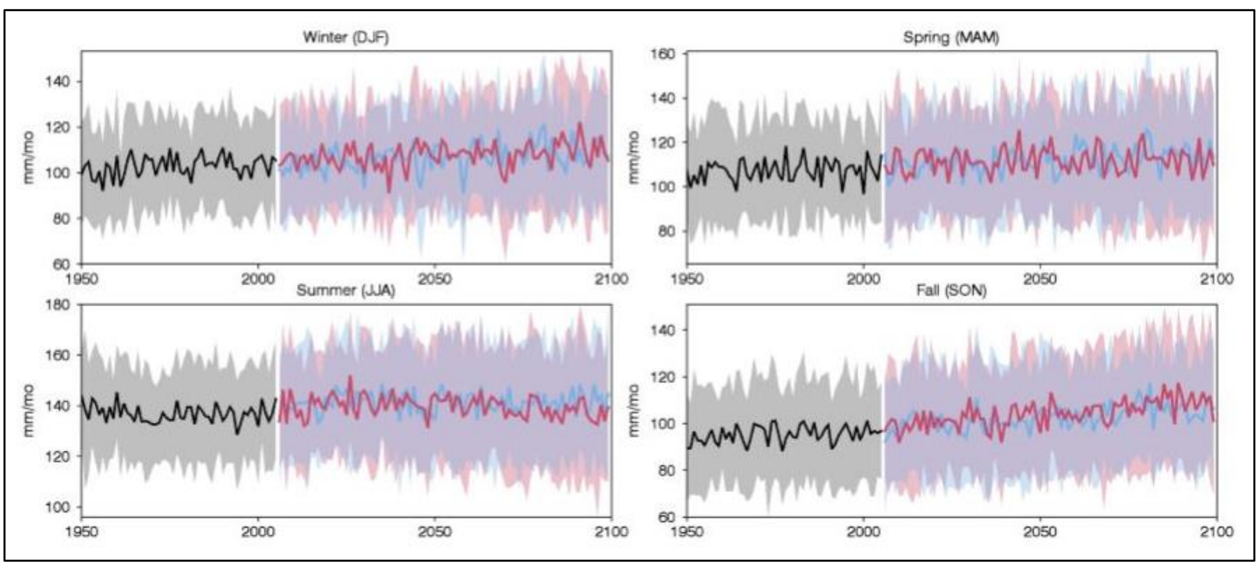


Figure 3.2. Time series of the seasonal average of precipitation in the South Atlantic region with historical (black), RCP4.5 projection (blue), and RCP8.5 projection (red). “The historical period ends in 2005 and the future periods begin in 2006. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes.” Source: USGS National Climate Change Viewer (Credit: Alder and Hostetler 2013, unpaginated; Hostetler and Adler 2016, entire; Thrasher *et al.* 2013, entire).

While it is not entirely clear if climate change will lead to an increase in droughts in the southeastern US (Ingram et al. 2013, p. 34), the broader historical record indicates that the region has been subject to multi-decade droughts and overall drier than the 20th century which has been comparatively wetter (Seager et al. 2009, p. 5043). Therefore, it is essential to consider how drier conditions will influence the southeastern USA. A higher occurrence of droughts could negatively affect stream flows in the region. Stream flow is strongly correlated with important physical and chemical parameters that limit the distribution and abundance of riverine species (Power et al. 1995, entire; Resh et al. 1988, pp. 438-439) and it regulates the ecological integrity of flowing water systems (Poff et al. 1997, p. 770).

It should be recognized that the greatest threat to many species from climate change may come from synergistic effects. That is, factors associated with a changing climate may act as risk multipliers by increasing the risk and severity of more imminent threats. The dual stressors of climate change and direct human impact have the potential to affect aquatic ecosystems by altering stream flows and nutrient cycles, eliminating habitats, and changing community structure. (Moore et al. 1997, p. 942). Increased water temperatures and a reduction in stream flow are the climate change effects that are most likely to affect stream communities (Poff 1992, entire), and each of these variables is strongly influenced by land use patterns. For example, in agricultural areas, lower precipitation may trigger increased irrigation resulting in reduced stream flow (Hatfield et al. 2008, pp. 42-43). In forested areas, trees influence instream temperatures through the direct effects of shading. Reductions in temperature by vegetative cover may be particularly important in low-order streams, where canopy vegetation significantly reduces the magnitude and variation of the stream temperature compared with that of clear-cut regions (Ringler and Hall, 1975, pp. 111-121).

To understand how climate change is projected to change where frecklebelly madtom occurs, we used the National Climate Change Viewer (NCCV), a climate-visualization tool developed by the U.S. Geological Survey (USGS), to generate future climate projections across the range of the species. The NCCV is a web-based tool for visualizing projected changes in climate and water balance at watershed, State, and county scales (USGS 2020, unpaginated). This tool uses air temperature and precipitation data from 30 downscaled climate models for two Representative Concentration Pathway (RCP) scenarios, RCP 4.5 and RCP 8.5, as input to a simple water-balance model to simulate changes in the surface water balance over historical and future time periods, providing insight into potential for climate-driven changes in water resources. To evaluate the effects of climate change in the future, we used projections from RCP 4.5 and RCP 8.5 to characterize projected future changes in climate and water resources, averaged for the South-Atlantic Gulf Region encompassing the range of the frecklebelly madtom. The projections estimate change in mean annual values for maximum air temperature (Figure 3.1), minimum air temperature, monthly precipitation (Figure 3.2), and monthly runoff, among other factors.

Within the range of the frecklebelly madtom, the NCCV projects that, under the RCP 4.5 scenario, maximum air temperature will increase by 1.9 degrees Celsius (°C) (3.4 degrees Fahrenheit (°F)), minimum air temperature will increase by 1.8 degrees C (3.2 °F), precipitation will increase by 5.36 millimeters (0.2 inches) per month, and runoff will remain the same (USGS 2020, unpaginated). These estimates indicate that, despite projected minimal increases in annual precipitation, anticipated increases in maximum and minimum air temperatures will likely offset those gains. Based on these projections, frecklebelly madtom will on average be exposed to increased air temperatures across its range, despite limited increases in precipitation; however, these projections are not a one-to-one air to stream water temperature comparison.

Within the range of the frecklebelly madtom, the NCCV projects that, under the more extreme RCP 8.5 scenario, maximum air temperature will increase by 2.8 degrees Celsius (°C) (5 degrees Fahrenheit (°F)), minimum air temperature will increase by 2.7 degrees C (4.9 °F), precipitation will increase by 5.36 millimeters (0.2 inches) per month, and runoff will remain the same (USGS 2020, unpaginated). Similarly as under the RCP 4.5 scenario, these estimates indicate that, despite projected minimal increases in annual precipitation, anticipated increases in maximum and minimum air temperatures will likely offset those gains. Based on these projections, frecklebelly madtom will on average be exposed to increased air temperatures across its range, despite limited increases in precipitation; however, these projections are not a one-to-one air to stream water temperature comparison.

Despite the recognition of climate effects on ecosystem processes, there is uncertainty within each model and model ensembles about what the exact climate future for the southeastern United States will be, and there is uncertainty in how the ecosystems and species will respond. Although there are several potential risks associated with long-term climate change as described above, there is uncertainty regarding the how the frecklebelly madtom will respond to these risks. The species occupies some tributaries throughout its range, but the frecklebelly madtom has a preference for habitat in larger rivers and this may provide a buffer to changes in maximum temperature and precipitation induced by climate change (Dodds et al. 2004, p. 208). In addition, the species does not appear susceptible to impacts from sea level rise due to the inland location of frecklebelly madtom populations. For these reasons, we do not consider climate change to be a primary risk factor for the species at this time.

4.5 Conservation Efforts

The frecklebelly madtom is recognized as a species of concern in all states where it occurs and protected by State statute in four states where it occurs. This species is listed as endangered by the State of Georgia (GADNR 2015, p. 74), endangered by the State of Mississippi (Mississippi Museum of Natural Science 2015, p. 36), and threatened by the State of Tennessee (TWRA 2015, Appendix C). In Alabama, the frecklebelly madtom is designated as a protected nongame species under Alabama Code 220-2-.92. In general, the protections accorded to the frecklebelly madtom by Mississippi, Alabama, Georgia, and Tennessee prohibit direct exploitation of the species without a permit within those states.

Beginning in 2017, the Private John Allen National Fish Hatchery partnered with the Mississippi Department of Wildlife Fisheries and Parks to collect individuals of the frecklebelly madtom within that state to study marking techniques, to establish captive husbandry methods, and to conduct life history studies. This effort has documented important components of the species' life-history and has collected data that can be used to develop long-term, captive-propagation efforts.

Throughout the range of the species, portions of occupied rivers and surrounding lands are owned and managed by State and Federal entities that prioritize conservation as a management objective. Generally, all these properties help to maintain the natural ecosystem functioning of a river by managing terrestrial areas in a more natural state and limiting disturbance adjacent to rivers. However, properties managed by the Service, U.S. Forest Service, and the Dawson Forest Wildlife Management Area (WMA), managed by the Georgia Department of Natural Resources, are known to specifically consider and manage for the conservation of aquatic species and their habitats. It is expected that the frecklebelly madtom will be positively affected by management on all these lands that is designed to maintain a more natural ecosystem in the surrounding terrestrial environments and within the aquatic habitats. These conservation lands and the adjacent rivers occupied by the frecklebelly madtom that are benefited include: portions of the Bogue Chitto and Pearl rivers within the Bogue Chitto National Wildlife Refuge (NWR, Service) in Louisiana; portions of the Bogue Chitto River within Bogue Chitto State Park (Louisiana Department of Culture, Recreation, and Tourism) in Louisiana; portions of the Pearl River within the Pearl River WMA (Louisiana Department of Wildlife and Fisheries) in Louisiana; portions of the Cahaba River with in the Cahaba NWR (Service) in Alabama; portions of the Conasauga River within the Cherokee National Forest (U.S. Department of Agriculture (USDA) U.S. Forest Service) in Georgia; and portions of the Etowah River within the Dawson Forest WMA (Georgia Department of Natural Resources) in Georgia. In addition, the Etowah River catchment area upstream of habitat occupied by the frecklebelly madtom and managed by the Chattahoochee-Oconee National Forest (USDA U.S. Forest Service) is expected to benefit the species by providing good water quality to lower river reaches.

NRCS designated the Conasauga River as a Working Lands for Wildlife landscape in 2017 and is providing additional funds and manpower to improve water quality and aquatic habitat in the watershed. The project provides technical and financial assistance to help landowners improve water quality and help producers plan and implement a variety of conservation activities, or practices that benefit aquatic species. The frecklebelly madtom would likely benefit from water quality improvements in portions of the Conasauga River that are affected by agricultural practices implemented through the WLFW project.

4.6 Synergistic and Cumulative Effects

In addition to impacting frecklebelly madtom individually, it is possible that several of the above summarized risk factors are acting synergistically or cumulatively on the species. The combined impact of multiple stressors is likely more harmful than a single stressor acting alone. The dual stressors of climate change and direct human impact have the potential to affect aquatic ecosystems by altering stream flows and nutrient cycles, eliminating habitats, and changing community structure. (Moore *et al.* 1997, pp. 942). Increased water temperatures and a reduction in stream flow are the climate change effects that are most likely to affect stream communities (Poff 1992, entire), and each of these variables is strongly influenced by land use patterns. For example, in agricultural areas, lower precipitation may trigger increased irrigation resulting in reduced stream flow (Hatfield *et al.* 2008, pp. 42–43). In forested areas, trees influence instream temperatures through the direct effects of shading. Reductions in temperature by vegetative cover may be particularly important in low-order streams, where canopy vegetation significantly reduces the magnitude and variation of the stream temperature compared with that of clear-cut regions (Ringler and Hall, 1975, pp. 111–121).

CHAPTER 5 – CURRENT CONDITION

As the population is a biologically meaningful unit in a resilience analysis, which is then scaled up to redundancy and representation at the species scale, appropriately defining and delineating populations is a crucial step to assess species viability. Below we discuss the challenges of delineating population for the frecklebelly madtom and our approach. After delineating resilience units or analysis units (i.e. populations), we then assessed the resilience of each as described in the following sections (5.3) by synthesizing the best available information about observations of the frecklebelly madtom. Resilience of analysis units was used to assess current redundancy and representation for the frecklebelly madtom.

5.1 Delineating Resilience Units

Home range sizes and movements for frecklebelly madtom are not well known and studies designed to clarify population level genetic structuring have not been implemented, so delineating biological populations is not possible. Thus, we delineated what we term resilience units for the species to assess resilience. These units are not meant to represent "populations" in a biological sense; they may represent multiple or portions of groups of demographically linked interbreeding individuals. As data are not available to delineate biological populations at this time, these units, were intended to subdivide the species range in a way that facilitates assessing and reporting the variation in current and future resilience across the range.

Frecklebelly madtom resilience units were delineated using HUC10 (10-digit hydrologic unit code) hydrologic units, taken from the USGS Water Boundary Dataset. HUC10 hydrologic units correspond to watersheds, with units denoted by fewer digits (e.g., HUC6 or HUC8) corresponding to larger areas (basin or subbasin, respectively), and those with more digits (e.g., HUC12) corresponding to smaller units or subwatersheds. Hydrologic units of smaller sizes (more digits) are nested within units of larger sizes (fewer digits).

Resilience units were delineated as aggregations of adjacent HUC10 watersheds that contain a frecklebelly madtom observation, either visual or eDNA and are not disconnected by dams or other major habitat alterations that may present a barrier to movement. All frecklebelly madtom resilience units are aggregations of multiple HUC10 watersheds except the Alabama River and Coosawattee River units, which contain only one HUC10 each. Using this methodology, we identified 16 analysis units consisting of a total of 66 HUC10 watersheds across the range of the species (Figure 5.1). These resilience units were then considered as components of representation, as described in the next section (Table 5.1).

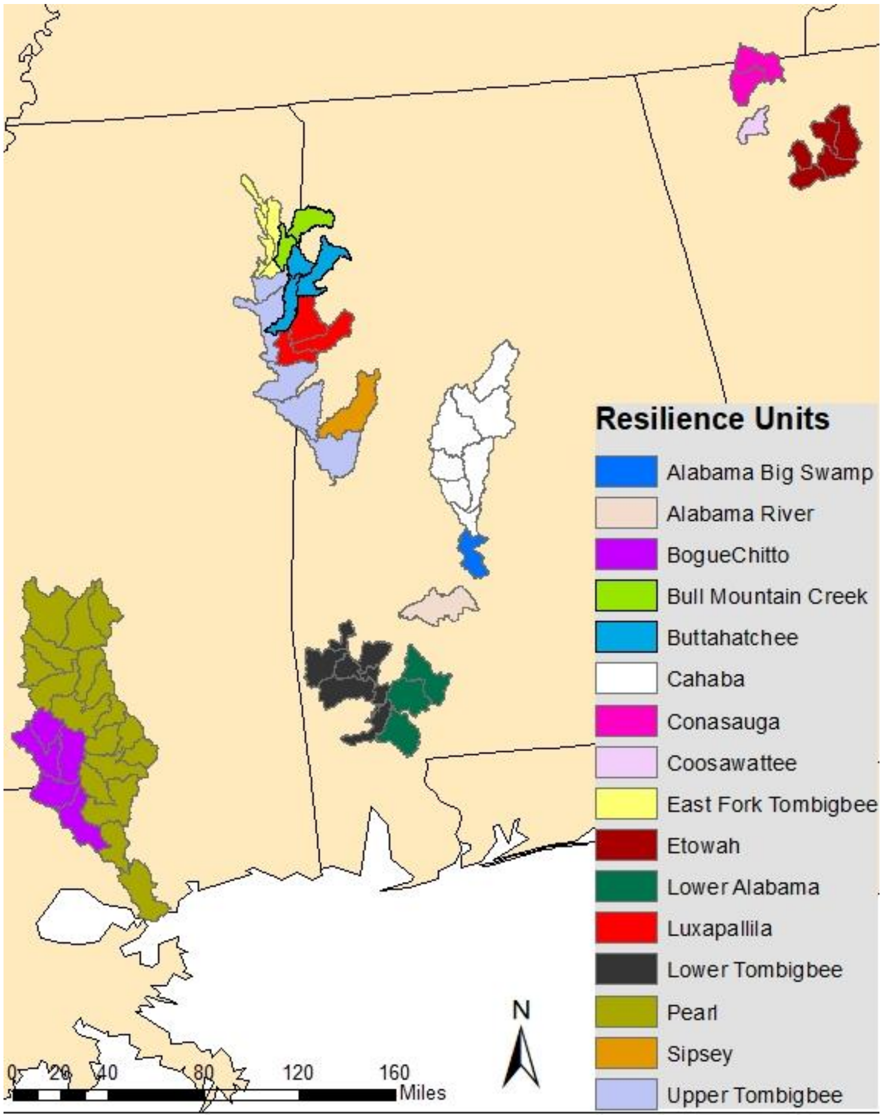


Figure 5.1. Resilience units for frecklebelly madtom.

