Species Status Assessment Report for the Altamaha spinymussel (*Elliptio spinosa)*

Version 1.0

Photo Credit Jason Wisniewski

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U.S. Fish and Wildlife Service
Southeast Region
Atlanta, GA

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EXECUTIVE SUMMARY

The Altamaha spinymussel (*Elliptio spinosa*) is an endangered freshwater mussel endemic to the Altamaha River and major tributaries in southeastern Georgia. The primary threats to the species are habitat loss and modification, water quality degradation, particularly from legacy sedimentation from past agricultural practices, range curtailment, small population size, and vulnerability to natural or human-induced catastrophic events (e.g., drought, pollution spills, etc.). There are gaps in our understanding of the spinymussel's life history, particularly the identity of the host fish, crucial for successful reproduction. Without knowing the identity of the host fish, we cannot know if host fish population dynamics threaten the persistence of the Altamaha spinymussel.

We delineated four populations, the Oconee, Ohoopee, Ocmulgee/Altamaha, and Lower Altamaha, and assessed the current condition in terms of species presence, evidence of reproduction, water quality, water quantity, and the community of potential host fish. Currently, 2 out of the 4 populations are presumed extirpated (Oconee and Lower Altamaha), one has low resiliency (Ohoopee) due to threats from water quality and water quantity, and one has moderate resiliency (Ocmulgee/Altamaha). Populations appear to be declining, but there has not been a recent range-wide survey, and detectability for this species is low. Current redundancy is low, given that half of the populations are presumed extirpated and 1 of the remaining populations has low resiliency and is unlikely to be able to serve as a refuge or source population if the other faces a catastrophic event like a pollution spill. As a narrow-ranging endemic species that inhabits similar habitat throughout its range, the species has low representation, likely limiting its ability to adapt to changing future conditions.

We assessed the future condition over 2 time frames. Within 20 years, given the uncertainty in the current condition, population trends, and status of the host fish of the species, it is plausible that the Altamaha spinymussel could be extinct, or that the species will persist at low densities. If these population conditions allow the spinymussel to persist at the species level, there is additional uncertainty in whether it will persist in both currently extant populations or whether the Ohoopee population is likely to be extirpated anyways due to habitat threats. Given that the species persists past 20 years, we explored multiple scenarios at a 50-year time frame. We projected land use and water quantity projections under different climate scenarios. Land use changes depended on the climate scenario, and are predicted to either remain similar to current conditions, or show a transition of some natural lands to cropland. Because the species is believed to be impacted more from legacy sedimentation from past agricultural practices than from current land uses, and that the river is buffered by natural land cover, much of which is in conservation, the predicted land use changes may not have a strong effect on population resiliency. Similarly, water quantity projections, depending on the climate scenario, are likely to remain similar to the current condition or change in ways favoring spinymussel persistence,

leading to no categorical changes between the current and future conditions, although the water quantity model used is limited in that it does not incorporate anthropogenic water withdrawal.

We explored a Status Quo scenario where conditions in the Altamaha Basin continue along their present trajectory in terms of conservation actions, and a Conservation scenario where conservation efforts are increased. Desired conservation actions include the development of captive propagation protocols, which would require the identification of the host fish and successful captive breeding, and it is uncertain whether this can be accomplished. Thus, we explored an additional add-on scenario to the Conservation scenario that includes successful captive propagation.

Within 20 years, it is possible that the Altamaha spinymussel could be extinct or functionally so if apparent population declines continue and reproduction and recruitment are unable to keep pace with adult mortality. However, if apparent declines are instead due at least in part to limited surveys and low detectability, and reproduction and recruitment are occurring, the species is likely to persist, though at low densities, in 1-2 populations beyond 20 years. Given that the species does not go extinct within 20 years, the Ohoopee population has opportunities to improve in resiliency under both the Status Quo and Conservation 50-year scenarios. The Ocmulgee/Altamaha population is likely to see no change in resiliency under the Status Quo scenario, but resiliency will improve under the Conservation scenario. The biggest increases in resiliency across multiple populations will occur if methods are successfully developed to propagate the Altamaha spinymussel in captivity and then use captive-bred mussels to reintroduce or augment populations in the wild. Without captive propagation, the two populations currently presumed extirpated will most likely remain so.

There is a high degree of uncertainty in both the current and future condition of the species. Future assessments of this species' current and future condition can be improved by conducting a new range-wide survey for the species to better understand current abundance and population trends, and increased research into its life history, especially its host fish. If populations are truly declining, as they appear to be based on available monitoring data, we need to better understand the threats driving this decline in order to develop specific conservation actions to counteract them.

1 INTRODUCTION

The Altamaha spinymussel (*Elliptio spinosa*) is a freshwater mussel endemic to the Altamaha River drainage of southeastern Georgia and was listed as federally endangered on October 11, 2011 (76 FR 62928). The primary threats to the species are loss of habitat, water quality degradation, range curtailment, small population size, and vulnerability to natural or human-induced catastrophic events (e.g., drought, pollution spills, etc.).

The Species Status Assessment (SSA) framework (Service 2016, entire) is intended to support 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 to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from Candidate Assessment to Listing to Consultations to Recovery. This SSA for the Altamaha spinymussel is intended to provide the biological support for the development of a recovery plan. Importantly, the SSA does not result in a decision by the Service on whether this species should be proposed for reclassification under the Act. Rather, this SSA provides a review of the available information strictly related to the biological status of the species. Any future reclassification decisions will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of any proposed decision will be announced in the Federal Register, with appropriate opportunities for public input.

For the purpose of this assessment, we define viability as the ability of a species to maintain populations in the wild over time. To assess viability, we use the conservation biology principles of resiliency, redundancy, and representation (Shaffer and Stein 2000, pp. 308-311). To sustain populations over time, a species must have the capacity to withstand:

(1) environmental and demographic stochasticity and disturbances (Resiliency),
(2) catastrophes (Redundancy), and
(3) novel changes in its biological and physical environment (Representation).

A species with a high degree of resiliency, representation, and redundancy (the 3Rs) is better able to adapt to novel changes and to tolerate environmental stochasticity and catastrophes. In general, species viability will increase with increases in resiliency, redundancy, and representation (Smith et al. 2018, p. 306).

- **Resiliency** is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature, rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity; Redford et al. 2011, p. 40). Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions.

We can best gauge resiliency by evaluating population level characteristics such as: demography (abundance and the components of population growth rate -- survival, reproduction, and migration), genetic health (effective population size and heterozygosity), connectivity (gene flow and population rescue), and habitat quantity, quality, configuration, and heterogeneity. Also, for species prone to spatial synchrony (regionally correlated fluctuations among populations), distance between populations and degree of spatial heterogeneity (diversity of habitat types or microclimates) are also important considerations.

- **Redundancy** is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population heath and for which adaptation is unlikely (Mangal and Tier 1993, p. 1083).

  We can best gauge redundancy by analyzing the number and distribution of populations relative to the scale of anticipated species-relevant catastrophic events. The analysis entails assessing the cumulative risk of catastrophes occurring over time. Redundancy can be analyzed at a population or regional scale, or for narrow-ranged species, at the species level.