5.2 Delineating Representative Units

Representation refers to the breadth of genetic and environmental diversity within and among populations, which influences the ability of a species to adapt to changing environmental conditions over time. Differences in life history traits, habitat features, and/or genetics across a species range often aid in the delineation of representative units, which are used to assess species representation.

There is some evidence of differentiation of habitat use, morphology, and/or genetics for areas that frecklebelly madtoms occupy which are disconnected spatially (i.e. units as described above). For example, frecklebelly madtom populations in individual drainage basins exhibit some differences in their use of mainstem and tributary habitat types (Trauth et al. 1981, p. 66; Neely 2018, p. 11). Also, meristics indicate some morphological differences between basins (Neely 2018, pp. 7-9). Finally, a recent genetics study has suggested that these populations be managed, minimally, as distinct evolutionary significant units or ESUs (Neely 2018, p. 10). The basins recommended for management as ESUs include the Pearl River, Tombigbee River, Cahaba River, Alabama River, and upper Coosa River drainage. Therefore, these basins were each considered as separate representative units. In addition to these historically known rivers, evidence of presence of the frecklebelly madtom has been documented in two other distinct areas from water samples that contained eDNA for the species (the lower Tombigbee and Alabama rivers and Coosawattee River). The Coosawattee River is geographically located between the Conasauga and Etowah rivers. Therefore, it is included within the upper Coosa River representation unit. The frecklebelly madtom has never been observed from the lower Tombigbee and Alabama rivers in the reaches that contained water samples with positive eDNA for the frecklebelly madtom. Furthermore, dams isolate these areas from sites where the animal itself has been observed in the upper Tombigbee River and upstream reaches of the Alabama River. The lower reaches of the Tombigbee River and Alabama River where the eDNA was collected are not disconnected from each other by any known barriers. Therefore, we have delineated these reaches as a separate representative unit (Table 5.1 and Fig 5.2).

Of particular interest are the frecklebelly madtom that occur in the upper Coosa River drainage (Coosawattee, Etowah, and Conasauga rivers). Preliminary morphological data suggests that while there is considerable variation across the range, specimens from the Coosa River drainage above the Fall Line were the most distinctive (Neely 2018, p. 1). Furthermore, these are the only analysis units of the frecklebelly madtom known to occur in a physiographic province other than the Coastal Plain (i.e. the Ridge and Valley and Piedmont; Figure 5.2). We believe these populations deserve additional attention in regards to representation.

We have delineated six representative units as follows (Figure 5.2): Pearl River, upper Tombigbee River, Cahaba River, Alabama River, lower Tombigbee-Alabama Rivers, and upper Coosa River. The approach used here to discuss representation should be refined as future studies reveal more about the genetic diversity and structuring within the species range. We summarize resilience of each of the units in the results section of this chapter.

Table 5.1. Resilience units and representative units used in assessing viability of the frecklebelly madtom.

Resiliency Units	***Representative Units***
Bogue Chitto River *Pearl River*	Pearl River
East Fork Tombigbee *Sipsey River* *Luxapallila Creek* *Buttahatchee River* *Bull Mountain Creek* *Upper Tombigbee River (mainstem)*	Upper Tombigbee River
Alabama River	Alabama River
Cahaba River *Alabama River/Big Swamp*	Cahaba River
Conasauga River *Etowah River* *Coosawattee River*	Upper Coosa River
Lower Tombigbee River *Lower Alabama River*	Lower Tombigbee/Alabama River

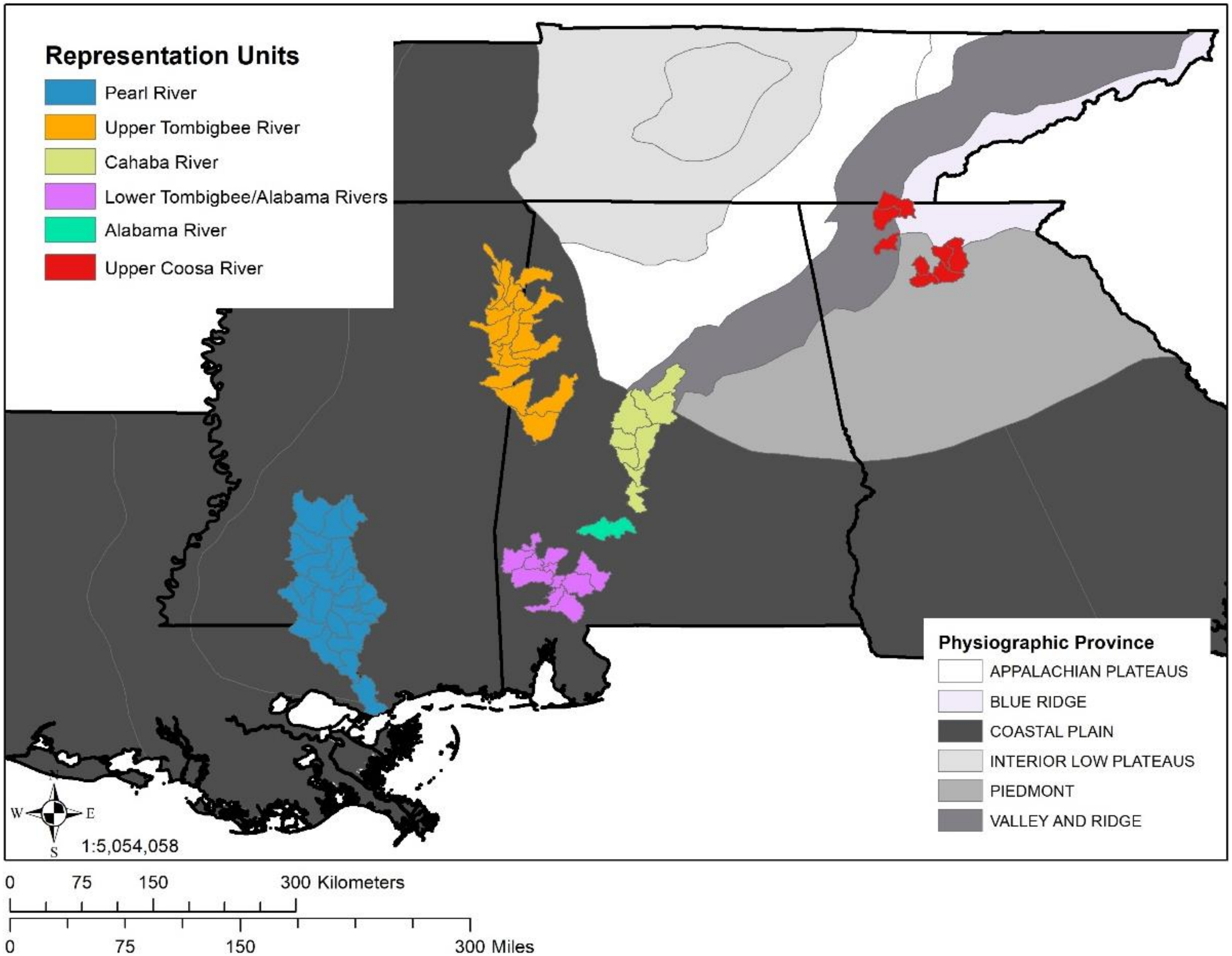


Figure 5.2. Representative units for frecklebelly madtom.

5.3 Assessing Current Resilience

We assessed resiliency of frecklebelly madtom units by considering occurrence data throughout the species' range. Occurrences are georeferenced data that record frecklebelly madtom presence at a specific location and date. Multiple frecklebelly madtoms may be documented at one occurrence. While we acknowledge that it may be difficult to infer long term trends using only occurrence data because this information is derived from a variety of studies that employ a variety of methods, we believe that these data can be used to assess range extent, range geometry, and persistence through time. We believe that substantial declines should be identifiable by evaluating the number of occurrences and their distribution through time. However, we don't rely solely on the occurrence data to identify potential trends, but instead use it in addition to scientific literature and reports to identify potential population declines. Evaluation of occurrences may also help to inform how prevalent the species is in a unit and provide for limited, relative comparisons between units. Uncertainty inherent with eDNA data such as that arising from false positives, false negatives, DNA contamination, and poor spatial or temporal resolution (Cristescu and Hebert 2018 pp. 216-224), limits our ability to assess range extent and geometry using eDNA data because this information does not necessarily allow for individual or multiple individuals of the frecklebelly madtom to be placed at a specific place and time. Furthermore, the eDNA data available to us provided no quantitative information. Therefore, we used eDNA to support the statement that the probability of the species being present in a particular river is greater than zero. To account for uncertainty inherent to eDNA data but present the information it provides, we use eDNA for defining resilience units and the current range of the species as discussed on page eight and do not use it for estimating resilience. Therefore, only occurrence data was used in our resilience estimates. In rivers where eDNA is the only evidence supporting occurrence, we report resilience as "unknown".

We use occurrence data to estimate range extent and range geometry. These metrics in particular can be useful for evaluating resiliency as larger areas of occupied habitat and multiple occupied streams (more complex ranges) would be robust to stochastic events (i.e., a single more localized event would be unlikely to negatively affect the entire population or unit if many and larger reaches of streams were occupied). Data was classified into time periods to assess time specific state of the knowledge of the species which helps to inform persistence through time. Data used in our resiliency assessment was acquired from the Georgia Department of Natural Resources

(GA DNR) Conservation Status Maps program. The Georgia DNR was able to compile a comprehensive database of frecklebelly madtom occurrences throughout its range for their Conservation Status Map of the species. These data were both thorough and easy to manipulate for our assessment. Because surveys for this species are currently ongoing, we subsequently added data provided to us by the Mississippi Museum of Natural Science and the Louisiana Department of Wildlife and Fisheries. Resiliency was assessed using occurrence data by tabulating the number of occurrences, the number of stream reaches (defined by USGS in the National Hydrology Dataset [NHD]) with occurrences, the length of discrete stream reaches with occurrences (termed: "Length of Discrete Stream Reaches), the length of the NHD HydroNet network between the upstream-most and downstream-most occurrences (termed: "Maximum Stream Length", and the number of named streams with occurrences. We classified occurrences into six time periods based on the date of observation (2009-2019, 1998-2008, 1997-1988, 1978-1987, 1968-1977, and 1950-1967). Our two length analyses, "Length of Discrete Stream Reaches" and "Max Stream Length" also estimated lengths when occurrence data from all time periods was combined to provide estimates of the maximum range of the frecklebelly madtom based on the available data.

For the "Length of Discrete Stream Reaches", we identified stream reaches with occurrences by buffering the NHDplus (medium resolution) dataset by 100 meters in ArcGIS and selected reaches that intersected occurrence point data. Sixty-three occurrence point data did not intersect with the buffered streams reaches. These occurrences were individually attributed to the nearest NHD stream reach in the GIS. Only two occurrences did not intersect a buffered stream reach and did not contain enough information to attribute to a nearby stream reach. The number and length of the identified stream reaches in each resiliency and representation unit were tabulated. Length measurements were rounded to the nearest multiple of ten, except where measurements were less than five, which were rounded to the nearest integer.

"Max Stream Length" was estimated by selecting all reaches between the upstream-most and downstream-most occurrence in the NHDPlus HydroNet (high resolution dataset) using Utility Network Analyst in ArcMap 10.6.1 within each resilience unit. This method ensures that all stream reaches that participate in the network between the two occurrence points are included in the measurement. Length measurements were rounded to the nearest multiple of ten, except where measurements were less than five, which were rounded to the nearest integer. Further, we estimated the total length within each representation unit by summing the measurements of its constituent resilience unit, except for total max stream length in the Pearl River and upper Tombigbee representative units. When we consider all occurrence data it appears that broad connectivity exists or once existed in these representative units. Therefore, the maximum inferred extent from the data is measured from upstream-most to downstream-most occurrence in the representative unit for the Pearl River and upper Tombigbee River units.

In addition to length tabulation, it is useful to consider both the number of total occurrences and the number of occupied stream reaches because these data can provide an estimate of how many times the species has been encountered and an approximation of the number of unique sites where it has been found. Further we consider the number of named streams with occurrences of the frecklebelly madtom to provide an estimate of range geometry. For this analysis we tabulated the number of named streams with occurrences of the frecklebelly madtom in each resilience unit. Representation unit totals are the sums of named streams with occurrences in the constituent resilience units.

Occurrence data for the frecklebelly madtom is only known from the Pearl River, upper Tombigbee River, Alabama River, Cahaba River, and upper Coosa River representation units. Therefore, we conducted our assessment of occurrences only on those units. Environmental DNA belonging to the frecklebelly madtom was collected in the Coosawattee River and portions of the Alabama River and Tombigbee River. Due to the lack of observations in these watersheds and a history of alteration from dams and channelization, we consider these units to potentially be extant, however, if the frecklebelly madtom persist, it is likely at extremely low numbers, and thus, extremely susceptible to extirpation. For the purposes of this SSA, we consider these units to have an unknown resiliency. Future work is needed to document the status of the frecklebelly madtom in these areas.

In order to better facilitate comparisons of current and future conditions, we categorized resiliency into 4 levels, as follows:

- High—population substantially contributes to overall species viability. Population occurrence data indicate a relatively high number of occurrences, number of occupied stream reaches and/or total length of occupied stream reaches is relatively high.
- Moderate—population contributes to overall species viability. Population occurrence data indicate persistence over time, though the total number of occurrences or occupied stream length may be low-moderate.
- Low—population is likely persisting, but does not contribute to overall species viability. Population occurrence data indicate substantial declines over time.
- Unknown—lack of direct observations; occurrence is only known from positive eDNA samples
- Likely extirpated—population is likely not persisting, and thus is not contributing to overall species viability. Population occurrence data suggests the species has been extirpated due to lack of recent detections and probable extirpation recognized in scientific literature.

5.4 Assessing Current Threats

As mentioned previously, water quality is an important component of frecklebelly madtom resilience because it affects how well they survive and reproduce. In the absence of site-specific water quality measurements taken at frecklebelly madtom locations within each unit, we used data available at the resiliency unit scale from the National Land Cover Database (NLCD) as a means to characterize nonpoint source pollution (i.e., development and agriculture). We believe that land use can be an indicator of overall watershed health and provide insight to water quality. Agricultural land use within riparian zones has been shown to directly impact biotic integrity when assessed within the intermediate-sized zones (i.e., 200 m buffer) surrounding the streams in the region (Diamond et al. 2002, p. 1150). Urbanization has also been shown to impair stream quality by impacting riparian health (Diamond et al. 2002, p. 1150). We assessed watershed health by combining several metrics within each frecklebelly madtom unit: percent urbanization and agriculture land use at the watershed level, as well as riparian effects, which included urbanization and agriculture within close proximity to the stream (200 meter buffer from the center of the waterbody). Many best management practices stipulate maintaining a natural buffer of 100m to protect water quality, thus the buffer chosen for our analysis captures the area adjacent to the stream that is believed to be most important to water quality (EPA 2005, p. 9). We discussed additional specific threats and there influence on the frecklebelly madtom during resilience and representation unit discussions, when known.

Watershed Health

Watershed health within units was calculated using urban and agricultural land use information. Land cover data was compiled from the 2016 National Land Cover Dataset Version 1, accessed via the Multi-Resolution Land Characteristics (MRLC) consortium online. Increased agricultural land use within a watershed has the potential to increase nutrient and other pollutant loading to stream systems. In addition to other impacts on aquatic habitat structure and quality, urban cover increases runoff volume into streams, likely increasing loads of sediments, nutrients, metals, pesticides, and other nonpoint source pollutants (CWP 2003, entire).

To establish current threat levels within a unit, we created thresholds of low, moderate, and high threats to frecklebelly madtoms. By creating current threat levels, we enable an assessment of the projected changes in the levels of these threats in future scenarios, as well as subsequent predictions about changes in resilience. The scaling of urban watershed impacts was derived from the Impervious Cover Model (ICM) and studies on amphibians and other taxa (Scheuler 1994, entire) which is widely used in planning and zoning. An updated model includes ranges of impervious cover likely impacting stream quality (Schuler et al. 2009, p. 313) and indicates good stream quality is <5-10% impervious cover, fair quality (i.e., impacted) ranges from 5-25% impervious cover, and poor quality occurs at >20-25% impervious cover within the watershed. Several other studies have found impacts of urbanization on biotic health occur at 8-12% impervious cover (Horner et al. 1997, entire; Wang et al. 2001 p. 259), although results from a recent study in the Etowah (Wegner et al. 2008, pp.1260-1261) indicate some species could become rare at impervious cover as low as 2%.

Riparian Health

Riparian impairment, either through urbanization or agriculture use, can amplify negative effects of nonpoint source pollution within the watershed as well as impact stream quality independent of land use within the watershed.

Impacts from impervious cover can be mitigated through riparian forest cover and good riparian health (Roy et al 2005, p. 2318; Walsh et al. 2007, entire); however, several studies have indicated benefit of the riparian cover diminishes when impervious cover (i.e. urban cover) exceeds ~10% within the watershed (Booth and Jackson 1997, p. 1084; Goetz *et al*. 2003, p. 205). Diamond et al. (2002, entire) assessed the relationship between human land uses (urban and agriculture) and fauna in the Clinch and Powell River watersheds. They found that when urban areas and major highways approached 12.2% cover within 200 m of the stream, the stream was more likely to be classified as impaired within the Clinch River, Powell River, and Copper Creek while unimpaired sections of those streams averaged 5.6% urban cover (Diamond et al. 2002, p. 1151). We calculated percent cover of urban land use within 200 m of each stream in each population and classified percentages to a low(<6%)-moderate(6-12%)-high(>12%) threat scale (Table 5.2).

Like the effects of urban use in riparian zones, agriculture impacts can directly decrease riparian vegetation cover and health. Agricultural practices within the riparian zones can further impact water quality and aquatic organisms via increased exposure to chemical fertilizers, pesticides, livestock waste, and sedimentation which has been implicated in amphibian malformation, susceptibility to disease, and declines in population numbers, reproductive success, and biodiversity (Beja and Alcazar 2003, entire; Montag *et al*. 2019, entire; Burkholder *et al*. 2007, pp. 309-310). There is little information regarding the threshold for agriculture land use within a riparian area that will begin to have an impact on stream quality. Therefore, we used the thresholds for urban land use to inform thresholds for agricultural land cover. However, because the relationship between area of agricultural land and water quality is less certain than the relationship between urban area and water quality, we reduced the number of classifications used to assess agricultural land use threats (Table 5.3). A threshold of 10%, rather than the 5% threshold used for urban development, to distinguish between and low and moderate levels of threats is reasonable because agrees with suggested values from the literature (i.e. 8-12% threshold; Horner et al. 1997, entire; Wang et al. 2001 p. 259; Schuler et al. 2009, p. 313), and agriculture is typically not associated with high amounts of impervious cover, thus percent agriculture of <10% is unlikely to significantly impact infiltration capacity, and thus water quality.

Table 5.2. Metrics used to categorize impacts of urbanization within units.

		% Urban in unit			
		0-5%	5-10%	10-20%	>20%
Urban Cover in Riparian Areas	Low (0-6%)	Low	Low	Moderate	High
	Moderate (6-12%)	Low	Moderate	Moderate	High
	High (>12%)	High	High	High	High

Table 5.3. Metrics used to categorize impacts of agriculture within units.

		% Agriculture in unit		
		0-10%	10-20%	>20%
Ag Cover in Riparian Areas	Low (0-10%)	Low	Moderate	High
	Moderate (10-20%)	Low	Moderate	High
	High (>20%)	High	High	High

Land Use Composite Score

In our analysis, overall watershed health within a population is considered to be influenced by a combination of direct impacts by urbanization and agriculture. To generate a single composite score for watershed health for each unit, all agriculture and urban composite water quality scores were combined. Classifications were averaged together for each composite watershed score as if low, moderate, and high threats were equal to values of 1, 2, and 3, respectively. If averaging the two factors resulted in a value ending in .5, the overall water quality score was rounded down (rather than typical mathematical convention of rounding up) to be conservative (i.e. to avoid over estimating threats derived from land use). Composite population land use scores were then categorized on a low (1)-moderate (2)-high (3) threat scale.

5.5 Current Resilience Results

Occurrence Assessment

Table 5.4 summarizes the number of occurrences of frecklebelly madtom over six time periods. The number of occurrences range-wide in the current decade is lower than some previous decades but not substantially. Indeed, the number of occurrences from 2009-2019 (242) is equivalent to the mean number of occurrences for the five previous time periods (241.8). Therefore, the number of current occurrences is comparable to the number of occurrences from historical periods (Table 5.4 and Figure 5.3). Our occurrence assessment does provide support to substantial declines or extirpation in some resiliency units (upper Tombigbee River [mainstem], Bull Mountain Creek, and Alabama River) as there are no occurrences in these units in the more recent time periods. It is important to realize that this metric does not account for different levels of sampling effort between time periods. Therefore, it is not entirely clear whether fluctuations in occurrence data represent population dynamics. When known, we identify large survey efforts that have been conducted within a resilience unit below.

Table 5.4. Number of occurrences of frecklebelly madtom range-wide, and for each resilience unit and representative unit (shaded grey) over six time periods: 1950-1967, 1968-1977, 1978-1987, 1988-1997, 1998-2008, and 2009-2019.

	Number of Occurrences (1950-1967)	**Number of Occurrences (1968-1977)**	**Number of Occurrences (1978-1987)**	**Number of Occurrences (1988-1997)**	**Number of Occurrences (1998-2008)**	**Number of Occurrences (2009-2019)**
Pearl River	148	117	51	73	15	99
Bogue Chitto	8	42	16	8	6	29
Pearl River Total	**156**	**159**	**67**	**81**	**21**	**128**
East Fork Tombigbee River	0	4	12	3	11	17
Upper Tombigbee River	17	77	47	0	1	0
Sipsey River	0	0	3	5	0	1
Luxapallila Creek	0	3	7	5	5	10
Buttahatchie River	0	2	15	32	12	40
Bull Mountain Creek	0	0	10	0	0	0
Upper Tombigbee Total	**17**	**86**	**94**	**45**	**29**	**68**
Alabama River	10	0	0	0	0	0
Alabama River Total	**10**	**0**	**0**	**0**	**0**	**0**
Cahaba River	10	2	27	77	22	10
Alabama River-Big Swamp Creek	1	0	0	0	0	0
Cahaba River Total	**11**	**2**	**27**	**77**	**22**	**10**
Conasauga River	0	3	4	12	9	0
Etowah River	0	0	31	79	167	36
Coosawattee River	0	0	0	0	0	**eDNA**
Upper Coosa River Total	**0**	**3**	**35**	**91**	**176**	**36**
Lower Tombigbee River	0	0	0	0	0	**eDNA**
Lower Alabama River	0	0	0	0	0	**eDNA**
Lower Tombigbee/Alabama River Total	**0**	**0**	**0**	**0**	**0**	**eDNA**
Range-wide Total	**194**	**250**	**223**	**294**	**248**	**242**

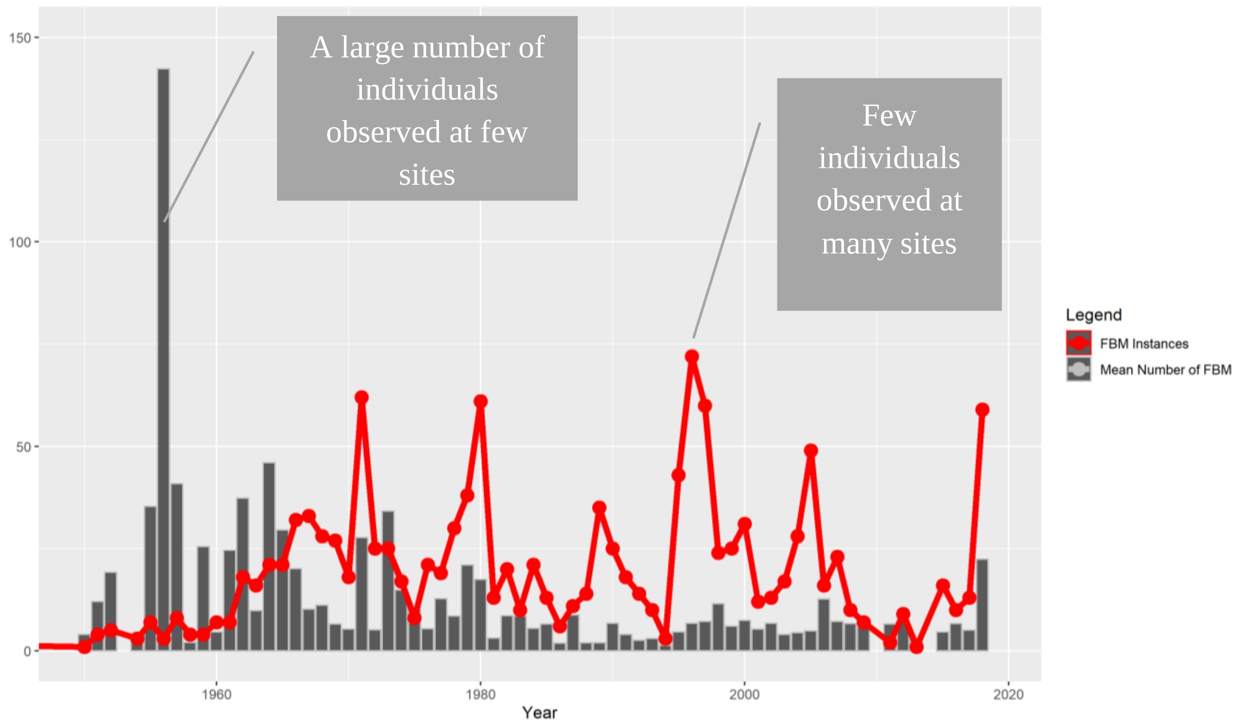


Figure 5.3. Total frecklebelly madtom occurrences by year (red) rangewide. Also shown are the mean number of frecklebelly madtoms observed per year (gray).

Stream Reach Assessment

An assessment of the number of occupied stream reaches over time revealed some interesting patterns (Table 5.5). Range-wide, the number of currently occupied stream reaches is greater than the previous time periods and it represents approximately 36% of the total number of reaches that have ever had occurrences. The Pearl River resilience unit appears to be a stronghold for the species as there are still 65 stream reaches occupied. Indeed, this unit has been considered a stronghold by other researchers (Wagner et al. 2018, p. 16; Albanese et al. 2018, p. 41). The number of occupied reaches in the Etowah River peaked between 1998-2008 but has since declined to levels more comparable to the time periods prior to 1998. The Cahaba River unit has shown a noticeable decrease in the number of occupied stream reaches. However, these reduction in the number of stream reaches may be related to sampling effort as this unit appears relatively stable and the species is considered fairly common here (Bennett et al. 2008, p.467). It is important to note that while the upper Tombigbee representation unit appears relatively stable, substantial declines have occurred in some of its constituent resilience units. The apparent overall stability is due to an increased knowledge of the species' distribution in tributaries of the upper Tombigbee River.

Table 5.5. Number of occupied stream reaches for frecklebelly madtom range-wide, and for each resilience unit and representative unit (shaded grey) over six time periods. Negative numbers reflect losses due to probable extirpation reported in literature.

	Number of Stream Reaches (1950-1967)	Number of Stream Reaches (1968-1977)	Number of Stream Reaches (1978-1987)	Number of Stream Reaches (1988-1997)	Number of Stream Reaches (1998-2008)	Number of Stream Reaches (2009-2019)	Total Number of Unique Stream Reaches
Pearl River	47	52	32	39	10	65	145
Bogue Chitto	8	27	14	2	7	32	53
Pearl River Total	**55**	**79**	**46**	**41**	**17**	**97**	**198**
East Fork Tombigbee River	0	4	14	7	10	22	36
Upper Tombigbee River	13	27	28	0	1	0	-56
Sipsey River	0	0	1	3	0	1	5
Luxapallila Creek	0	4	5	3	4	11	14
Buttahatchie River	0	4	15	13	19	37	60
Bull Mountain Creek	0	0	8	0	0	0	-8
Upper Tombigbee Total	**13**	**39**	**70**	**26**	**34**	**71**	**179 (-64)**
Alabama River	5	0	0	0	0	0	-5
Alabama River Total	**5**	**0**	**0**	**0**	**0**	**0**	**-5**
Cahaba River	6	2	28	72	3	7	84
Alabama River-Big Swamp Creek	1	0	0	0	0	0	-1
Cahaba River Total	**7**	**2**	**28**	**72**	**3**	**7**	**85 (-1)**
Conasauga River	0	2	5	5	9	0	16
Etowah River	0	0	21	32	50	24	65
Coosawattee River	0	0	0	0	0	**eDNA**	**eDNA**
Upper Coosa River Total	**0**	**2**	**26**	**37**	**59**	**24**	**81**
Lower Tombigbee River	0	0	0	0	0	**eDNA**	**eDNA**
Lower Alabama River	0	0	0	0	0	**eDNA**	**eDNA**
Lower Tombigbee/ Alabama River Total	**0**	**0**	**0**	**0**	**0**	**eDNA**	**eDNA**
Range-wide Total	**80**	**122**	**170**	**176**	**113**	**199**	**548 (-70)**

Discrete Stream Reach Length Assessment

Occupied discrete stream reach length was also assessed within each unit (Table 5.6). Similar patterns to the total number of occupied stream reaches can be seen in this analysis. Range-wide, the total length of stream reaches with occurrences is greater than it has ever been known and this represents approximately 42% of the total length of all stream reaches with occurrences. The Pearl River unit again appears to be the stronghold for the species, with approximately 240 total km of occupied stream in the most recent time period, which represents 24% of all reaches with known occurrences. Based on this analysis, reaches that are likely to be extirpated make up approximately 13% of all known reaches.

Maximum Stream Length Assessment

Similar to our analysis of discrete stream reaches, an analysis of maximum stream length (length of all reaches between the upstream-most and downstream-most occurrence) shows that the frecklebelly madtom is known to occur at a broader range extent in the current time period than in any previous time period and this represents approximately 70% of the entire possible range extent inferred from our data (Table 5.7). Streams believed to be extirpated represent approximately 15% of the entire inferred range. This analysis also indicates that the species continues to occur at the expected range extent in the Pearl River, Bogue Chitto River, Luxapallila Creek, Buttahatchie River, Cahaba River, and the Etowah River. The majority of lost habitat was in the upper Tombigbee representative units, with approximately 330 km habitat lost to the Tenn-Tom waterway. Additionally, of concern is the decline of potentially 150 km of habitat in the Conasauga River. Of note is the strikingly high estimate in the Pearl River and Bogue Chitto River. This is a result of the complex network of braided channels in the lower reaches of these two rivers. Since we do not have enough information to remove any of the braided channels from analysis all that are involved in the NHD network are included in our length tabulation.

Table 5.6. Length in kilometers of discrete stream reaches with occurrences for frecklebelly madtom range-wide, and for each resilience unit and representative unit (shaded grey) over six time periods. Negative numbers reflect losses due to probable extirpation reported in literature.

	Length of Discrete Stream Reaches (1950-1967)	**Length of Discrete Stream Reaches (1968-1977)**	**Length of Discrete Stream Reaches (1978-1987)**	**Length of Discrete Stream Reaches (1988-1997)**	**Length of Discrete Stream Reaches (1998-2008)**	**Length of Discrete Stream Reaches (2009-2019)**	**Total Length of Discrete Stream Reaches (All Records)**
Pearl River	140	90	50	90	40	180	340
Bogue Chitto	10	40	20	4.0	20	60	90
Pearl River Total	**150**	**130**	**80**	**90**	**60**	**240**	**430**
East Fork Tombigbee River	0	10	20	10	20	30	50
Upper Tombigbee River	20	60	50	0	6.4	0	-100
Sipsey River	0	0	2.4	10	0	3.5	10
Luxapallila Creek	0	10	20	10	10	30	30
Buttahatchie River	0	6.5	20	20	20	50	70
Bull Mountain Creek	0	0	10	0	0	0	-10
Upper Tombigbee Total	**20**	**80**	**110**	**40**	**50**	**100**	**260 (-110)**
Alabama River	30	0	0	0	0	0	-30
Alabama River Total	**30**	**0**	**0**	**0**	**0**	**0**	**-30**
Cahaba River	10	3.1	40	110	3.5	20	120
Alabama River-Big Swamp Creek	2.5	0	0	0	0	0	-2.5
Cahaba River Total	**10**	**3.1**	**40**	**110**	**3.5**	**20**	**120 (-2.5)**
Conasauga River	0	4.1	10	10	20	0	30
Etowah River	0	0	40	60	90	50	110
Coosawattee River	0	0	0	0	0	**eDNA**	**eDNA**
Upper Coosa River Total	**0**	**4.1**	**50**	**70**	**110**	**50**	**150**
Lower Tombigbee River	0	0	0	0	0	**eDNA**	**eDNA**
Lower Alabama River	0	0	0	0	0	**eDNA**	**eDNA**
Lower Tombigbee/Alabama River Total	**0**	**0**	**0**	**0**	**0**	**eDNA**	**eDNA**
Range-wide Total	**200**	**210**	**270**	**310**	**230**	**410**	**980 (-130)**

Table 5.7. Length in kilometers of all stream reaches between the upstream-most and downstream-most occurrence of the frecklebelly madtom range-wide, and for each resilience unit and representative unit (shaded grey) over six time periods. Negative numbers reflect losses due to probable extirpation reported in the literature.