- **Representation** is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments-- referred to as adaptive capacity--is essential for viability, as species need to continually adapt to their continuously changing environments (Nicotra et al. 2015, p. 1269). Species adapt to novel changes in their environment by either [1] moving to new, suitable environments or [2] by altering their physical or behavioral traits (phenotypes) to match the new environmental conditions through either plasticity or genetic change (Beever et al. 2016, p. 132; Nicotra et al. 2015, p. 1270). The latter (evolution) occurs via the evolutionary processes of natural selection, gene flow, mutations, and genetic drift (Crandall et al. 2000, p. 290-291; Sgro et al. 2011, p. 327; Zackay 2007, p. 1).

  We can best gauge representation by examining the breadth of genetic, phenotypic, and ecological diversity found within a species and its ability to disperse and colonize new areas. In assessing the breadth of variation, it is important to consider both larger-scale variation (such as morphological, behavioral, or life history differences which might exist across the range and environmental or ecological variation across the range), and smaller-scale variation (which might include measures of interpopulation genetic diversity). In assessing the dispersal ability, it is important to evaluate the ability and likelihood of the species to track suitable habitat and climate over time. Lastly, to evaluate the evolutionary processes that contribute to and maintain adaptive capacity, it is important to assess [1] natural levels and patterns of gene flow, [2] degree of ecological diversity occupied, and [3] effective population size. In our species status assessments, we assess all three facets to the best of our ability based on available data.

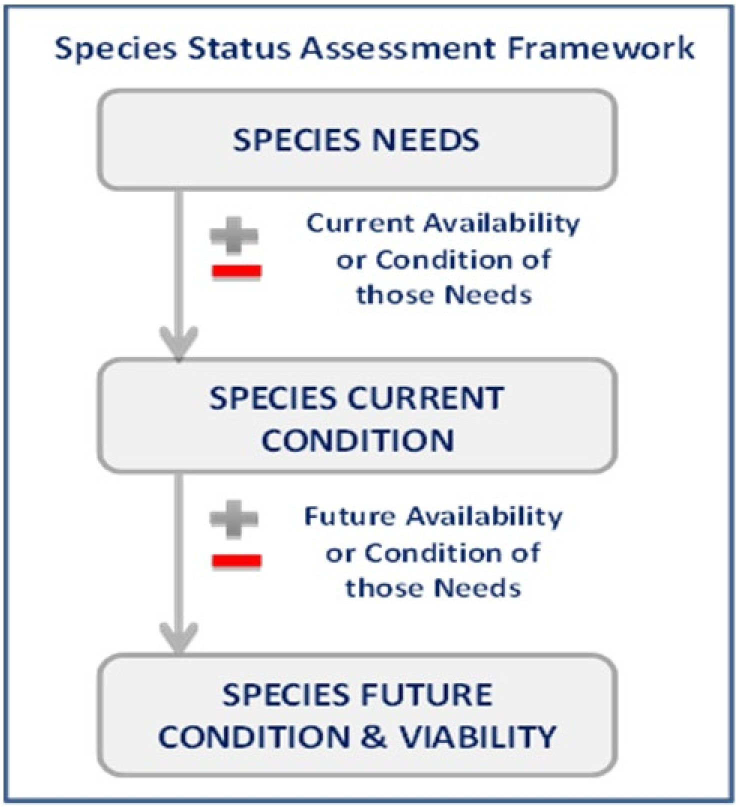

Figure 1-1. Species status assessment framework

To evaluate the biological status of the Altamaha spinymussel, we assessed a range of conditions to allow us to consider the 3Rs of the species currently and in the future. This SSA report provides a thorough assessment of biology and natural history and assesses risks, stressors, and limiting factors in the context of determining the viability of the species.

The format for this SSA includes: species biology and individual needs (Chapter 2), influences on viability (Chapter 3), current condition (Chapter 4), and future condition (Chapter 5). This document is a compilation of the best available scientific and commercial information and a description of past, present, and plausible future population and habitat conditions for the Altamaha spinymussel.

1.1 Species Protection Status

The Altamaha spinymussel was listed as endangered under the Endangered Species Act in 2011 (76 FR 62928). The primary threats in the listing decision were range curtailment, small population sizes, stream habitat degradation, and water quality impacts, and due to these factors, high vulnerability to natural or human induced catastrophic events. Approximately 237 km (147 mi) of mainstream river channel across four units in the Ocmulgee River (Ben Hill, Telfair, Coffee, and Jeff Davis counties), upper Altamaha River (Wheeler, Toombs, Montgomery, Jeff Davis, Appling, and Tattnall counties), middle Altamaha River (Tattnall, Appling, Wayne, and Long counties), and lower Ohoopee River (Tattnall County) were designated as critical habitat for this mussel (76 FR 62928). Currently, there is no approved recovery plan or objectives. The species has been assigned a recovery priority number of 5, indicating a high degree of threat and low recovery potential.

2 SPECIES BIOLOGY AND INDIVIDUAL NEEDS

2.1 Species Description and Taxonomy

The Altamaha spinymussel is a medium-sized mussel, growing up to 110 mm (4.3 in) in length (Johnson 1970, p. 303; Figure 2-1). The shell is sub-rhomboidal or sub-triangular in shape and moderately inflated. The anterior end, which is typically buried in the substrate, is rounded, whereas the exposed posterior end of the shell is slightly broader and pointed. The umbo (the inflated dorsal area of the shell) is slightly elevated above the hinge line. The posterior ridge (which runs from the umbo to the posterior end) is sharply angular, often with a faint secondary ridge above that can give the shell a corrugated texture if present. The periostracum (outside of the shell) is a greenish-yellow with faint greenish rays in young specimens, but often darkens with age to a deep brown, occasionally with rays still present. The texture of the shell is generally smooth and shiny. The nacre (interior of the shell) is pink or purple in color.


Figure 2-1. Altamaha spinymussel. Photo by Jason Wisniewski.

The Altamaha spinymussel was described by Isaac Lea in 1836 from the Altamaha River near Darien, Georgia. The Altamaha spinymussel is classified in the unionid tribe Pleurobemini and is considered a valid taxon (Williams et al. 2017, p. 38). It is also one of three North American spinymussels, rare mussels characterized by the presence of conspicuous spines. Phylogenetic analysis of the three spinymussels (Tar River spinymussel [*Elliptio steinstansana*], James River spinymussel [*Pleurobema collina*], and Altamaha spinymussel) suggested that the three spinymussels do not form a monophyletic group (Perkins et al. 2017, pp. 753-754). Based on the analysis of both nuclear and mitochondrial DNA, spinymussels can be placed in two genetically divergent monophyletic groups: one clade containing the Altamaha spinymussel and a second clade containing the Tar River and James River spinymussels. The Tar River and James River spinymussels clade was also distinct from other species in the *Elliptio* and *Pleurobema* genera, prompting their inclusion in a newly described genus, *Parvaspina*. Thus, the Altamaha spinymussel is genetically divergent from the other spinymussel species, suggesting that spines may have evolved independently in these two lineages and that management strategies based on the life histories of the Tar River and James River spinymussels may not be appropriate for or relevant to the Altamaha spinymussel. Furthermore, while mitochondrial DNA suggested some similarities with other *Elliptio* species, analysis also suggested the Altamaha spinymussel diverged from the ancestors of related *Elliptio* species in the more distant past (around 3.76 mya) as opposed to the more recent divergence of those *Elliptio* species beginning around 1.87 mya. Taken together with the ambiguous relationship found with the nuclear DNA dataset, this suggests that the Altamaha spinymussel may not be a true *Elliptio* species. Considering that much of the life history of the Altamaha spinymussel is not well known or documented, management strategies based solely on known *Elliptio* species life histories may not be optimal.