	Max Stream Length (1950-1967)	**Max Stream Length (1968-1977)**	**Max Stream Length (1978-1987)**	**Max Stream Length (1988-1997)**	**Max Stream Length (1998-2008)**	**Max Stream Length (2009-2019)**	**Total Max Stream Length (All Records)**
Pearl River	950	910	880	940	560	970	1090
Bogue Chitto°	130	210	130	90	210	290	320
Pearl River Total	**1080**	**1140**	**1010**	**1030**	**770**	**1270**	**1310**
East Fork Tombigbee River	0	40	50	10	60	40	70
Upper Tombigbee River	180	270	150	0	4	0	-270
Sipsey River	0	0	2	20	0	2	90
Luxapallila Creek	0	10	30	20	20	30	40
Buttahatchie River	0	10	150	270	270	310	310
Bull Mountain Creek	0	0	60	0	0	0	-60
Upper Tombigbee Total	**180**	**330**	**450**	**330**	**350**	**380**	**890 (-330)**
Alabama River	70	0	0	0	0	0	-70
Alabama River Total	**70**	**0**	**0**	**0**	**0**	**0**	**-70**
Cahaba River	110	10*	80	120	110	120	130
Alabama River-Big Swamp Creek	2	0	0	0	0	0	-2
Cahaba River Total	**110**	**10***	**80**	**120**	**110**	**120**	**130 (-2)**
Conasauga River†	0	40	20	30	30	0	150
Etowah River	0	0	70	70	100	80	100
Coosawattee River	0	0	0	0	0	**eDNA**	**eDNA**
Upper Coosa River Total	**0**	**40**	**90**	**100**	**130**	**80**	**250**
Lower Tombigbee River	0	0	0	0	0	**eDNA**	**eDNA**
Lower Alabama River	0	0	0	0	0	**eDNA**	**eDNA**
Lower Tombigbee/ Alabama River Total	**0**	**0**	**0**	**0**	**0**	**eDNA**	**eDNA**
Range-wide Total	**1440**	**1520**	**1630**	**1580**	**1360**	**1850**	**2670 (-410)**

Occupied Streams Assessment

Assessing the number occupied streams within an analysis unit may also inform resilience, because a greater number of occupied streams, indicative of a population with a more complex range geometry, has been found to exhibit longer persistence times (i.e. reduced probability of extirpation) than more simple, linear geometries (Fagan 2002, p. 3244). Generally, it appears the number of occupied named streams has remained stable or increased through time (Table 5.8). There is variation between units in the number of occupied streams. The Pearl River unit by far has the greatest number of currently occupied streams (n=15), whereas no other unit has more than four. Based on our assessment, the number of occupied streams has declined in the upper Tombigbee River unit and its vulnerability to extirpation from stochastic events has increased. Although the rest of the units have very few occupied tributaries, it appears that the species never occupied many tributaries in the past based on the pre-1998 data. These results are expected due to this species' preference for larger river habitats.

Table 5.8. Number of occupied tributaries for frecklebelly madtom range-wide, and for each resilience unit and representative unit (shaded grey) over six time periods. Negative numbers reflect losses due to probable extirpation reported in literature.

	Number of Named Streams (1950-1967)	**Number of Named Streams (1968-1977)**	**Number of Named Streams (1978-1987)**	**Number of Named Streams (1988-1997)**	**Number of Named Streams (1998-2008)**	**Number of Named Streams (2009-2019)**	**Total Number of Named Streams (All records)**
Pearl River	12	6	4	10	6	15	20
Bogue Chitto	1	3	5	1	2	4	5
Pearl River Total	**13**	**9**	**9**	**11**	**8**	**19**	**25**
East Fork Tombigbee River	0	1	2	1	1	1	2
Upper Tombigbee River	1	1	1	0	1	0	-1
Sipsey River	0	0	1	1	0	1	1
Luxapallila Creek	0	1	2	1	1	2	2
Buttahatchie River	0	1	2	1	1	2	2
Bull Mountain Creek	0	0	1	0	0	0	-1
Upper Tombigbee Total	**1**	**4**	**9**	**4**	**4**	**7**	**9 (-2)**
Alabama River	1	0	0	0	0	0	-1
Alabama River Total	**1**	**0**	**0**	**0**	**0**	**0**	**-1**
Cahaba River	1	2	1	1	2	1	2
Alabama River-Big Swamp Creek	1	0	0	0	0	0	-1
Cahaba River Total	**2**	**2**	**1**	**1**	**2**	**1**	**3 (-1)**
Conasauga River	0	1	1	1	1	0	1
Etowah River	0	0	1	2	3	1	3
Coosawattee River	0	0	0	0	0	**eDNA**	**eDNA**
Upper Coosa River Total	**0**	**1**	**2**	**3**	**4**	**1**	**4**
Lower Tombigbee River	0	0	0	0	0	**eDNA**	**eDNA**
Lower Alabama River	0	0	0	0	0	**eDNA**	**eDNA**
Lower Tombigbee/ Alabama River Total	**0**	**0**	**0**	**0**	**0**	**eDNA**	**eDNA**
Range-wide Total	**17**	**16**	**21**	**19**	**18**	**28**	**42 (-4)**

Resilience Summary Results

Table 5.9 and Figure 5.4 show the results of the current resilience assessment. Across the range, resilience of units is as follows: three high resilience; five moderate resilience; one low resilience; three unknown resilience (i.e. based only off of eDNA); and four likely extirpated. The resilience of these units is based on assessment of the population factors discussed in the previous section. Below, we discuss the specific assessment of each unit independently.

Table 5.9. Current resilience for all analysis units for frecklebelly madtom. * refers to units that were assessed exclusively based on positive eDNA samples.

Representation Unit	Resiliency Unit	Resiliency Estimate
Pearl River	Pearl River	High
	Bogue Chitto	High
Upper Tombigbee	East Fork Tombigbee River	Moderate
	Upper Tombigbee River	Likely Extirpated (Millican et al. 2006, Shepard 2004, Bennett et al. 2008)
	Sipsey River	Moderate
	Luxapallila Creek	Moderate
	Buttahatchie River	High
	Bull Mountain Creek	Likely Extirpated (Shepard et al. 1997, Shepard 2004)
Alabama River	Alabama River	Likely Extirpated (Shepard et al. 1997, Bennet et al. 2008)
Cahaba River	Cahaba River	Moderate
	Alabama River-Big Swamp Creek	Likely Extirpated (Shepard et al. 1997, Bennet et al. 2008)
Upper Coosa River	Conasauga River	Low
	Etowah River	Moderate
	Coosawattee River	Unknown*
Lower Tombigbee/Alabama River	Lower Tombigbee River	Unknown*
	Lower Alabama River	Unknown*

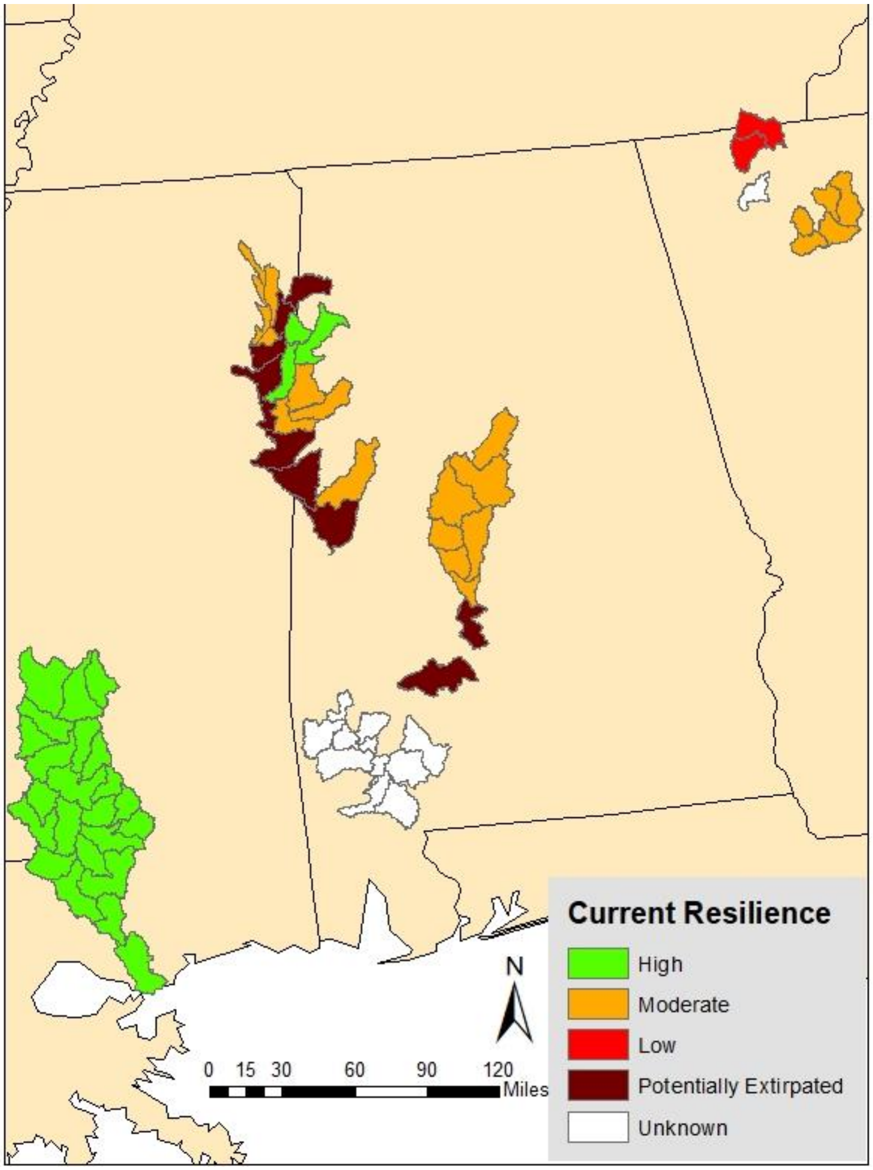


Figure 5.4. Current resiliency of frecklebelly madtom populations. Resiliency categories are: high (green), moderate (orange), red (low), maroon (likely extirpated), white (unknown).

5.5.1 Cahaba River

Two resiliency units are in the Cahaba River representation unit (Cahaba River and Alabama River-Big Swamp Creek). The metrics we tabulated to consider resiliency of the frecklebelly madtom suggest that the species may have declined from the 1988-1997 time period. However, two large survey efforts occurred in the Cahaba River in the 1988-1997 time period. One surveyed all fishes in the river (Pierson et al. 1989, entire) and the other targeted the frecklebelly madtom specifically (Shepard et al. 1997, entire). Therefore, we believe that the larger number of occurrences and stream reaches during this time period are due to a considerable amount of surveys for fish being undertaken.

This river system is believed to be a stronghold for the species (Neely 2018, p. 11) where it appears to be common (Bennet et al. 2008, p. 467). This combination of consistent collections at relatively high numbers but the relatively simple geometry of its occupied range (roughly confined to the main-stem of the Cahaba River) indicates this unit would be **moderately resilient** to stochastic events.

No collections have been made of this species in the Alabama River-Big Swamp Creek unit since the late 1960's and after the construction of Miller's Lock and Ferry and Claiborne Dam. Previous researchers have considered the species to have become extirpated in the Alabama River-Big Swamp Creek resiliency unit (Shepard et al 1997 p. 18; Bennett et al 2008 p. 467). It is believed that construction of dams and associated dredging eliminated habitat for the frecklebelly madtom in this portion of the Alabama River. We accept the interpretations of previous researchers and consider the frecklebelly madtom to be **<u>extirpated</u>** from the Alabama River-Big Swamp Creek resiliency unit. However, recent research has found environmental DNA in portions of the Alabama River downstream of the reaches of the Alabama River with known historical occurrences. Therefore we recommend future researchers to survey this unit to confirm the status of the frecklebelly madtom throughout the Alabama River. Until additional work can confirm the status of populations in this unit, we don't believe that it meaningfully contributes to the viability of the species range-wide.

5.5.2 Upper Coosa River

Three resiliency units occur in the upper Coosa River representation unit (Conasauga River, Etowah River, and Coosawattee River).

The number of occurrences, occupied reaches, and occupied reach length has declined drastically in the Conasauga River. Additionally, no tributaries are known to support this species. This drastic decline has been noted since the late 1990s (Shepard et al. 1997, p. 22) and supported by current occupancy modelling effort (Freeman et al. 2017, p. 424). Despite targeted effort to locate this species, it has not been observed in the Conasauga River since 2000 (Freeman et al. 2005 p.; Bennett et al. 2008 p. 466). Because recent surveys have found environmental DNA of the frecklebelly madtom in this unit, it is believed to be persisting but demonstrating **low resiliency** to stochastic events and in need of management to prevent extirpation.

The number of occurrences of frecklebelly madtom appears to have declined in the Etowah River from the 1998-2008 time period as has the number of occupied stream reaches and their total length. However, similar to the Cahaba River in the 1988-1997 time period, a species specific survey effort was progress during 1998-2008 time period in the upper Coosa River watershed (Freeman et al. 2003, entire). Therefore, while there are fewer occurrences of the frecklebelly madtom in the current time period, we cannot conclude that this represents a decline in the species in the Etowah River. Instead, we believe populations in the Etowah River have remained stable for the period of record as the patterns of occurrences in the most recent time period is similar to the time periods prior to 1998. This conclusion is supported by recent work that quantified occupancy of frecklebelly madtom and found it to be relatively consistent in the Etowah River (Freeman et al. 2017, p. 428). Similar to the Cahaba River, the frecklebelly madtom is largely confined to the main stem of the Etowah River. However, some of the highest quality habitat for the frecklebelly madtom in this river can be found flowing through the Dawson Forest Wildlife Management Area (Shepard et al. 1997, p. 21), a state managed property. Approximately 19 km of the Etowah River flows through or is adjacent (at least one river bank) to property owned by the GADNR, which represents approximately 19% of the maximum known range extent of the frecklebelly madtom in the Etowah River. Therefore, this river system is believed to currently be afforded some protection from encroaching developments. Due to the apparent stability of the range extent in this unit but historically low abundances (Bennet et al. 2008, p. 465), its relatively simple range geometry, and exposure to threats from development, the Etowah River appears to be **moderately resilient** to stochastic events.

No occurrence data is available for the Coosawattee River unit. However, environmental DNA for the frecklebelly madtom was found in portions of it. In the Coosawattee River, there were 5 positive environmental DNA assays, and occupancy probability was estimated as 0.49-0.99 (Figure 5.9; Freeman and Bumpers 2018, p. 9). Due to the lack of observations in this watershed and a history of alteration from dams and channelization, we consider it to have an **unknown resiliency**. Until additional work can confirm the status of populations in this resilience unit we don't believe that the Coosawattee River unit meaningfully contributes to the resiliency of the upper Coosa River unit nor the species range-wide.

5.5.3 Pearl River

The overall number of occurrences in this unit has fluctuated through time and the number of occurrences in the most recent time period is less than the number of occurrence for the two earliest time periods. However, the number of occurrences recorded in the 2009-2019 time period is greater than the mean number of occurrences for the five earlier time periods. Additionally, the overall number of occupied stream reaches and the stream reach length appears to have increased through time, with approximately 184 km of stream reaches occupied by the species in the years 2009-2018. While we don't consider this apparent increase to reflect a range increase or expansion (it is more likely related to increased survey efforts), we consider this as evidence of stable populations of frecklebelly madtom occurring in this river system. This is further supported by surveys conducted by the Mississippi Museum of Natural Science that observed the frecklebelly madtom at 83% of known historical collection sites. Due to the apparent stability of the frecklebelly madtom in this unit and its more complex geometry (15 occupied named streams), the Pearl River unit of frecklebelly madtom is expected to have a **high resilience** to stochastic events.

The Bogue Chitto River mirrors the Pearl River and it appears to be a stronghold for the species. Therefore, it appears to have a **high resilience** to stochastic events and substantially contributes to the overall resiliency of the Pearl River representative unit.

5.5.4 Alabama River

There are no occurrences of this species in the Alabama River representation unit since the late 1960's and after the construction of Miller's Lock and Ferry and Claiborne Dam, nor are there records of positive eDNA in this unit. It is believed that these major construction projects and associated dredging eliminated habitat for the frecklebelly madtom. We accept the interpretations of previous researchers and consider the frecklebelly madtom to be <u>**extirpated**</u> from the Alabama River resiliency/representation unit. However, we recommend future researchers survey this unit to confirm the status of the frecklebelly madtom throughout the Alabama River. Until additional work can confirm the status of populations in this unit, we don't believe that it meaningfully contributes to the viability of the species range-wide.

5.5.5 Upper Tombigbee River

We considered six resiliency units to constitute the upper Tombigbee River representation unit. They are the upper Tombigbee River (mainstem), East Fork of the Tombigbee River, Bull Mountain Creek, Sipsey River, Luxapallila Creek, and the Buttahatchee River.

Historically, the main-stem of the upper Tombigbee River (mainstem) supported the frecklebelly in high numbers with 2305 individuals being observed at 35 sites as assessed by Bennet and others (2008, p. 466). Our analysis of occurrences supports this trend with 141 occurrences of the frecklebelly madtom being recorded in the upper Tombigbee River (mainstem) in the three earliest time periods assessed. Observations of the species abruptly ends in the upper Tombigbee River (mainstem) resiliency unit after 1978-1987 time period, with only one individual being observed in the upper Tombigbee River (mainstem) unit after the 1978-1987 time period at the Hwy 17 crossing in 1999. This coincides with the construction of the Tennessee-Tombigbee Waterway, a canal system that connects the Tombigbee River to the Tennessee River for commercial navigation. The habitat lost from this major engineering activity is believed to have caused the **extirpation** of the frecklebelly madtom in the upper Tombigbee River (Millican et al. 2006 p. 84; Shepard 2004, p. 221; Bennett et al. 2008, p. 467).

Our analyses of occurrences found more occurrences of frecklebelly madtom in the East Fork during the most recent time period (2009-2019) than in any of the previous five time periods. Furthermore, some of these occurrences represented collections of over 100 individuals of the frecklebelly madtom. Therefore, the species appears to be thriving in the East Fork of the Tombigbee River. However, like other portions of the Tombigbee River, the East Fork has been drastically altered by the Tenn-Tom Waterway, with numerous structures installed to maintain minimum flows that disconnected historical fish dispersal routes and alter natural water parameters (Millican et al. 2006, p. 3-4). Due to the loss of habitat and connectivity in the East Fork, but the fact that the species continues to persist at a relatively high numbers, we consider the East Fork of the Tombigbee to have a **moderate resilience** to stochastic events.

Of the six time periods we assessed, the frecklebelly madtom was only recorded from Bull Mountain Creek in one time period (1978-1987). Several researchers have surveyed for the species in this stream since that time period (Shepard 1997, p. 9; Millican 2006, p. 3; and Wagner *in litt*) and have failed to locate the species. Interestingly, the stream is considered to have habitat suitable for the frecklebelly madtom (Shepard 1997, p. 17). However, Bull Mountain Creek has been drastically altered by the construction of the Tenn-Tom Waterway and is currently bisected by the canal system (Millican et al. 2006, p. 3). Because observations of the species end during the time period of major habitat alteration from the Tenn-Tom waterway and numerous researchers have been unable to locate the species in Bull Mountain Creek, we agree with previous authors (Shepard 2004, p. 221) that indicate the species is likely **extirpated** from Bull Mountain Creek.

Nine occurrence records exist for the Sipsey River across the time periods we assessed with no occurrence representing more than nine individuals. The occurrences are spread across five stream reaches that total 10 km. The maximum known range extent between the upstream-most and downstream-most occurrence is 90 km. However, documentation of the species in this unit is sparse and the species is generally only documented at a few sites per decade. Researchers have indicated that habitat is excellent in this river and the populations appear stable with few threats (Shepard et al. 1997, p. 9 and 23). The few records of the species in this river have been attributed to difficult sampling conditions (Shepard et al. 1997, p. 9; Neely 2018, p. 11). Because researchers consider this river to support the frecklebelly madtom, albeit with a patchy distribution (Neely 2018, p. 11), and be exposed to few threats, we consider the Sipsey River to have a **moderate** resiliency to stochastic events.

More occurrences of the frecklebelly madtom have been recorded in the most recent time period than in any of the previous time periods analyzed in Luxapallila Creek. Furthermore, these occurrences are spread across more stream reaches than previously known. Some occurrences from 2019 represent collections of almost 100 individuals of the frecklebelly madtom. While past researchers have indicated habitat loss and potential population declines (Shepard et al. 1997, p. 13), we believe that surveys conducted in 2019 indicate that stable populations are persisting in Luxapallia Creek. However, due to channelization being identified as a potential cause of declines in earlier decades (Shepard et al. 1997, p. 23), we believe this resiliency unit has a **moderate** resiliency to stochastic events.

The Buttahatchee River has been identified as a stronghold of the species where it can consistently be collected in abundance (Shepard et al. 1997, p. 23, Bennett et al. 2008, p. 470). This is supported by our analysis of occurrence data that found 40 occurrences in the most recent time period in the Buttahatchee River, second only to the Pearl River. Furthermore, these occurrences are from numerous stream reaches that indicate the species is widely distributed in this river and in several of its tributaries. Therefore, we consider the Buttahatchee River to have a **high** resilience to stochastic events.

5.5.6 Lower Tombigbee/Alabama River

No occurrence data is available for either the lower Tombigbee or the lower Alabama River unit. However, environmental DNA for the frecklebelly madtom was found in portions of both resiliency units. In the Lower Tombigbee/Alabama River unit, 36 sites were sampled for eDNA, and 11 of those samples were positive for frecklebelly madtom DNA (Figure 5.5 and 5.6; Janosik and Whittaker 2018, p. 7). Due to the lack of observations in these watersheds and a history of alteration from dams and channelization, we consider the Lower Tombigbee and Alabama rivers to have an **unknown resiliency**. Until additional work can confirm the status of populations in these units, we don't believe that these resiliency units or the representation unit itself meaningfully contributes to the viability of the species range-wide.

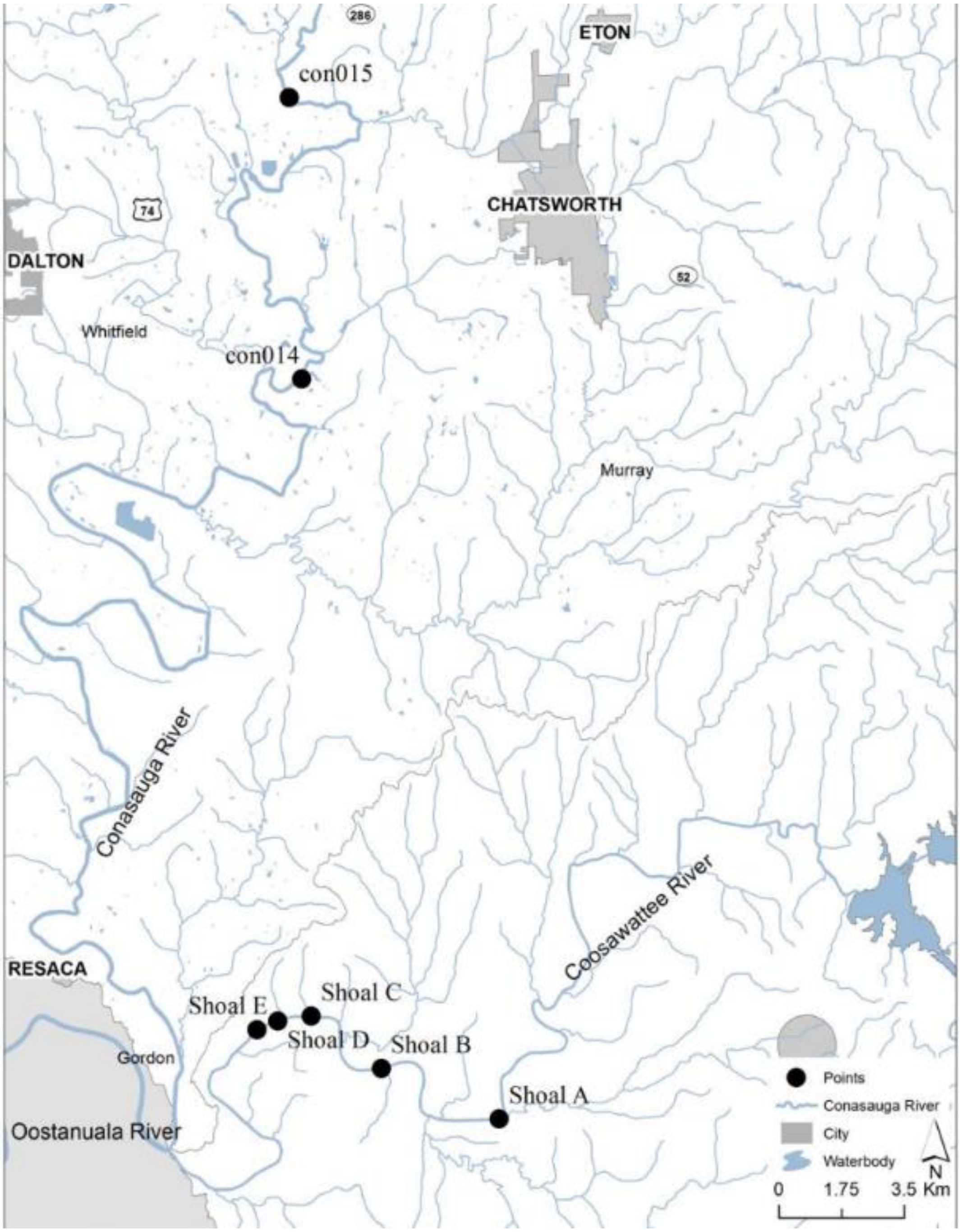


Figure 5.5 *From Freeman and Bumpers 2018, p. 12.* Map of the Conasauga and Coosawattee Rivers with sites sampled for eDNA. All 5 sites in the Coosawattee River contained water samples positive for frecklebelly madtom eDNA.

Figure 5.6. *From Janosik and Whittaker 2018, p. 7.* Map of collection sites and positive eDNA for frecklebelly madtom. Circles indicate sampling sites (n=36). White circles indicate positive eDNA water samples (n=11). Black circles indicate negative eDNA water samples (n=25).

5.6 Current Land Use Assessment

In this section, we describe the results of our assessment of the current threat levels from land use; specifically in regards to development and agriculture. We used the methods and thresholds described in section 5.4. Assessing current threat levels allows us to establish a baseline for an assessment of future conditions by projecting land use into the future under several scenarios. Below, we report the results of the current threat assessment for each of the units.

5.6.1 Cahaba River

The Cahaba River representation unit is composed of two resiliency units: Alabama River-Big Swamp Creek and the Cahaba unit. Frecklebelly madtom is likely extirpated in the Alabama River-Big Swamp Creek resiliency unit due to loss of habitat due to construction of dams and associated dredging. In the Cahaba River, frecklebelly madtom abundance seems to have remained stable throughout the modification periods in surrounding drainages, with the species being common and abundant below the Fall Line. However, channel geomorphology and substrate in the Cahaba River is likely being affected by head cutting due to impoundment of the Alabama River, similar to changes occurring in the upper Tombigbee River (Bennett et al. 2008, p. 468).

Alabama River-Big Swamp Creek

Current resilience was assessed as **Likely Extirpated** for the Alabama River-Big Swamp Creek unit population, whereas overall land use was assessed as **good** (i.e. low threat levels; Table 5.12). Development and agriculture land use are currently relatively low within the Alabama River-Big Swamp Creek unit, although agriculture across the unit is moderate (Tables 5.10 and 5.11).

Table 5.10. Summary of current development across the Alabama River-Big Swamp Creek unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
65301.01	1783.93	2.73%	136.21	1.44%

Table 5.11. Summary of current agriculture across the Alabama River-Big Swamp Creek unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
65301.01	8622.99	13.20%	538.76	5.71%

Table 5.12. Composite land use score for the Alabama River-Big Swamp Creek unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Fair	Good

Cahaba River

Current resilience was assessed as **moderate** for the Cahaba River population, whereas overall land use was assessed as **good** (i.e. low threat levels; Table 5.15). Development and agriculture land use are currently relatively low within the Cahaba unit, although development across the unit is moderate, and agriculture within riparian areas is moderate as well (Tables 5.13 and 5.14).

Table 5.13. Summary of current development across the Cahaba River unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
903991.79	83173.00	9.20%	10916.15	2.84%

Table 5.14. Summary of current agriculture across the Cahaba River unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
903991.79	76872.15	8.50%	41023.2	10.67%

Table 5.15. Composite land use score for the Cahaba River unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Good	Good

5.6.2 Upper Coosa River Units

The Upper Coosa River representative unit is composed of three resiliency units: Coosawattee, Conasauga, and Etowah units. Current presence of frecklebelly madtom in the Coosawattee and Conasauga units are inferred based on recent positive eDNA samples. The Etowah unit appears relatively stable over time, however, exposure to development could represent a significant threat to the species in this unit.

Coosawattee River

Although frecklebelly madtom have not been observed in the Coosawattee River unit, recent positive eDNA samples suggest the species may be present. Thus, current resilience was assessed as **unknown.** Overall land use within the unit was assessed as **fair** (i.e. moderate threat levels; Table 5.18). Agricultural land use is very high across the unit and within riparian areas, which is driving the threat level (Table 5.17). Developed land was assessed as moderate (Table 5.16). Further sampling is warranted in this unit to confirm presence of the species, however high levels of agricultural land use could be a significant threat to this resilience unit.

Table 5.16. Summary of current development across the Coosawattee River unit and within riparian areas.

Total Acres	**Current Acres Developed**	**% Developed Current**	**Current Acres Developed Riparian**	**% Developed Riparian**
50186.24	3311.89	6.60%	504.67	5.06%

Table 5.17. Summary of current agriculture across the Coosawattee River unit and within riparian areas.

Total Acres	**Current Acres Agriculture**	**% Agriculture Current**	**Current Acres Agriculture Riparian**	**% Agriculture Riparian**
50186.24	13663.45	27.23%	2671.06	26.80%

Table 5.18. Current resilience for the Coosawattee River unit based on composite land use score.

Developed	**Agriculture**	**Overall**
Fair	Poor	Fair

Conasauga River

Current resilience was assessed as **low** for the Conasauga River population, and overall land use was assessed as **fair** (i.e. moderate threat levels; Table 5.21). Development land use across the Conasauga River unit and within riparian areas was assessed as moderate (Table 5.19). Agricultural land use is driving the classification, as it is currently high across the unit and within riparian areas (Table 5.20). As discussed previously in Chapter 4, agricultural practices such as use of herbicides have corresponded with marked declines in populations of fish, and researchers have postulated that declines seen in the Conasauga unit may be at least partially due excess nutrients and herbicide surfactants associated with agricultural practices (Freeman et al. 2017).

Table 5.19. Summary of current development across the Conasauga River unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
207876.34	16688.60	8.03%	2297.71	5.64%

Table 5.20. Summary of current agriculture across the Conasauga River unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
207876.34	44275.52	21.30%	8287.14	20.36%

Table 5.21. Composite land use score for the Conasauga River unit based on development and agriculture levels.

Developed	Agriculture	Overall
Fair	Poor	Fair

Etowah River

Current resilience was assessed as **moderate** for the Etowah River population, and overall land use was assessed as **fair** (i.e. moderate threat levels; Table 5.24). Developed land use across the Etowah River unit and within riparian areas was assessed as moderate (Table 5.22). Agricultural land use across the unit was assessed as moderate, whereas agricultural land use within riparian areas was assessed as good (Table 5.23). Any future increases in development within the Etowah could represent a significant threat to frecklebelly madtom.