The currently accepted taxonomic ranking for the Altamaha spinymussel is described below.

Kingdom	Animalia
Subkingdom	Bilateria
Infrakingdom	Protostomia
Superphylum	Lophozoa
Phylum	Mollusca
Class	Bivalvia Linnaeus, 1758
Subclass	Palaeoheterodonta Newell, 1965
Order	Unionoida Stoliczka, 1871
Superfamily	Unionoidea Rafinesque, 1820
Family	Unionidae Rafinesque, 1820
Subfamily	Ambleminae Rafinesque, 1820
Tribe	Pleurobemini Hannibal, 1912
Genus	*Elliptio* Rafinesque, 1819
Species	*Elliptio spinosa* (Lea, 1836) – Altamaha spinymussel

*Retrieved 7/23/2019 from the Integrated Taxonomic Information System on-line database, http://www.itis.gov

2.2 Life History

Freshwater mussels, including the Altamaha spinymussel, have a complex life history (*Figure 2-2*). Males release sperm into the water column, which females take in through their siphons during feeding and respiration. Fertilization takes place inside the shell, and the fertilized eggs are retained in an area of the gills called the marsupium until they develop into mature larva known as glochidia. Glochidia are obligate parasites on suitable host fish, and once mature, glochidia are released by gravid female mussels into the water column where they attach to a host and become encysted on the host's tissue, developing into juvenile mussels (Cummings and Graf 2010, pp. 336-337). Freshwater mussel species vary in both onset and duration of spawning, duration of brooding period (during which developing larvae are held in the marsupial gill chambers), and which fish species serve as hosts.

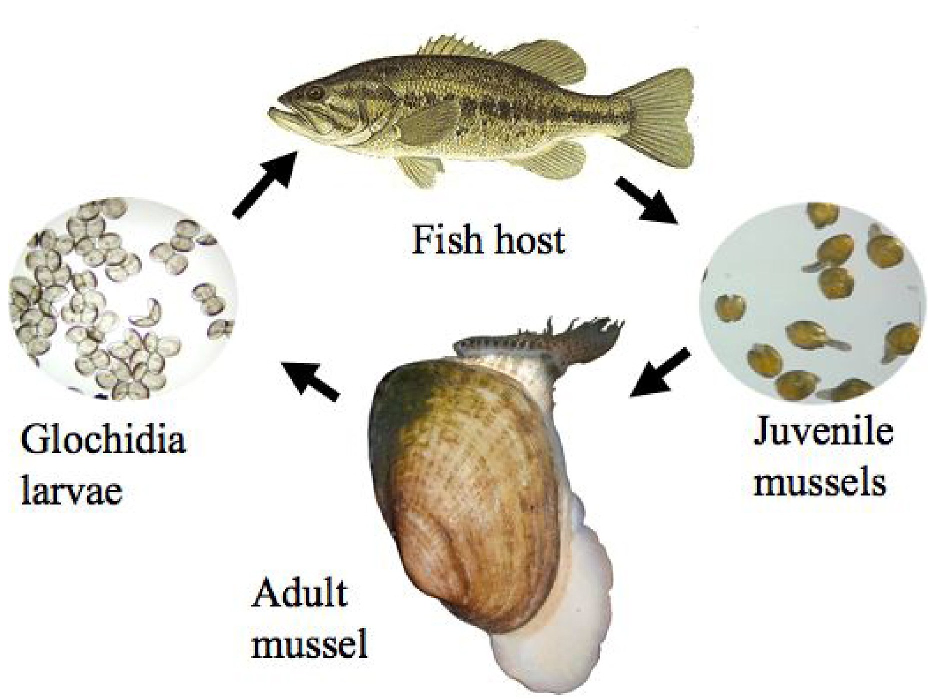

Figure 2-2. Generic illustration of the freshwater mussel reproductive cycle (FMCS 2019).

The life history traits of the Altamaha spinymussel are not currently well known, though the mussel is thought to be a short-term brooder, with spawning occurring in the late spring and glochidia release occurring by May or June (Johnson 2004, p. 2). Host fish trials have been conducted for the Altamaha spinymussel (Johnson 2004, entire; Johnson et al. 2012, entire), however, the results were inconclusive. Johnson (2004, entire) tested glochidia from gravid females collected from the Altamaha River using 12 common fish species, however, no host fish were identified for the spinymussel due to a lack of transformation of glochidia into juveniles (Johnson 2004, p. 3). A number of fish did retain encysted glochidia for more than 30 days: redbreast sunfish (*Lepomis auritus*), bluehead chub (*Nocomis leptocephalus*), flat bullhead (*Ameiurus platycephalus*), pirate perch (*Aphredoderus sayanus*), largemouth bass (*Micropterus salmoides*), and the eastern mosquitofish (*Gambusia holbrooki*; Johnson 2004, p. 3). Similarly, Johnson et al. (2012, p. 734-741) used 10 common southeastern fish species, but was unable to confirm a host fish also due to a lack a metamorphosis from glochidia into juveniles (Johnson et al., 2012, p. 737-739). Of the 10 fish species tested, Altamaha spinymussel glochidia had sloughed from the potential host fish within 5 days after attachment, but remained attached to lake sturgeon (*Acipenser fulvescens*) and redbreast sunfish the longest (4 and 5 days, respectively; Johnson et al. 2012, p. 739). Both studies also note that the quality of glochidia may have been poor, with few mature glochidia available. Furthermore, Johnson (2004, p. 3) suggested that the encystment of glochidia on a wide variety of fish representing multiple families indicates that the Altamaha spinymussel may be a host generalist, capable of transforming on a wide range of hosts.

The life histories of other mussels in the *Elliptio* genus have been studied. In general, mussels in the genus *Elliptio* broadcast free glochidia (larvae) into the water column. This strategy is typical of species that lack adaptations to attract host fish to the female mussel (Barnhart et al. 2008, p. 374-376; Cummings and Graf 2010, p. 337) . The glochidia of *Elliptio* species are often contained in fragile conglutinates (membrane-bound packets of larvae that resemble prey items such as insect larvae) that break up before or during release from the female. Broadcasting mussels are typically host generalists (i.e., they utilize several different types of host fish) and release large quantities of glochidia to increase the odds of glochidia encountering a host fish. However, only a very small proportion of glochidia are likely to encounter a host even when host fish are abundant (Barnhart et al. 2008, p. 375; Cummings and Graf 2010, p. 337). While the reproductive strategy used by the Altamaha spinymussel is not known, both Johnson (2004, p. 2) and Johnson et al. (2012, p. 741) observed gravid females releasing sub-cylindrical white conglutinates, though these conglutinates largely contained immature glochidia. Johnson et al. (2012, p. 744) described the shape of mature glochidia of the spinymussel as being subelliptical, hookless, and similar in shape to other *Elliptio* species (*Figure 2-3*). Hookless glochidia of mussels that release conglutinates generally attach to gills (Cummings and Graf 2010, p. 337).