Table 5.22. Summary of current development across the Etowah River unit and within riparian areas.

Total Acres	**Current Acres Developed**	**% Developed Current**	**Current Acres Developed Riparian**	**% Developed Riparian**
288457.16	42785.46	14.83%	4800.3	8.29%

Table 5.23. Summary of current agriculture across the Etowah River unit and within riparian areas.

Total Acres	**Current Acres Agriculture**	**% Agriculture Current**	**Current Acres Agriculture Riparian**	**% Agriculture Riparian**
288457.16	30097.27	10.43%	4801.5	8.29%

Table 5.24. Composite land use score for the Etowah River unit based on development and agriculture levels.

Developed	**Agriculture**	**Overall**
Fair	Fair	Fair

5.6.3 Pearl River Units

The Pearl River representative unit is composed of two resiliency units: Bogue Chitto and Pearl River units. The Pearl River is a stronghold for the frecklebelly madtom, as current resilience for both resiliency units was assessed as **high**. Frecklebelly madtom within both units have shown stability through time, and occupy many stream reaches throughout the units as described in the resiliency results section previously.

Bogue Chitto

Current resilience was assessed as **high** for the Bogue Chitto population, and overall land use was assessed as **fair** (i.e. moderate threat levels; Table 5.27). Development land use across the Bogue Chitto unit was assessed as moderate, whereas development within riparian areas was assessed as good (Table 5.25). Agricultural land use is driving the classification, as it is currently high across the unit and moderate within riparian areas (Table 5.26).

Table 5.25. Summary of current development across the Bogue Chitto unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
563549.04	34243.79	6.08%	4376.95	3.52%

Table 5.26. Summary of current agriculture across the Bogue Chitto unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
563549.04	117568.01	20.86%	15131	12.17%

Table 5.27. Composite land use score for the Bogue Chitto unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Poor	Fair

Pearl River

Current resilience was assessed as **high** for the Pearl River population, and overall land use was assessed as **good** (i.e. low threat levels; Table 5.30). Development land use across the Pearl River unit was assessed as moderate, whereas development within riparian areas was assessed as good (Table 5.28). Agricultural land use across the unit was assessed as moderate, whereas agriculture land use within riparian areas was assessed as good (Table 5.29).

Table 5.28. Summary of current development across the Pearl unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
1851156.12	117019.22	6.32%	12692.70	3.29%

Table 5.29. Summary of current agriculture across the Pearl unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
1851156.12	265091.20	14.32%	33205	8.60%

Table 5.30. Composite land use score for the Pearl unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Fair	Good

5.6.4 Alabama River

Current resilience was assessed as **likely extirpated** for the Alabama River population given no recent observations. Overall land use was assessed as **good** (i.e. low threat levels; Table 5.33). Development and agricultural land use levels are very low both across the unit and within riparian areas (Tables 5.31 and 5.32). Although land use as measured by percent development and agriculture is likely not contributing to any declines within this unit, it is believed that the construction of several dams and the associated dredging from these projects may have eliminated habitat and led to precipitous declines (Shepard et al. 1997, p. 18,). Recent positive eDNA samples from reaches of the Alabama River downstream of this unit warrant further sampling to see if frecklebelly madtom still persist in this unit.

Table 5.31. Summary of current development across the Alabama River unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
962233.19	4135.17	0.43%	474.41	1.26%

Table 5.32. Summary of current agriculture across the Alabama River unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
962233.19	39020.76	4.06%	930.2	2.48%

Table 5.33. Composite land use score for the Alabama River unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Good	Good

5.6.5 Upper Tombigbee River Units

The Upper Tombigbee River representative unit is composed of six resiliency units: Bull Mountain Creek, Buttahatchee River, East Fork Tombigbee River, Luxapallila Creek, Sipsey River, and Upper Tombigbee River units. Construction of the Tennessee-Tombigbee Waterway, which artificially connects the Tennessee River to the Gulf of Mexico through the Tombigbee River with 10 lock and dam structures, began in 1972 and has greatly affected the ecology of the river system, and has likely led to extirpation of frecklebelly madtom in the mainstem of the river. It is important to note that although substantial declines of the frecklebelly madtom have occurred in this representative unit since the 1980s, it can be abundant in the constituent resiliency units where it remains present.

Bull Mountain

Current resilience was assessed as **likely extirpated** for the Bull Mountain population, and overall land use was assessed as **good** (i.e. low threat levels; Table 5.36). Development land use across the Bull Mountain unit and within riparian areas was assessed as good (Table 5.34). Agricultural land use across the unit and within riparian areas was assessed as fair (Table 5.35).

Table 5.34. Summary of current development across the Bull Mountain unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
126001.89	5667.90	4.50%	830.45	3.41%

Table 5.35. Summary of current agriculture across the Bull Mountain unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
126001.89	13390.25	10.63%	2542	10.45%

Table 5.36. Composite land use score for the Bull Mountain unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Fair	Good

Buttahatchee

Current resilience was assessed as **high** for the Buttahatchee population, and overall land use was assessed as **good** (i.e. low threat levels; Table 5.39). Development land use across the Buttahatchee unit and within riparian areas was assessed as good (Table 5.37). Agricultural land use across the unit and within riparian areas was assessed as fair (Table 5.38).

Table 5.37. Summary of current development across the Buttahatchee unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
223152.35	12460.79	5.58%	1662.44	3.66%

Table 5.38. Summary of current agriculture across the Buttahatchee unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
223152.35	27033.27	12.11%	5373	11.83%

Table 5.39. Composite land use score for the Buttahatchee unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Fair	Good

East Fork Tombigbee

Current resilience was assessed as **moderate** for the East Fork Tombigbee population, and overall land use was assessed as **good** (i.e. low threat levels; Table 5.42). Development land use across the East Fork Tombigbee unit and within riparian areas was assessed as good (Table 5.40). Agricultural land use across the unit and within riparian areas was assessed as fair (Table 5.41).

Table 5.40. Summary of current development across the East Fork Tombigbee unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
139944.14	10584.78	7.56%	1342.19	4.18%

Table 5.41. Summary of current agriculture across the East Fork Tombigbee unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
139944.14	23629.87	16.89%	5023	15.63%

Table 5.42. Composite land use score for the East Fork Tombigbee unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Fair	Good

Luxapallila

Current resilience was assessed as **moderate** for the Luxapallila population, and overall land use was assessed as **good** (i.e. low threat levels; Table 5.45). Development land use across the Luxapallila unit and within riparian areas was assessed as good (Table 5.43). Agricultural land use across the unit and within riparian areas was assessed as fair (Table 5.44).

Table 5.43. Summary of current development across the Luxapallila unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
283948.88	21025.95	7.40%	2643.28	4.28%

Table 5.44. Summary of current agriculture across the Luxapallila unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
283948.88	40005.08	14.09%	6882	11.15%

Table 5.45. Composite land use score for the Luxapallila unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Fair	Good

Sipsey

Current resilience was assessed as **moderate** for the Sipsey population, and overall land use was assessed as **good** (i.e. low threat levels; Table 5.48). Development and agricultural land use across the Sipsey unit and within riparian areas was assessed as good (Table 5.46 and 5.47).

Table 5.46. Summary of current development across the Sipsey unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
180580.41	4321.59	2.39%	470.93	1.25%

Table 5.47. Summary of current agriculture across the Sipsey unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
180580.41	12718.38	7.04%	1820	4.84%

Table 5.48. Composite land use score for the Sipsey unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Good	Good

Upper Tombigbee

Current resilience was assessed as **likely extirpated** for the Upper Tombigbee population, and overall land use was assessed as **fair** (i.e. moderate threat levels; Table 5.51). Development land use across the Upper Tombigbee unit and within riparian areas was assessed as good (Table 5.49). Agricultural land use is driving the classification, as it is currently high across the unit and moderate within riparian areas (Table 5.50).

Table 5.49. Summary of current development across the Upper Tombigbee unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
615908.21	32335.75	5.25%	3966.86	3.28%

Table 5.50. Summary of current agriculture across the Upper Tombigbee unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
615908.21	145218.91	23.58%	19382	16.04%

Table 5.51. Composite land use score for the Upper Tombigbee unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Poor	Fair

5.6.6 Lower Tombigbee-Alabama River Units

This representative unit is composed of two resiliency units: lower Tombigbee and the lower Alabama units. Frecklebelly madtom have not been directly observed in either resiliency unit, however recent positive eDNA samples suggest the species may be present. Development and agricultural land use is extremely low in this representative unit, where most land use is forest and/or open space. Similar to the Alabama River unit, in stream habitat alteration may be a more prominent threat to the frecklebelly madtom in this unit. Further sampling is warranted in this unit to confirm presence of the species.

Lower Tombigbee

Current resilience for the Lower Tombigbee population was assessed as **unknown,** and overall land use was assessed as good (i.e. low threat levels; Table 5.54). Development land use is low in this unit, and was assessed as good both across the unit and within riparian areas (Tables 5.52). Agricultural land use across the unit was assessed as fair, whereas agricultural land use within riparian areas was assessed as good (Table 5.53).

Table 5.52. Summary of current development across the Lower Tombigbee unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
115440.79	16568.17	2.66%	1344.18	1.13%

Table 5.53. Summary of current agriculture across the Lower Tombigbee unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
115440.79	17683.48	15.32%	1157	0.97%

Table 5.54. Composite land use score for the Lower Tombigbee unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Fair	Good

Lower Alabama River

Current resilience for the Lower Alabama population was assessed as **unknown,** and overall land use was assessed as good (i.e. low threat level; Table 5.57). Development land use is extremely low in this unit, and was assessed as good both across the unit and within riparian areas (Table 5.55). Agricultural land use across the unit and within riparian areas is also very low, and was assessed as good (Table 5.56).

Table 5.55. Summary of current development across the Lower Alabama River unit and within riparian areas.

Total Acres	Current Acres Developed	% Developed Current	Current Acres Developed Riparian	% Developed Riparian
216604.14	4987.66	2.30%	502.65	0.69%

Table 5.56. Summary of current agriculture across the Lower Alabama River unit and within riparian areas.

Total Acres	Current Acres Agriculture	% Agriculture Current	Current Acres Agriculture Riparian	% Agriculture Riparian
216604.14	16091.30	7.43%	600	0.82%

Table 5.57. Composite land use score for the Lower Alabama River unit based on development and agriculture levels.

Developed	Agriculture	Overall
Good	Good	Good

5.7 Current Redundancy and Representation

Redundancy refers to the ability of a species to withstand catastrophic events and is measured by the amount and distribution of resilient populations across the species range. Catastrophic events that could severely affect or extirpate entire frecklebelly madtom units include chemical spills, changes in upstream land use that alters stream characteristics and water quality downstream, new impoundments, and potential effects of climate change such as drought and increases in occurrence of flash flooding events. Because extant units of frecklebelly madtom are distributed relatively widely, and several of those units are classified as moderate or better resilience, it is highly unlikely that a catastrophic event would impact the entire species' range. Because of this, frecklebelly madtom exhibits a moderate-high degree of redundancy, and that level of redundancy has stayed relatively stable over time.

Because of the disjunct nature of the species range, there is a potential that representation has been reduced from historical levels. However, occurrences of the species show that it remains extant in four of the six delineated representation units. While the resilience of the Lower Tombigbee/Alabama River are not known, because only positive eDNA records were available to support presence in these representative units, we don't believe that these representative units meaningfully contribute to representation of the species. The upper Coosa River unit continues to be represented predominately by populations of the frecklebelly madtom in the Etowah River. The Coosawattee River and the Conasauga River units were assessed as having unknown and low resilience, respectively. The frecklebelly madtom has not been observed in Conasauga River since 2000 and declined precipitously along with other fish species in that river during the late 1990s and the Coosawattee River is only known from eDNA samples. Thus, although these units are represented, they are vulnerable to extirpation. It is believed that the Conasauga River is in need of dedicated conservation action and management to protect the frecklebelly madtom population in this unit and further work is necessary to determine the status of the species in both the Conasauga and Coosawattee River. The Cahaba and Upper Tombigbee units are classified as moderate resilience, and are currently contributing to representation of the species. The stronghold of the species seems to be in the Pearl River where the unit is assessed as having high resilience, and occupies over 128 stream km, including over known tributaries.

CHAPTER 6 – FUTURE CONDITION

To assess future condition of frecklebelly madtom units, we projected the primary current threat factors (agriculture and developed land use) into the future under three different scenarios. Other threats such as construction of dams and impoundments, channelization, and novel industry or resumption of historical industries (pulp mills), or modification of management such as water control manual were not included in our future conditions assessment due to the high amount of uncertainty regarding their implementation across the landscape. The three scenarios (low development, moderate development, and high development) capture the range of uncertainty in the changing human population footprint on the landscape, and how the frecklebelly madtom populations will respond to these changing conditions.

All three scenarios were projected out to the year 2050 (i.e. 30 years). This time frame was based on input from species experts, and the fact that beyond 30 years, the ability to predict patterns of urbanization and agriculture, and how these land uses will interact with the frecklebelly madtom and its habitat diminishes. It should be noted that frecklebelly madtom are relatively short-lived species and several of the current units are small and restricted on the landscape. Therefore, catastrophic events (e.g., invasive species, disease, chemical spill) could have an immediate impact on the species, especially on the units with limited abundance and distributions. Such immediate effects have been observed as rapid and abrupt declines in the main-stem Tombigbee, Alabama, and Conasauga rivers.

6.1 Future Resilience Factors

We considered projected changes in agricultural and developed land uses in assessing future resilience of each analysis unit for frecklebelly madtom. We use these land use classes as surrogates for potential changes in water quality, a primary risk factor for the species. The potential risks of invasive species and climate change were not used directly in the analysis of future condition scenarios because they are currently not clearly defined, the risks for each population are difficult to define, and the actual impacts to a unit are unknown. In the case of climate change, the species preference for larger rivers may provide a buffer to changes in climate, such as increased drought conditions. We assessed resilience under three future scenarios. Methods for projecting each resilience factor 30 years into the future under three scenarios, low development, moderate development, and high development, are described below.

6.1.1 Land Use and Water Quality

To project water quality 30 years into the future, we used projected trends in land use change from two models, the National Land Cover Database (NLCD), and the SLEUTH model (Slope, Land use, Excluded, Urban, Transportation and Hillshade; Jantz et al. 2010). Here, we describe the general methods we used to generate these land use change projections for each unit.

Future projections for agricultural land use were developed from NLCD data. We calculated a 15-year trend in agricultural land use change between 2001 and 2016 for each analysis unit using NLCD shapefiles (Table 6.1). This 15-year trend was converted to an annual rate of change for each unit, and was used to assess changes in agricultural land use from the baseline current level (Chapter 5). Unlike the SLEUTH model (described below), calculating agricultural trend data is not spatially explicit, thus we used the annual rate of change in agricultural land use across each resilience unit to project changes both across the analysis unit and within riparian areas. We projected land use change forward 30 years from the present in all three scenarios. The annual rate of agricultural change was held constant across all scenarios. While the changes in agricultural area varied among the resilience units we evaluated in our analysis, with the exception of the Alabama River resilience unit, we found an overall decline in the amount of land used for agriculture (Table 6.1). This result is consistent with broader trends that show the amount of agricultural land is declining with time in the Eastern U.S. with a net loss of 6.5% between 1973 and 2000 (Sayler et al. 2016, p. 12). Therefore, we believe it is reasonable to assume that the trends in agricultural land use we calculated will continue for the next 30 years.

Table 6.1. Summary of agricultural land use change from 2001-2016. Annual % change in agricultural land use was used to project forward to the year 2050 under 3 scenarios.