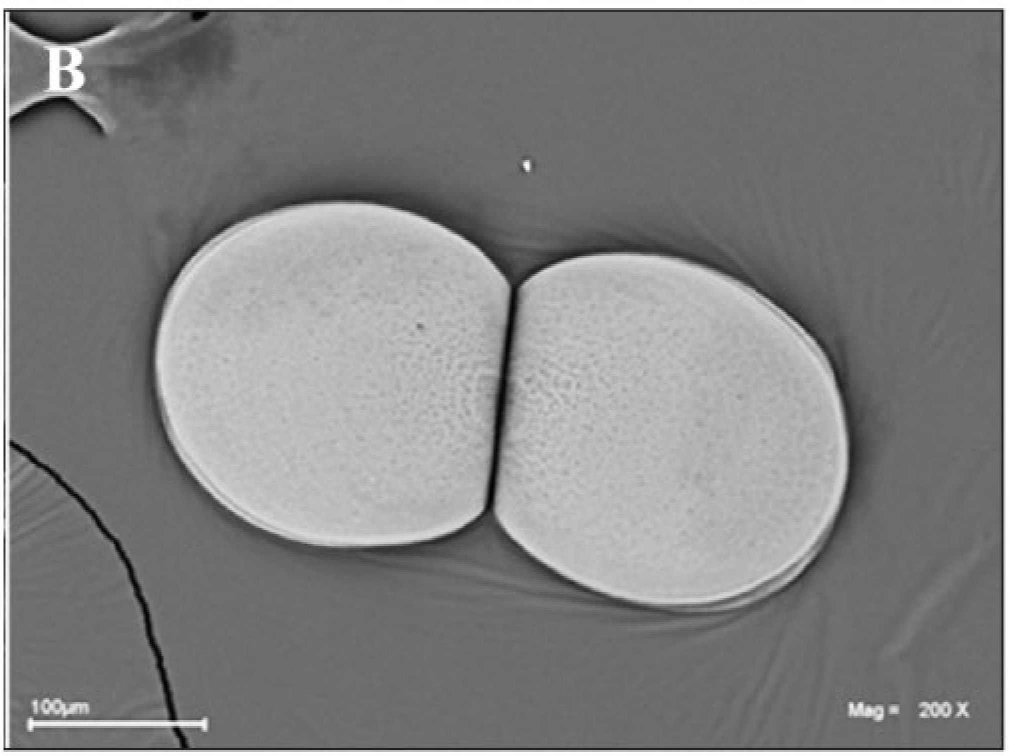

Figure 2-3. Scanning electron microscope image of hookless Altamaha spinymussel (Elliptio spinosa) glochidia. Image reproduced from Johnson et al. (2012, p. 741).

Neither longevity nor age at sexual maturity are known for the Altamaha spinymussel. Additionally, these values can be difficult to extrapolate since other members of the genus *Elliptio* vary greatly in their maximum age from short to long-lived (range: 14 – 57 years; Haag and Rypel 2011, p. 228-230, 234). Similarly, variable age at maturity has been documented for *Elliptio* species. Longer lived *Elliptio* typically reach maturity between 4 – 7 years, while some *Elliptio* species mature much earlier, between 1 – 2 years (Haag 2012, p. 194-196).

2.3 Genetics

Genetics of the Altamaha spinymussel have not been well-studied. Perkins et al. (2017 pp. 753-754), described above in Section 2.1, represents the most robust genetic investigation that has been conducted for the Altamaha spinymussel.

2.4 Diet

The diet of the Altamaha spinymussel is likely similar to that of other freshwater bivalves, and includes food items such as detritus (disintegrated organic debris), algae, diatoms, and bacteria (Vaughn et al. 2008, pp. 410-411). Adult freshwater mussels are filter feeders and generally orient themselves on or near the substrate surface to take in food and oxygen from the water column by siphoning water into their shells and across four gills that are specialized for food collection and respiration. Juveniles lack developed filter feeding structures and typically feed using their large muscular foot (pedal feeding) until those structures are more fully developed. Juveniles burrow completely beneath the substrate surface, bringing food particles inside the shell for ingestion by extending their foot to collect fine organic particles from the substrate using ciliary tracts on their foot (Yeager et al. 1994, pp. 219-220; Cummings and Graf 2010, p. 325).

2.5 Habitat

The Altamaha spinymussel is endemic to the main stem of the Altamaha River and its larger tributaries (greater than 500 cubic feet per second mean monthly discharge (MMD)), and is not known to occur in smaller tributaries, lakes, or ponds. Spinymussels are generally associated with stable, coarse-to-fine sandy sediments of sandbars, sloughs, and mid-channel islands, and they appear to be restricted to swiftly flowing water (Sickel 1980, p. 12). Flowing water maintains the river bottom, sandbars, sloughs, and mid-channel islands habitat where this species is found, transports food items to the sedentary juvenile and adult life stages of the Altamaha spinymussel, removes wastes, and provides oxygen for respiration for this species. Sandbars, sloughs, and mid-channel islands provide space for the spinymussel and also provide cover, shelter, and sites for breeding, reproduction, and growth of offspring. These are dynamic habitats formed and maintained by water quantity, channel slope, and sediment input to the system through periodic flooding, which maintains connectivity and interaction with the flood plain.

The ranges of standard physical and chemical water quality parameters (such as temperature, dissolved oxygen, pH, and conductivity) that define suitable habitat conditions for the Altamaha spinymussel have not been investigated. However, as relatively sedentary animals, mussels must tolerate the full range of such parameters that occur naturally within the streams where they persist. Both the amount (flow) and the physical and chemical conditions (water quality) where this species currently exists vary widely according to season, precipitation events, and seasonal human activities within the watershed. Conditions across their historical range varies even more due to geology, geography, and differences in human population densities and land uses. In general, the species survives in areas where the magnitude, frequency, duration, and seasonality of water flow is adequate to maintain stable sandbar, slough, and mid-channel-island habitats (for example, sufficient flow to remove fine particles and sediments without causing degradation), and where water quality is adequate for year-round survival (for example, moderate to high levels of dissolved oxygen, low to moderate input of nutrients, and relatively unpolluted water and sediments). Thermal tolerance data do not exist for the spinymussel or other Altamaha mussel species. The best available data to approximate spinymussel thermal tolerance is found in Pandolfo et al. (2010*a*, p. 959), which determined a low 48-hr LT50 (median lethal temperature) to be 33.8 °C, although the test species in Pandolfo et al. (2010*a*) all occur several degrees of latitude north of the Altamaha River, suggesting that a more southerly species may have greater thermal tolerance.

2.5.1 Critical Habitat

Based on current knowledge of the life history, biology, and ecology of the species, the Service has determined that the primary constituent elements, used in designating critical habitat, for the Altamaha spinymussel are:

> (1) Geomorphically stable river channels and banks (channels that maintain lateral dimensions, longitudinal profiles, and sinuosity patterns over time without an aggrading or degrading bed elevation) with stable sandbar, slough, and mid-channel-island habitats of coarse-to-fine sand substrates with low to moderate amounts of fine sediment and attached filamentous algae.
>
> (2) A hydrologic flow regime (the magnitude, frequency, duration, and seasonality of discharge over time) necessary to maintain benthic habitats where the species are found and to maintain connectivity of rivers with the floodplain, allowing the exchange of nutrients and sediment for sand bar maintenance, food availability, and spawning habitat for native fishes.
>
> (3) Water quality necessary for normal behavior, growth, and viability of all life stages, including specifically temperature (less than 32.6 °C (90.68 °F) with less than 2 °C (3.6 °F) daily fluctuation)), pH (6.1 to 7.7), oxygen content (daily average DO concentration of 5.0 mg/l and a minimum of 4.0 mg/L), an ammonia level not exceeding a maximum of 1.5 mg N/L or continuous exposure of 0.22 mg N/L (normalized to pH 8 and 25 °C (77 °F)), and other chemical characteristics.

(4) The presence of fish hosts (currently unknown) necessary for recruitment of the Altamaha spinymussel. The continued occurrence of diverse native fish assemblages currently occurring in the basin will serve as an indication of host fish presence until appropriate host fishes can be identified for the Altamaha spinymussel.

Four critical habitat units have been designated for the Altamaha spinymussel, totaling 237.4 km (147.5 mi) of occupied and unoccupied stream habitat (*Table 2-1*). Units 1, 2, and 3 contain all of the above-listed primary constituent elements. Unit 4 (Lower Ohoopee River) currently meets primary constituent elements 1, 2, and 4, but did not meet the water quality requirement as of listing in 2011. The Ohoopee still does not currently meet state water quality standards for mercury based on fish tissue concentrations.

Table 2-1. Altamaha spinymussel critical habitat units and ownership of adjacent lands.

Unit	Location	Occupancy	Total length km (mi)	Private* km (mi)	Conservation/ private* km (mi)	Conservation km (mi)
1	Ocmulgee River	Occupied	110 (68.3)	89.2 (55.4)	14.3 (8.8)	6.4 (4.0)
2A	Upper Altamaha River A	Occupied	31.4 (19.5)	2.7 (1.7)	21.6 (13.4)	7.1 (4.4)
2B	Upper Altamaha River B	Occupied	30.7 (19.1)	22.9 (14.2)	7.8 (4.9)	0 (0)
3	Middle Altamaha River	Occupied	50.9 (31.6)	18.8 (11.7)	32.1 (19.9)	0 (0)
4	Lower Ohoopee River	Unoccupied	14.4 (9.0)	14.4 (9.0)	0 (0)	0 (0)
Total			237.4 (147.5)	148 (92)	75.9 (47)	13.4 (8.4)

* Ownership is categorized by private ownership on both banks of the river (Private), conservation area on one bank and private on the other (Conservation/Private), and conservation area on both banks (Conservation).

Critical habitat units 1, 2, and 3 are contiguous, making them vulnerable to a catastrophic event that could eliminate all known occupied habitat for the Altamaha spinymussel. Therefore, designating critical habitat on non-contiguous stream segment (i.e., the Lower Ohoopee River unit) significantly reduces the impact of stochastic threats to the species' survival and is essential to the conservation of the species.

2.6 Distribution and Abundance

The historical range of the Altamaha spinymussel was restricted to the Coastal Plain portion of the Altamaha River and the lower portions of its three major tributaries: the Ohoopee, Ocmulgee, and Oconee Rivers. The Altamaha River is formed by the confluence of the Ocmulgee and Oconee rivers and lies entirely within the State of Georgia. This mussel is known only from Georgia in Glynn, Ben Hill, McIntosh, Telfair, Tattnall, Long, Montgomery, Toombs, Wheeler, Appling, Jeff Davis, Coffee, and Wayne Counties (*Figure 2-4*). Despite fairly extensive historical collections, the species has never been collected from a tributary smaller than the Ohoopee River.

Comprehensive, targeted surveys for the Altamaha spinymussel have been conducted since the 1960s (Keferl 1993, pp. 299-300), and the most recent surveys have revealed a dramatic decline in recruitment, the number of populations, and number of individuals within populations throughout the species' historic range (Keferl 1995, pp. 3-6; Stringfellow and Gagnon 2001, pp. 1-2; Wisniewski et al. 2005, pp. 2-3).

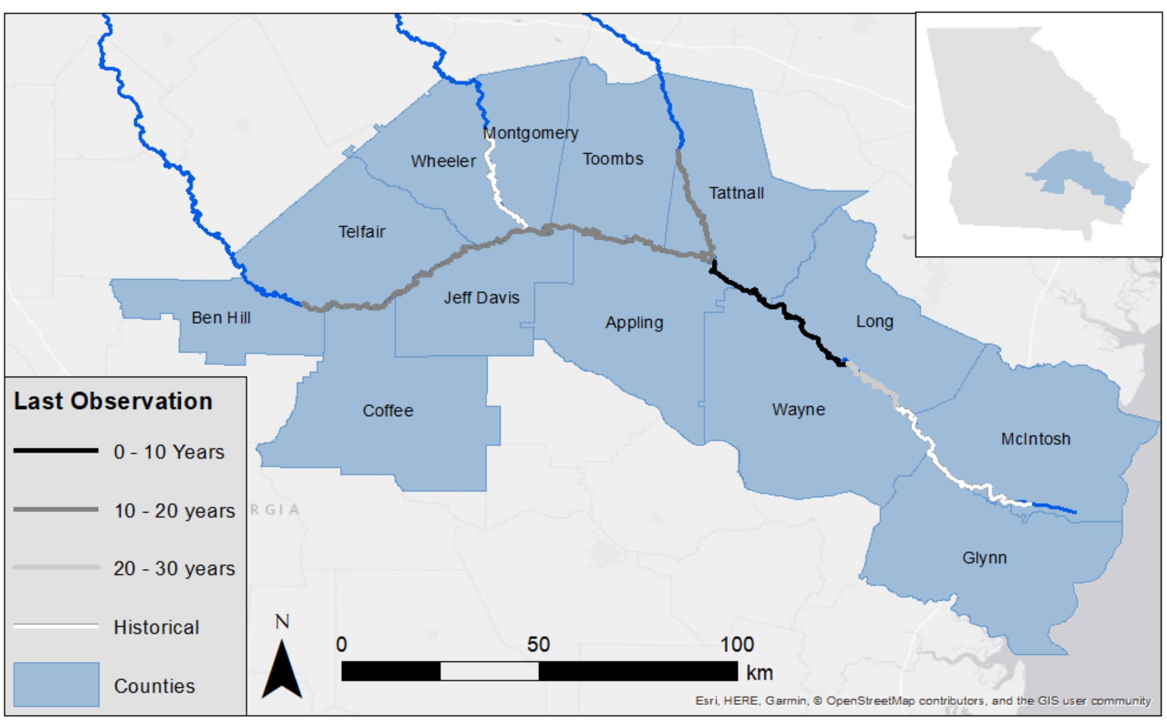

Figure 2-4. Distribution of the Altamaha spinymussel, categorized by how recently live specimens have been observed ("current" year for reference is 2020).