Representation Unit	Resilience Unit	% AG 2001	% AG 2016	% Change	Annual % Change
Pearl River	Pearl River	20.38%	14.32%	-6.06%	-0.40%
	Bogue Chitto	30.92%	20.86%	-10.06%	-0.67%
Upper Tombigbee River	East Fork Tombigbee River	21.86%	16.89%	-4.97%	-0.33%
	Upper Tombigbee River	35.65%	23.58%	-12.07%	-0.80%
	Sipsey River	9.49%	7.04%	-2.45%	-0.16%
	Luxapallila Creek	17.56%	14.09%	-3.47%	-0.23%
	Buttahatchie River	15.32%	12.11%	-3.21%	-0.21%
	Bull Mountain Creek	14.35%	10.63%	-3.72%	-0.25%
Alabama River	Alabama River	1.18%	4.06%	2.88%	0.19%
Cahaba River	Cahaba River	11.18%	8.50%	-2.67%	-0.18%
	Alabama River-Big Swamp Creek	20.01%	4.06%	-6.81%	-0.45%
Upper Coosa River	Conasauga River	22.21%	21.30%	-0.91%	-0.06%
	Etowah River	12.39%	10.43%	-1.96%	-0.13%
	Coosawattee River	33.64%	27.23%	-6.42%	-0.43%
Lower Tombigbee/Alabama River	Lower Tombigbee River	17.89%	15.32%	-2.57%	-0.17%
	Lower Alabama River	10.95%	7.43%	-3.52%	-0.23%

We used the Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade (SLEUTH) model to generate a projection of future urbanization at both the watershed and riparian scales. The SLEUTH model has previously been used to predict probabilities of urbanization across the southeastern US in 10-year increments, and the resulting GIS data are freely available (Belyea and Terrando 2013, unpaginated). The SLEUTH model simulates patterns of urban expansion across the Southeast based on observations of past urban growth and transportation networks, including the sprawling, fragmented, “leapfrog” development, which has been the dominant form of development in the Southeast (Terando, et al., 2014, entire). The

SLEUTH model predicts the probability of urbanization ranging from 0-100%, with higher probabilities indicating areas more likely to be developed.

For our future projections, we used the SLEUTH data sets from the year 2050 (closest to 30 years in the future), and examined development across analysis units (Table 6.2) and within riparian areas (Table 6.3). For the low development scenario, we considered all areas predicted to be developed at a >90% probability; moderate development scenario considered all areas to be developed at a >50% probability; and the high development scenario considered all areas to be developed at a >10% probability.

Table 6.2. Current % **analysis unit scale** development and results of the SLEUTH analysis for projecting development forward to 2050 under three scenarios: low development (probability of development >90%), moderate development (probability of development >50%), and high development (probability of development >10%).

Representation Unit	Resilience Unit	% Developed Current	% Developed 2050 (Low)	% Developed 2050 (Mod)	% Developed 2050 (High)
Pearl River	Bogue Chitto	6.08%	9.17%	10.24%	11.90%
	Pearl River	6.32%	13.24%	14.82%	17.19%
Upper Tombigbee River	East fork Tombigbee River	7.56%	15.37%	17.10%	19.91%
	Upper Tombigbee River	5.25%	12.36%	14.02%	16.98%
	Sipsey River	2.39%	6.61%	8.17%	9.78%
	Luxapallila Creek	7.40%	10.16%	11.32%	13.25%
	Buttahatchee River	5.58%	11.22%	12.68%	14.91%
	Bull Mountain Creek	4.50%	7.34%	8.17%	9.32%
Alabama River	Alabama River	0.43%	0.69%	0.78%	0.95%
Cahaba River	Cahaba River	9.20%	15.40%	16.41%	17.92%
	Alabama-Big Swamp Creek	2.73%	5.26%	6.30%	8.23%
Upper Coosa River	Conasauga River	8.03%	12.85%	14.57%	16.78%
	Etowah River	14.83%	35.11%	38.47%	42.22%
	Coosawattee	6.60%	9.50%	10.66%	12.41%
Lower Tombigbee/Alabama River	Lower Tombigbee River	2.66%	21.55%	24.58%	29.31%
	Lower Alabama River	2.30%	3.26%	3.64%	4.23%

Table 6.3. Current % **riparian** scale development and results of the SLEUTH analysis for projecting development forward to 2050 under three scenarios: low development (probability of development >90%), moderate development (probability of development >50%), and high development (probability of development >10%).

Representation Unit	Resilience Unit	% Developed Riparian Current	% Developed Riparian 2050 (Low)	% Developed Riparian 2050 (Mod)	% Developed Riparian 2050 (high)
Pearl River	Pearl River	3.29%	8.39%	9.81%	12.30%
	Bogue Chitto	3.52%	5.01%	5.73%	7.02%
Upper Tombigbee River	East Fork Tombigbee River	4.18%	10.12%	11.51%	14.18%
	Upper Tombigbee River	3.28%	8.87%	10.50%	13.87%
	Sipsey River	1.25%	4.06%	5.17%	6.41%
	Luxapallila Creek	4.28%	6.12%	7.00%	8.67%
	Buttahatchee River	3.66%	7.77%	9.16%	11.43%
	Bull Mountain Creek	3.41%	5.83%	6.54%	7.91%
Alabama River	Alabama River	1.26%	2.09%	2.55%	3.57%
Cahaba River	Cahaba River	2.84%	6.30%	7.38%	9.42%
	Alabama-Big Swamp Creek	1.44%	3.14%	4.36%	6.79%
Upper Coosa River	Conasauga River	5.64%	9.74%	11.14%	13.15%
	Etowah River	8.29%	24.63%	27.80%	31.79%
	Coosawattee River	5.06%	7.83%	8.70%	10.19%
Lower Tombigbee/Alabama River	Lower Tombigbee River	1.13%	1.88%	2.28	3.01%
	Lower Alabama River	0.69%	0.78%	0.86%	1.00%

The results of the projections for future agriculture and development were then added to the current agriculture and urbanization levels for all frecklebelly madtom units. Like in the current conditions, a single composite score for land use was generated for each population for 2050 for each scenario. Classifications were averaged together for each composite watershed score as if good, fair, and poor were equal to values of 1, 2, and 3, respectively. If averaging the two factors resulted in a value ending in .5, the overall score was rounded down (rather than typical mathematical convention of rounding up) to be conservative (i.e. avoid overestimating the impacts of land use changes on water quality and frecklebelly madtom).

Composite population land use scores were then categorized on a good (1)-moderate (2)-poor (3) scale. We then implemented the following rule sets to assess future resilience:

- If a composite land use score changed to poor from its baseline current condition score (i.e. threat level increased substantially), future resilience was considered to be low.
- If projected development across a unit was greater than 40% (i.e. twice the threshold for determining poor baseline development threat level), or if projected development within riparian areas was greater than 25% (i.e. more than a quarter of the riparian area likely impervious cover), that unit was automatically assessed as low resilience, regardless of the level of agriculture.
- If composite land use score dropped from good to fair, we adjusted the resilience down to moderate if the population is currently considered high; if the population is currently considered moderate, no adjustment was made to future resilience.
- If composite land use score dropped from fair to poor, and the current resilience was low, we assessed resiliency as likely extirpated.
- All populations assessed as unknown resilience for current condition, maintain unknown resilience across all scenarios.

6.2 Future Resilience

Below, we summarize the results of the resilience assessment for each analysis unit under three scenarios: low development, moderate development, and high development. Agriculture across 15 of 16 resilience units was projected to decrease, thus changes in development drove any changes in resilience. It is important to remember that frecklebelly madtom have yet to be found in the Coosawattee and Lower Tombigbee-Alabama units; rather their presence is supported by recent positive eDNA samples.

6.2.1 Low development

Under the low development scenario, we projected agriculture land use based on trend data from 2001-2016, and development with the SLEUTH model, where we considered any area with a probability of >90% in 2050 to be developed. Resiliency of units is predicted to be as follows: high (1); moderate (7); low (1); unknown (3); likely extirpated (4). Table 6.4 summarizes predicted development and agricultural land use in the year 2050 under the low development scenario. The Etowah is expected to become substantially more developed even under the low development scenario, although the percent of developed land across the unit and within riparian areas does not cross the critical threshold established in the rule set described in the previous section, so resiliency is still anticipated to be moderate. The Buttahatchee and Pearl populations both dropped from high to moderate resilience due to the fact that the land use composite scores fell from good to fair (Table 6.5 and 6.6). All other populations retain their current resiliency under the low development scenario.

Table 6.4. Projected agricultural and urban land cover in 2050 for the watershed level and riparian areas within each frecklebelly madtom analysis unit for the **LOW** development scenario. Predictions come from 2001-2016 trends in the National Land Cover Database and the SLEUTH model.

		SLEUTH (>90%)		NLCD 2001-2016 Trend	
Representation Unit	**Resilience Unit**	**Urban in Watershed**	**Urban in Riparian**	**Agriculture in Watershed**	**Agriculture in Riparian**
Pearl River	Pearl River	13.24%	8.39%	-12.58%	-7.56%
	Bogue Chitto	9.17%	5.01%	-16.66%	-9.72%
Upper Tombigbee River	East Fork Tombigbee River	15.37%	10.12%	-15.21%	-14.08%
	Upper Tombigbee River	12.36%	8.87%	-17.89%	-12.17%
	Sipsey River	6.61%	4.06%	-6.70%	-4.61%
	Luxapallila Creek	10.16%	6.12%	-13.11%	-10.38%
	Buttahatchee River	11.22%	7.77%	-11.34%	-11.07%
	Bull Mountain Creek	7.34%	5.83%	-9.84%	-9.67%
Alabama River	Alabama River	2.09%	1.26%	+4.29%	+2.62%
Cahaba River	Cahaba River	6.30%	2.84%	-8.05%	-10.10%
	Alabama-Big Swamp Creek	5.26%	3.14%	-11.41%	-4.93%
Upper Coosa River	Conasauga River	9.74%	5.64%	-20.91%	-19.99%
	Etowah River	24.63%	8.29%	-10.02%	-7.97%
	Coosawattee River	7.83%	5.06%	-23.73%	-23.36%
Lower Tombigbee/Alabama River	Lower Tombigbee River	21.55%	1.88%	-14.53%	-0.92%
	Lower Alabama River	3.26%	0.78%	-6.91%	-0.76%

Table 6.5. Projected land use composite scores based on levels of agriculture and development in the year 2050 under the **LOW** development scenario.

Representation Unit	Resilience Unit	2050 Developed Unit Scale	2050 Agriculture Unit Scale	2050 Land Use Composite Score
Pearl River	Pearl River	Fair	Fair	Fair
	Bogue Chitto	Good	Fair	Good
Upper Tombigbee River	East Fork Tombigbee River	Fair	Fair	Fair
	Upper Tombigbee River	Fair	Fair	Fair
	Sipsey River	Fair	Good	Good
	Luxapallila Creek	Fair	Fair	Fair
	Buttahatchee River	Fair	Fair	Fair
	Bull Mountain Creek	Good	Good	Good
Alabama River	Alabama River	Good	Good	Good
Cahaba River	Cahaba River	Fair	Good	Good
	Alabama-Big Swamp Creek	Good	Fair	Good
Upper Coosa River	Conasauga River	Fair	Poor	Fair
	Etowah River	Poor	Good	Fair
	Coosawattee River	Fair	Poor	Fair
Upper Tombigbee/Alabama River	Lower Tombigbee River	Poor	Fair	Fair
	Lower Alabama River	Good	Good	Good

Table 6.6. Projected resilience of frecklebelly madtom units based on land use composite scores in the year 2050 under the **LOW** development scenario. Also shown is current land use and resilience for reference to Current Condition.

Representation Unit	Resilience Unit	Current Land Use	Current Resilience	2050 Land Use	2050 Resilience
Pearl River	Pearl River	Good	High	Fair	Moderate
	Bogue Chitto	Fair	High	Good	High
Upper Tombigbee River	East Fork Tombigbee River	Good	Moderate	Fair	Moderate
	Upper Tombigbee River	Fair	Likely Extirpated	Fair	Likely Extirpated
	Sipsey River	Good	Moderate	Good	Moderate
	Luxapallila Creek	Good	Moderate	Fair	Moderate
	Buttahatchee River	Good	High	Fair	Moderate
	Bull Mountain Creek	Good	Likely Extirpated	Good	Likely Extirpated
Alabama River	Alabama River	Good	Likely Extirpated	Good	Likely Extirpated
Cahaba River	Cahaba River	Good	Moderate	Good	Moderate
	Alabama-Big Swamp Creek	Good	Likely Extirpated	Good	Likely Extirpated
Upper Coosa River	Conasauga River	Fair	Low	Fair	Low
	Etowah River	Fair	Moderate	Fair	Moderate
	Coosawattee River	Fair	Unknown*	Fair	Unknown*
Lower Tombigbee/Alabama River	Lower Tombigbee River	Good	Unknown*	Fair	Unknown*
	Lower Alabama River	Good	Unknown*	Good	Unknown*

6.2.2 Moderate Development

Under the moderate development scenario, we projected agriculture land use based on trend data from 2001-2016, and development with the SLEUTH model, where we considered any area with a probability of >50% in 2050 to be developed. Table 6.7 summarizes predicted development and agricultural land use in the year 2050 under the moderate development scenario. Resiliency of units is predicted as follows: high (1); moderate (6); low (2); unknown (3); likely extirpated (4). The Etowah is expected to become substantially more developed under the moderate development scenario, so much so, that development within riparian areas crosses the 25% threshold and resilience drops to low. The Buttahatchee and Pearl populations both dropped from high to moderate resilience due to the fact that the land use composite scores fell from good to fair (Tables 6.8 and 6.9). All other populations retain their current resiliency under the moderate development scenario.

Table 6.7. Projected agricultural and urban land cover in 2050 for the watershed level and riparian areas within each frecklebelly madtom analysis unit for the **MODERATE** development scenario. Predictions come from 2001-2016 trends in the National Land Cover Database and the SLEUTH model.

		SLEUTH (>50%)		NLCD 2001-2016 Trend	
Representation Unit	**Resilience Unit**	**Urban in Watershed**	**Urban in Riparian**	**Agriculture in Watershed**	**Agriculture in Riparian**
Pearl River	Pearl	14.82%	9.81%	-12.58%	-7.56%
	Bogue Chitto	10.24%	5.73%	-16.66%	-9.72%
Upper Tombigbee River	East Fork Tombigbee	17.10%	11.51%	-15.21%	-14.08%
	Upper Tombigbee	14.02%	10.50%	-17.89%	-12.17%
	Sipsey	8.17%	5.17%	-6.70%	-4.61%
	Luxapallila	11.32%	7.00%	-13.11%	-10.38%
	Buttahatchee	12.68%	9.16%	-11.34%	-11.07%
	Bull Mountain	8.17%	6.54%	-9.84%	-9.67%
Alabama River	Alabama River	0.78%	2.55%	+4.29%	+2.62%
Cahaba River	Cahaba River	16.41%	7.38%	-8.05%	-10.10%
	Alabama Big Swamp	6.30%	4.36%	-11.41%	-4.93%
Upper Coosa River	Conasauga River	14.57%	11.14%	-20.91%	-19.99%
	Etowah River	38.47%	27.80%	-10.02%	-7.97%
	Coosawattee River	10.66%	8.70%	-23.73%	-23.36%
Lower Tombigbee/Alabama River	Lower Tombigbee	24.58%	2.28%	-14.53%	-0.92%
	Lower Alabama	3.64%	0.86%	-6.91%	-0.76%

Table 6.8. Projected land use composite scores based on levels of agriculture and development in the year 2050 under the **MODERATE** development scenario.

Representation Unit	Resilience Unit	2050 Developed Unit Scale	2050 Agriculture Unit Scale	2050 Land Use Composite Score
Pearl River	Pearl River	Fair	Fair	Fair
	Bogue Chitto	Fair	Fair	Fair
Upper Tombigbee River	East Fork Tombigbee River	Fair	Fair	Fair
	Upper Tombigbee River	Fair	Fair	Fair
	Sipsey River	Good	Good	Good
	Luxapallila Creek	Fair	Fair	Fair
	Buttahatchee River	Fair	Fair	Fair
	Bull Mountain Creek	Fair	Good	Good
Alabama River	Alabama River	Good	Good	Good
Cahaba River	Cahaba River	Fair	Good	Good
	Alabama Big-Swamp Creek	Good	Fair	Good
Upper Coosa River	Conasauga River	Fair	Poor	Fair
	Etowah River	Poor	Good	Poor*
	Coosawattee River	Fair	Poor	Fair
Lower Tombigbee/Alabama River	Lower Tombigbee River	Poor	Fair	Fair
	Lower Alabama River	Good	Good	Good

Table 6.9. Projected resilience of frecklebelly madtom units based on land use composite scores in the year 2050 under the **MODERATE** development scenario. Also shown is current land use and resilience for reference to Current Condition.