2.6.1 Altamaha River

Most surveys conducted for the Altamaha spinymussel have occurred in the Altamaha River. Early surveys documented Altamaha spinymussels in the Lower Altamaha River near Fort Barrington, where several live spinymussels and hundreds of pairs of dead shells had been found, roughly 20 miles (32 km) downstream of Route 301 (Tomkins 1955, p. 132). The known range was extended upstream to Jesup and into the Ocmulgee River by Thomas and Scott (1965, pp. 66-67). Historical surveys beginning in the 1960s documented several collections of live individuals at U.S. Route 301 near Jesup, GA and downstream of U.S. Route 1 (Sickel 1980, p. 11). In 1972, over a dozen freshly dead spinymussel shells were collected just above the Route 301 crossing in what appeared to be a major die-off of mussels of many species and sizes (Williams 2020, pers. comm.). From 1993 to 1996, comprehensive surveys occurred throughout the main stem of the Altamaha River from the Ocmulgee–Oconee River confluence downstream to the Interstate 95 crossing near the river's mouth, encompassing approximately 189 river km (117 river mi; Keferl 1993, 1995, entire). Of the 164 sites surveyed, live Altamaha spinymussels were detected at 18 sites, primarily located between the Oconee River and U.S. Route 301 (116 river km/72 river mi). Additionally, the mussel beds containing the Altamaha spinymussel were patchily distributed within this reach and often isolated by long distances except for 10 sites occurring within a 4-km (2 mi) reach upstream of the U.S. Route 301 crossing near Jesup. At that time no spinymussels were found below U.S. Route 301, suggesting the species may be absent from this reach, or occurs in such low numbers as to be undetectable between U.S. Route 301 and the river's mouth (73 river km/45 river mi).

Subsequent surveys in the early 2000s documented similar results. Several sites were surveyed in the upper Altamaha River from the confluence of the Ocmulgee and Oconee Rivers downstream to U.S. Route 301 and the Altamaha spinymussel was primarily detected within a short reach of the Altamaha River just upstream of the U.S. Route 301 crossing near Jesup, GA (O'Brien 2002, pp. 3-4; GDNR 2020 n.p..). In September 2020, preliminary surveys of 5 previously occupied sites between Route 301 and the GA 144 bridge failed to find live or shell remnants of spinymussels, though large numbers of other mussel species were detected (Rowe 2020*a*, pers. comm.).

2.6.2 Oconee River

Historical records of Altamaha spinymussels from the Oconee River are scant. The only known record from the Oconee River was collected in 1964 by H.D. Athearn. At the time, Athearn collected 18 specimens near Mt. Vernon, GA, which appears to be the upstream extent of its known historical distribution (Johnson et al. 2008, Athearn database). The species has not been observed in the Oconee since that initial collection and is likely extirpated from the Oconee River system. In 1995, as part of a dam relicensing study, 41 sites encompassing 114 river km (71 river mi) between Lake Sinclair and Dublin, GA were surveyed for a total of 144 hours (EA Engineering 1995, pp. 1–1, 3–1, 3–2, 4–2, and 4–3). A total of 118 live mussels representing 7 species were collected, however, no Altamaha spinymussels were detected. Compared to the other rivers within the spinymussel's range, the Oconee River has not been extensively surveyed.

2.6.3 Ohoopee River

Historical records of the Ohoopee River from the early 1980s indicate the Altamaha spinymussel occurred in the lower portion of the river (Keferl 1981, p. 12) and was prevalent at the majority of the survey sites within the lower 8 km (5 mi) of the river (Keferl 1981, pp. 13-14). Spinymussels were not detected in the upper reaches of the watershed, presumably because the flows were insufficient to support the species. Since the early 1990s, only 1 live specimen has been observed in the Ohoopee River, found in 2005 (GDNR 2020, n.p.).

2.6.4 Ocmulgee River

The Altamaha spinymussel is known historically within the Ocmulgee River from its confluence with the Oconee River upstream to Red Bluff, GA in Ben Hill County, which encompasses approximately 110 km (68 mi). Early collecting efforts in the Ocmulgee River near Lumber City in the 1960's yielded robust numbers of live Altamaha spinymussels. Athearn collected 40 live spinymussels downstream of U.S. Highway 341 near Lumber City in 1962 (Johnson et al. 2008, Athearn database), while subsequent surveys in the 1960s extended the range of the Altamaha spinymussel to Red Bluff, GA in Ben Hill County (Thomas and Scott 1965, p. 67).

However, results from numerous surveys conducted in the lower Ocmulgee River from 1993 to 2004 indicate that the Altamaha spinymussel had declined significantly from its historical numbers (Keferl 1995, p. 1; Cammack et al. 2001, p. 11; O'Brien 2002, p. 2; Dinkins et al. 2004, pp. 1–1, 2–1). Of the over 90 sites surveyed since 1993, a total of 19 live Altamaha spinymussels were detected at only 10 sites, distributed from Jacksonville, GA downstream to the Oconee River confluence.

2.7 Individual Needs Summary

Resource needs for the Altamaha spinymussel to complete its life cycle are summarized below.

Table 2-2. Altamaha spinymussel individual needs.

Life Stage	Resources and/or circumstances needed for individuals to complete each life stage	Resource Function (BFSD*)	Information Source
Fertilized Eggs - late spring	• Flowing water • Sexually mature males upstream from sexually mature females • Appropriate spawning temperatures • Presence of gravid females	B	- Berg et al. 2008 - Haag 2012
Glochidia - late spring to early summer	• Flowing water • Presence of suitable host fish for attachment • Adequate water quality o See adult water quality needs, glochidia likely more vulnerable to pollutants than adults	B, D	- Johnson 2004 - Wang et al. 2007 -Shoults-Wilson 2008 - Haag 2012
Juveniles - excystment from host fish to ~30 mm in size**	• Flowing water • Host fish dispersal • Adequate water quantity to inundate suitable habitat • Adequate water quality - See adult water quality needs, juveniles likely more vulnerable to pollutants than adults • Appropriate substrate: Coarse-to-fine sand with low to moderate amounts of fine sediment and attached filamentous algae • Adequate food availability (detritus, algae, diatoms, bacteria)	F, S	- Sickel 1980- Wang et al. 2007 -Shoults-Wilson 2008 - Vaughn et al. 2008

Adult
> ~30 mm in size**
	• Flowing water
	• Appropriate substrate: Coarse-to-fine sand with low to moderate amounts of fine sediment and attached filamentous algae
	• Adequate food availability (detritus, algae, diatoms, bacteria)
	• Adequate water quality
	  - Temperature < 32.6 °C (90.68 °F) with < 2 °C (3.6 °F) daily fluctuation
	  - pH 6.1 to 7.7
	  - Dissolved oxygen > 4.0 mg/L
	  - Low levels of heavy metals and other pollutants
		B, F, S	- Sickel 1980
			-Augspurger et al. 2003
			- Vaughn et al. 2008
			- Pandolfo et al. 2010*a*, 2010*b*

* B=breeding; F=feeding; S=sheltering; D=dispersal

** Size at maturity is not known for the Altamaha spinymussel, 30 mm is an estimate inferred from other *Elliptio* mussels

3 INFLUENCES ON VIABILITY

In this section, we describe the influences on the needs and viability of the Altamaha spinymussel (*Figure 3-1*) within the framework of the five factors which can contribute to the listing of a species as threatened or endangered under the Endangered Species Act, and then discuss positive influences on the viability of the species.