Representation Unit	Resilience Unit	Current Land Use	Current Resilience	2050 Land Use	2050 Resilience
Pearl River	Pearl	Good	High	Fair	Moderate
	Bogue Chitto	Fair	High	Fair	High
Upper Tombigbee River	East Fork Tombigbee	Good	Moderate	Fair	Moderate
	Upper Tombigbee	Fair	Likely Extirpated	Fair	Likely Extirpated
	Sipsey	Good	Moderate	Good	Moderate
	Luxapallila	Good	Moderate	Fair	Moderate
	Buttahatchee	Good	High	Fair	Moderate
	Bull Mountain	Good	Likely Extirpated	Good	Likely Extirpated
Alabama River	Alabama	Good	Likely Extirpated	Good	Likely Extirpated
Cahaba River	Cahaba	Good	Moderate	Good	Moderate
	Alabama Big Swamp	Good	Likely Extirpated	Good	Likely Extirpated
Upper Coosa River	Conasauga	Fair	Low	Fair	Low
	Etowah	Fair	Moderate	Poor*	Low
	Coosawattee	Fair	Unknown*	Fair	Unknown*
Lower Tombigbee/Alabama River	Lower Tombigbee	Good	Unknown*	Fair	Unknown*
	Lower Alabama	Good	Unknown*	Good	Unknown*

6.2.3 High Development

Under the high development scenario, we projected agriculture land use based on trend data from 2001-2016, and development with the SLEUTH model, where we considered any area with a probability of >10% in 2050 to be developed. Table 6.10 summarizes predicted development and agricultural land use in the year 2050 under the high development scenario. Resiliency of units is predicted as follows: high (1); moderate (6); low (1); unknown (3); likely extirpated (5). The Etowah, once again, is expected to become substantially more developed under the moderate development scenario, so much so, that development within riparian areas crosses the 25% threshold, and crosses the 40% threshold across the unit, and thus resilience drops to low. The Buttahatchee and Pearl populations both dropped from high to moderate resilience due to the fact that the land use composite scores fell from good to fair. The Conasauga unit sees a projected level of development that results in a drop from "fair" to "poor" in the year 2050. This results in both development and agriculture being high threat levels in the future, thus the overall resilience of this unit was dropped from low, to likely extirpated (Tables 6.11 and 6.12). All other populations were assessed as having the same resiliency as current.

Table 6.10. Projected agricultural and urban land cover in 2050 for the watershed level and riparian areas within each frecklebelly madtom analysis unit for the **HIGH** development scenario. Predictions come from 2001-2016 trends in the National Land Cover Database and the SLEUTH model.

		SLEUTH (>10%)		NLCD 2001-2016 Trend	
Representation Unit	**Resilience Unit**	**Urban in Watershed**	**Urban in Riparian**	**Agriculture in Watershed**	**Agriculture in Riparian**
Pearl River	Pearl River	17.19%	12.30%	-12.58%	-7.56%
	Bogue Chitto	11.90%	7.02%	-16.66%	-9.72%
Upper Tombigbee River	East Fork Tombigbee River	19.91%	14.18%	-15.21%	-14.08%
	Upper Tombigbee River	16.98%	13.87%	-17.89%	-12.17%
	Sipsey River	9.78%	6.41%	-6.70%	-4.61%
	Luxapallila Creek	13.25%	8.67%	-13.11%	-10.38%
	Buttahatchee River	14.91%	11.43%	-11.34%	-11.07%
	Bull Mountain Creek	9.32%	7.91%	-9.84%	-9.67%
Alabama River	Alabama River	0.95%	3.57%	+4.29%	+2.62%
Cahaba River	Cahaba River	17.92%	9.42%	-8.05%	-10.10%
	Alabama-Big Swamp Creek	8.23%	6.79%	-11.41%	-4.93%
Upper Coosa River	Conasauga River	16.78%	13.15%	-20.91%	-19.99%
	Etowah River	42.22%	31.79%	-10.02%	-7.97%
	Coosawattee River	12.41%	10.19%	-23.73%	-23.36%
Lower Tombigbee/Alabama River	Lower Tombigbee River	29.31%	3.01%	-14.53%	-0.92%
	Lower Alabama River	4.23%	1.00%	-6.91%	-0.76%

Table 6.11. Projected land use composite scores based on levels of agriculture and development in the year 2050 under the **HIGH** development scenario.

Representation Unit	Resilience Unit	2050 Developed Unit Scale	2050 Agriculture Unit Scale	2050 Land Use Composite Score
Pearl River	Pearl River	Poor	Fair	Fair
	Bogue Chitto	Fair	Fair	Fair
Upper Tombigbee River	East Fork Tombigbee River	Poor	Fair	Fair
	Upper Tombigbee River	Poor	Fair	Fair
	Sipsey River	Fair	Good	Good
	Luxapallila Creek	Fair	Fair	Fair
	Buttahatchee River	Fair	Fair	Fair
	Bull Mountain Creek	Fair	Good	Good
Alabama River	Alabama River	Good	Good	Good
Cahaba River	Cahaba River	Fair	Good	Good
	Alabama-Big Swamp Creek	Fair	Fair	Fair
Upper Coosa River	Conasauga River	Poor	Poor	Poor
	Etowah River	Poor*	Good	Poor
	Coosawattee River	Fair	Poor	Fair
Lower Tombigbee/Alabama River	Lower Tombigbee River	Poor	Fair	Fair
	Lower Alabama River	Good	Good	Good

Table 6.12. Projected resilience of frecklebelly madtom units based on land use composite scores in the year 2050 under the **HIGH** development scenario. Also shown is current land use and resilience for reference to Current Condition.

Representation Unit	Resilience Unit	Current Land Use	Current Resilience	2050 Land Use	2050 Resilience
Pearl River	Pearl	Good	High	Fair	Moderate
	Bogue Chitto	Fair	High	Fair	High
Upper Tombigbee River	East Fork Tombigbee River	Good	Moderate	Fair	Moderate
	Upper Tombigbee	Fair	Likely Extirpated	Fair	Likely Extirpated
	Sipsey River	Good	Moderate	Good	Moderate
	Luxapallila Creek	Good	Moderate	Fair	Moderate
	Buttahatchee River	Good	High	Fair	Moderate
	Bull Mountain Creek	Good	Likely Extirpated	Good	Likely Extirpated
Alabama River	Alabama River	Good	Likely Extirpated	Good	Likely Extirpated
Cahaba River	Cahaba River	Good	Moderate	Good	Moderate
	Alabama-Big Swamp Creek	Good	Likely Extirpated	Fair	Likely Extirpated
Upper Coosa River	Conasauga River	Fair	Low	Poor	Likely Extirpated
	Etowah River	Fair	Moderate	Poor	Low
	Coosawattee River	Fair	Unknown*	Fair	Unknown*
Lower Tombigbee/Alabama River	Lower Tombigbee River	Good	Unknown*	Fair	Unknown*
	Lower Alabama River	Good	Unknown*	Good	Unknown*

6.2.4 Resilience Summary

Resilience levels did not change substantially under the low development scenarios, but there were changes in the resilience of a few populations under the moderate and high development scenarios. (Table 6.13). The Pearl River representative unit continues to be the stronghold for the species, as the resilience remains high for Bogue Chitto across all scenarios, and the Pearl River resilience unit maintains a moderate resilience across all scenarios. Although the Pearl River resilience unit drops from high to moderate under all scenarios, this was due to a drop in land use composite score from high to fair, and there is uncertainty in the species response to these land use changes, thus this unit might ultimately be highly resilient in the future.

The Cahaba are predicted to maintain their moderate resilience across all scenarios, contributing positively to the overall viability of the species. All extant resilience units in the Upper Tombigbee representative unit are anticipated to maintain moderate resilience, also contributing to the overall viability of the species. As with the Pearl River resilience unit, the Buttahatchee unit drops from high to moderate resilience across all scenarios, though the same uncertainty in species response remains, and this unit certainly could still display a high level of resilience under moderate threat levels.

The Etowah River unit is predicted to become substantially more urbanized by 2050 under all scenarios. In the moderate and high development scenarios, resilience drops from moderate to low, making it potentially much more vulnerable to stochastic events. Of particular concern is the high level of development predicted within riparian areas in the Etowah unit. Any increase in impervious area near frecklebelly madtom habitat could substantially decrease water quality, and thus impact the persistence of the species. Although agriculture is predicted to decrease in the Etowah River unit, agricultural land use is still predicted to remain at a relatively high level. High levels of both agriculture and development predicted in our assessment are driving the predicted low resiliency of this unit by the year 2050.

The Conasauga is the only other unit that is anticipated to change in resilience by 2050. Development under the high development scenario is projected to increase enough to drive resiliency further down. As with the Etowah Unit, agriculture and development are both expected to be at relatively high levels by 2050; however, the Conasauga is currently already at low resiliency, so the projected increase in development is anticipated to further impact the resiliency of the species. Given that the Conasauga is currently believed to be at risk of extirpation, and with the anticipated changes in land use in the future, we assigned the resiliency as "likely extirpated" under the high development scenario.

Finally, it is important to note that presence of frecklebelly madtom in the Coosawattee, Lower Tombigbee, and Lower Alabama resilience units is assumed based on recent positive eDNA samples. There is much uncertainty in the resilience assessment of these units without direct observation of the frecklebelly madtom. Future surveys should focus on detection of the species within these units, as this would help establish a baseline for current resiliency. We do know that, currently, threats from dredging and potentially industrial effluent persist, but based on our assessment of future land use, threat levels from agriculture and development land use practices are predicted to be relatively low in the Lower Tombigbee and Lower Alabama units. Thus if the species is present, there does not seem to be an increase in threats related to water quality from these sources. However, in the Coosawattee, relatively high amounts of agricultural and development land use may represent a threat to the individuals occupying this unit.

Table 6.13. Summary table of current and future resilience under 3 scenarios of frecklebelly madtom units in 2050. *Presence of frecklebelly madtom is unknown based on positive eDNA samples in this assessment.

Representation Unit	Resiliency Unit	Current Resilience	Low Development	Moderate Development	High Development
Pearl River	Pearl River	High	Moderate	Moderate	Moderate
	Bogue Chitto	High	High	High	High
Upper Tombigbee	East Fork Tombigbee River	Moderate	Moderate	Moderate	Moderate
	Upper Tombigbee River	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
	Sipsey River	Moderate	Moderate	Moderate	Moderate
	Luxapallila Creek	Moderate	Moderate	Moderate	Moderate
	Buttahatchie River	High	Moderate	Moderate	Moderate
	Bull Mountain Creek	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Alabama River	Alabama River	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Cahaba River	Cahaba River	Moderate	Moderate	Moderate	Moderate
	Alabama River-Big Swamp Creek	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Upper Coosa River	Conasauga River	Low	Low	Low	Likely Extirpated
	Etowah River	Moderate	Moderate	Low	Low
	Coosawattee River	Unknown*	Unknown*	Unknown*	Unknown*
Lower Tombigbee/Alabama River	Lower Tombigbee River	Unknown*	Unknown*	Unknown*	Unknown*
	Lower Alabama River	Unknown*	Unknown*	Unknown*	Unknown*

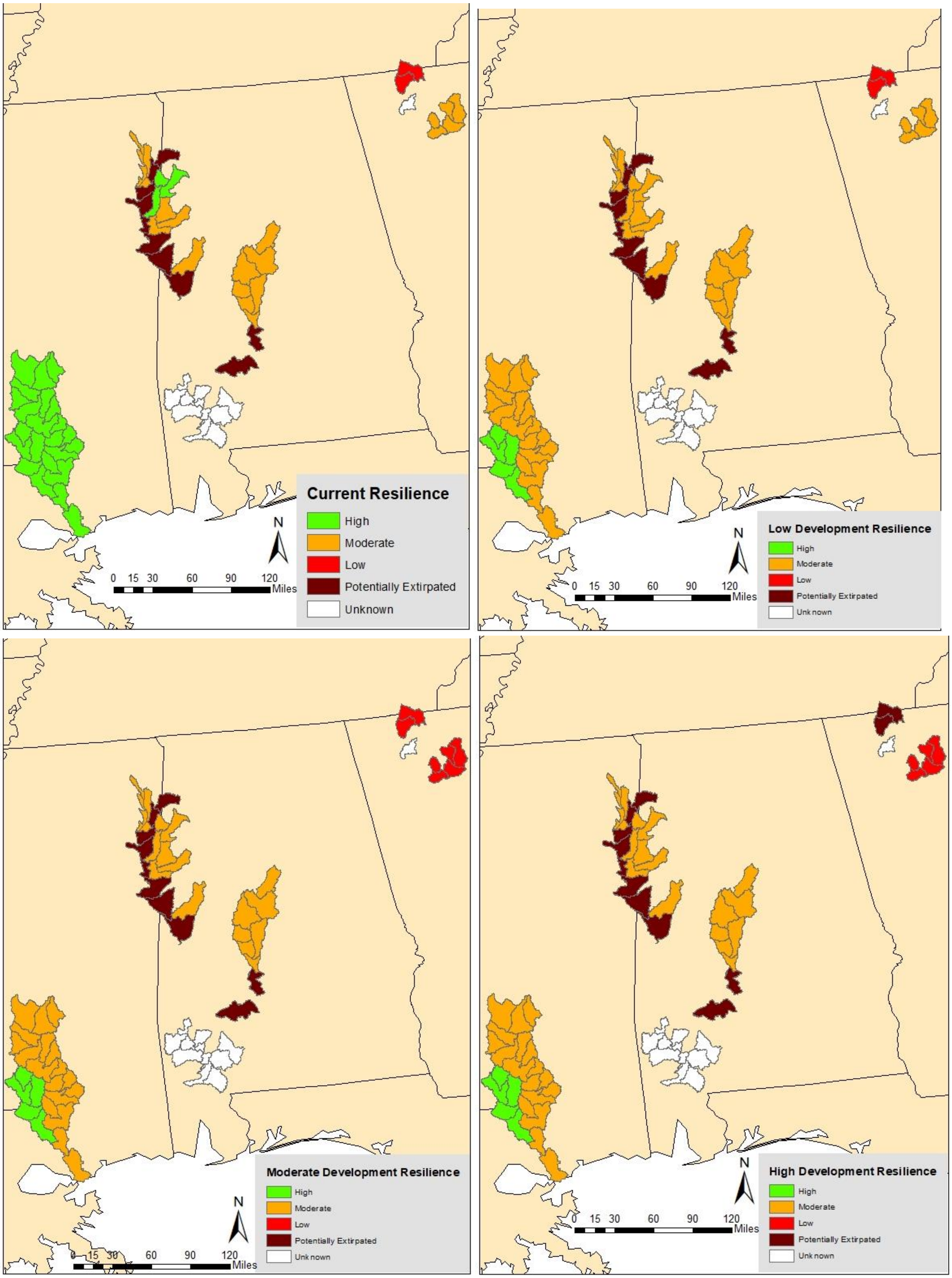


Figure 6.1. Population resilience for frecklebelly madtom currently, and under 3 scenarios.

6.3 Future Redundancy and Representation

Redundancy is maintained in the low and moderate development scenarios, as there are no resilience units predicted to be likely extirpated by 2050. In the Etowah River and Conasauga River units, drops in resiliency under the moderate and high development scenarios mean these units are at increased risk of extirpation given a catastrophic event. Historically, the most important catastrophic events have been related to large scale channelization projects and impoundments, such as the project described earlier in the Upper Tombigbee Unit. As long as projects such as these do not occur in the future, we would anticipate the frecklebelly madtom to persist, even at lower resiliency, thus contributing to the overall viability of the species. Because the frecklebelly madtom's range is relatively large, it is highly unlikely that any one catastrophic event would impact the entire range, although redundancy the Upper Coosa representative unit is anticipated to be further reduced given the susceptibility of the Conasauga and Etowah populations to changes in future land use.

We measure representation as a function of the resiliency of the populations within the delineated representative units. There is genetic evidence that suggest these units might differ significantly (Neely 2018, pp. 7-10), so assessing the resiliency of populations within these representative units gives us an idea about the overall representation of the species. Future representation is predicted to essentially stay the same in the low development scenario, as the only changes in resiliency under this scenario are a few populations (Buttahatchee and Pearl) that drop from high to moderate, and moderately resilient populations are anticipated to contribute to the viability of the species. Under the moderate and high development scenarios, the Etowah and Conasauga units are vulnerable to habitat degradation from predicted land use changes. This results in the Upper Coosa River representative unit being particularly vulnerable to extirpation, with a subsequent loss of representation. Of particular concern are the declines projected for the Etowah, and Conasauga units, and the uncertainty of the presence of the species in the Coosawattee. These units are located in the Upper Coosa drainage, and preliminary morphological data suggest this drainage may have the most distinctive populations, and they occupy unique physiographic provinces and habitat types (Neely 2018, pp. 7-10). Loss of any of these units could have profound effects on the future representation of the species.

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