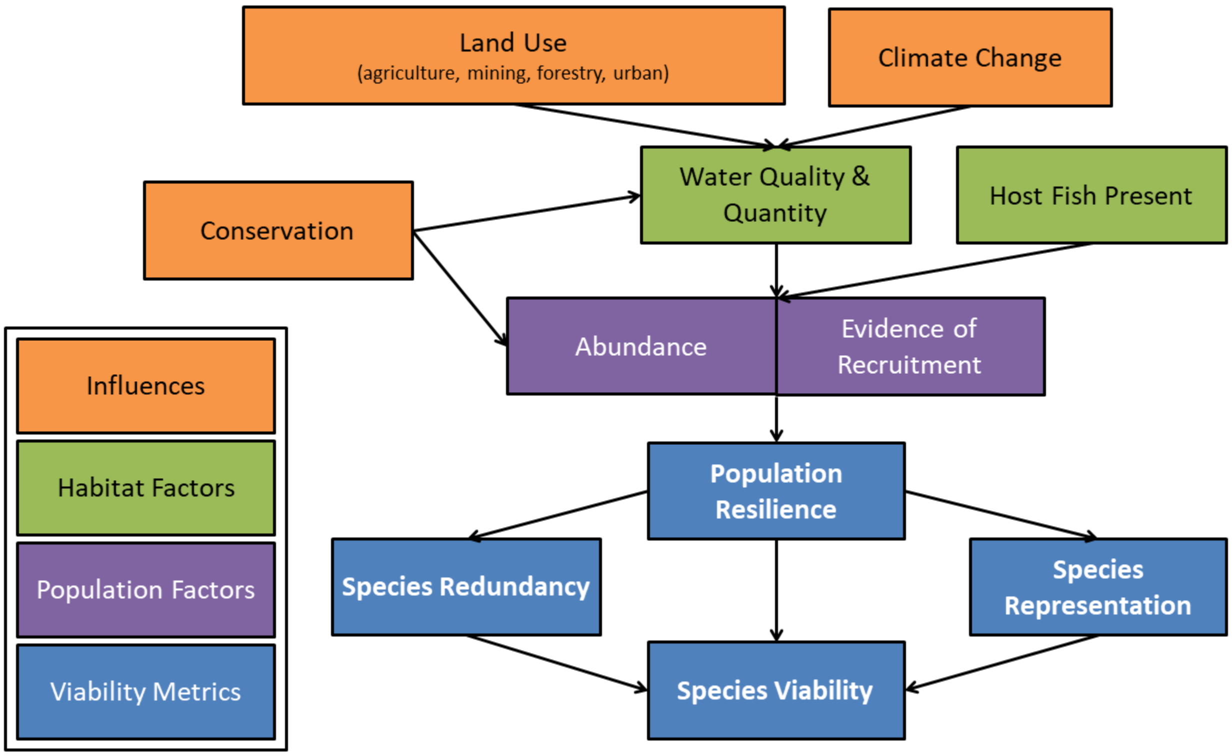

Figure 3-1. Influence diagram illustrating relationships between key habitat and population factors, influences on these factors, and species viability. This diagram does not represent a comprehensive view of all factors and influences on Altamaha spinymussel viability but highlights key components.

3.1 Factor A: Habitat destruction and modification

Influences on the viability of the species that result in the destruction or modification of Altamaha spinymussel habitat include sedimentation and water quality degradation.

3.1.1 Sedimentation

Optimal substrate for the Altamaha spinymussel is predominantly silt-free, detritus-free, stable sand (Sickel 1980, p. 12). The role of sedimentation in mussel declines in wild populations is not well understood (Haag 2019, p. 54), but there are several mechanisms by which sedimentation could negatively influence spinymussel fitness. Sediments deposited on the sandbar habitats associated with the Altamaha spinymussel could affect substrate stability, alter the composition of the substrate, or result in suffocation, making the habitat unsuitable for the species. Deposited fine sediments can negatively affect aquatic communities by filling interstitial spaces in the substrate leading to low oxygen and flow rates which can negatively impact the respiration, growth, reproductive success, and behavior of benthic organisms and fish (Waters 1995, pp. 173-175), and reduce the available habitat space for benthic organisms, particularly juvenile mussels (Brim Box and Mossa 1999, p. 100). Sediment deposition can also result in rapid changes beyond the stream bed such as alteration of channel morphology, stream channel position, channel shape, and bed elevation (Brim Box and Mossa 1999, p. 102). Excessive sedimentation can destroy mussel habitat, resulting in a corresponding shift in mussel fauna (Brim Box and Mossa 1999, p. 100). Turbidity resulting from suspended fine particles governs light penetration, which affects primary production (Brim Box and Mossa 1999), thermal regimes (Ellis 1936, p. 39-40), and can interfere with the visual cues mussels use to attract host fish (Brim Box and Mossa 1999, pp. 101-102). Sedimentation has also been shown to impair the filter feeding ability of mussels. When in high silt environments, mussels, particularly juveniles, experience reduced feeding rates, though mussels that evolved in highly turbid environments can have anatomical adaptations that make feeding more efficient (Tuttle-Raycraft 2017, pp. 1164-1167, Tuttle-Raycraft 2019, pp. 2530-2534).

Historical agricultural practices in the Southern Piedmont physiographic province resulted in extreme soil erosion and excess sedimentation inputs into nearby rivers and streams. The Ocmulgee, Oconee, and Ohoopee rivers drain the Piedmont region and sediment from these practices moved into stream channels and valleys, covering most of the original bottomlands (Trimble 1974, p. 26). Current sediment loads in the Altamaha River Basin resulted from historical agricultural practices and a legacy of past land use (EPD 2012, p. v). The mobilization of legacy sediments, principally through lateral migration of stream channels and bank erosion is an ongoing threat as it moves downstream covering suitable habitat (Jackson et al. 2005, p. 10) and has had a documented effect on fish populations within small tributaries of the Altamaha River basin (EPD 2012, pp. 11-15).

In addition to agriculture, forestry practices, mining activities, cattle grazing, and urban development have also been identified as contributing nonpoint sources of sediment within the region (EPD 2012, p. v). Forestry practices that involve the harvesting of trees up to the streambank can decrease bank stability, cause direct soil erosion into the stream, and increase runoff with resultant increases in water turbidity and scouring of the streambed, all of which can create unsuitable or unstable habitat for mussels (58 FR 49936). Streams that lose vegetated riparian buffers suffer a loss in the natural ability to filter sediment, debris, and pollutants. When trees are removed from alongside streams, the more open areas are more visible and provide easier access to the channel for humans and animals. Commercial forest management in the late 1990s was practiced on approximately 40,000 acres (or 33 percent) of the floodplain of the Altamaha River (TNC and GDNR 1997, p. 19). The Georgia Forestry Commission (GFC) is responsible for implementing the use of Best Management Practices (BMPs) to reduce erosion and sediment from activities related to forestry, such as timber harvest, haul road construction, stream crossings, stream side management zones, site preparation, and reforestation. However, the Erosion and Sediment Control Act (O.C.G.A. 12–7–1) exempts commercial forestry activities from the need to acquire permits and meet the minimum requirements of that act (GFC 2009, p. 64). Therefore, compliance with BMPs is voluntary and is dependent on education about BMPs to reduce sediment from reaching the Altamaha River.

Within the Oconee and Ocmulgee River basins, several kaolin mines are located along the Fall Line, a geologic land form that separates the Piedmont and Coastal Plain physiographic provinces. The operation of these mines and their supporting infrastructure, including haul roads and settling ponds, have the potential to increase downstream sediment loads if adequate erosion control measures are not maintained to stabilize areas subjected to mining associated ground disturbances (Lasier et al. 2004, p. 139).

3.1.2 Water Quality and Quantity

Changes in water quality and quantity could impact the success of the spinymussel throughout its range. Contaminants associated with agricultural runoff and industrial and municipal effluents, including unpermitted discharges, were identified as potential threats at the time of listing. Contaminants contained in point and nonpoint source discharges can degrade water and sediment quality and adversely impact mussel populations through direct mortality, impacts to reproduction or development, and/or impacts to host fish populations. In laboratory toxicity testing, mussels are among the most sensitive forms of aquatic life to toxicity from metals and major ions including ammonia, chlorine, chloride, copper, nickel, lead, potassium, sulfate, and zinc (Imlay 1973, pp. 103-110; Soucek 2006, pp. 18-20; Wang et al. 2007*a*, p. 2055; 2007*b*, pp. 2044-2046; 2007*c*, pp. 2034-235; 2008, pp. 1143-1145; 2009, pp. 2372-2375; 2010, pp. 2060-262; 2011*a*, pp. 2274-2275; 2011*b*, pp. 2122-2124; 2016, pp. 124-126; 2017, pp. 792-795; March et al. 2007, pp. 2070-2073; Besser et al. 2011, p. 35; 2013, pp. 2500-2501; Gillis 2011, pp. 1706-1707; Ivey et al. 2013, n.p.; EPA 2013, pp. 53-67). However, freshwater mussels do not generally display more sensitivity to most organic contaminants relative to other aquatic species, (Wang et al. 2017, pp. 792-795).

Shoults-Wilson et al. (2010, entire) quantified metal bioaccumulation in Asian clam (*Corbicula fluminea*) tissue from sites throughout the Altamaha River Basin both upstream and downstream of potential point sources and documented significantly higher tissue concentrations of cadmium, copper, and, mercury downstream of a kaolin processing plant, significantly higher tissue concentrations of zinc downstream of a tire cording facility (Americord), and significantly higher tissue concentrations of chromium downstream of a nuclear power plant (Edwin I. Hatch Nuclear Power Plant) and a paper mill (Rayonier pulp mill). While these results suggest that point sources may be contributing metals to the system, the authors did not draw any conclusions regarding the health threat posed to mussels by the observed tissue concentrations. Metal tissue concentration-based toxicity reference values have not been established for freshwater mussels limiting the conclusions that can be drawn from tissue residues.

Shoults-Wilson et al. (2010, entire) also conducted metal bioaccumulation studies using a native and exotic species of freshwater mussel across 14 sites in the Oconee, Ocmulgee, Ohoopee, and Altamaha Rivers, and determined that measured concentrations of metals in water and sediment from the sample sites did not pose a threat to aquatic species. Aqueous copper concentrations in some samples did exceed criteria previously recommended by the EPA, although those criteria were replaced by a recommendation from the EPA to determine site-specific copper criteria based on the biotic ligand model (BLM). Shoults-Wilson et al. (2010) did not determine all water quality parameters required for the BLM but hypothesized that the high concentration of organic matter in the subject waterbodies would have limited copper bioavailability and raised the BLM-calculated criteria value, hypothesizing that the observed copper concentrations were not problematic for aquatic species (pp. 2031-2032).

A natural flow regime that includes periodic flooding and maintains connectivity and interaction with the flood plain is critical for the exchange of nutrients, spawning activities for potential host fish, and sand bar maintenance. In 2007, persistent severe drought conditions throughout the southeastern United States created record low discharges (streamflow) in the Altamaha River at the U.S. Geological Survey (USGS) gauge station in Doctortown, Georgia. During the driest portions of the 2006-2009 drought period, the lowest discharges observed were 25 percent of the MMD for the 77-year period of record for the Doctortown gauge. Historic low flows were also observed in the Altamaha River during 2011 and 2012. Despite record low flows, native unionids (mussels) appeared to persist throughout most of the Lower Altamaha River Basin.

Designated critical habitat for the spinymussel in the Altamaha River Basin is more than 165 km (103 miles) from the nearest reservoir and thus the effects of hypolimnetic discharges on temperature or flow are not considered a threat to the Altamaha spinymussel.

3.2 Factor B: Overutilization

The Altamaha spinymussel is not harvested for consumption or commercial activities. It is not a commercially valuable species, nor are the streams it inhabits subject to harvesting for commercial mussel species. Illegal collecting for commercial or private use could pose a threat to this species as its rarity becomes known, particularly because this species has previously been sought for scientific and private collections. Overcollection may have been a localized factor in the decline of this species, particularly in the Ohoopee River where a 1986 collection consisted of at least 30 live individuals (Keferl 2020, pers. comm.). There is some need for collection of the species for research purposes. Obtaining a federal research permit and a state permit is required, which involves cooperation and consultation with the Service and with GDNR to develop measures to minimize potentially adverse impacts to the population. Therefore, overutilization for commercial, recreational, scientific, or educational purposes is not considered a threat to the Altamaha spinymussel at this time.

3.3 Factor C: Disease or predation

No studies have examined the fitness of the Altamaha spinymussel. Diseases of freshwater mussels are not well-studied, and there is no evidence indicating that disease poses a threat to the Altamaha spinymussel. Juvenile and adult mussels are prey items for some invertebrate predators and parasites (for example, nematodes [Phylum Nematoda], trematodes [Class Trematoda], and mites [Subclass Acari, ticks and mites]), and provide prey for a few vertebrate species (for example, raccoons [*Procyon lotor*], otters [*Lontra canadensis*], fish, and turtles [Order Testudines]; Hart and Fuller 1974, pp. 225–240). There is no evidence that native predators pose a significant threat to the Altamaha spinymussel. However, it is possible that since the introduction of the predatory flathead catfish (*Pylodictis olivaris*) into the Altamaha Basin, this species might pose a threat to the host fish (as yet unknown) for the Altamaha spinymussel.

3.4 Factor D: Inadequacy of existing regulation

The inadequacy of existing regulatory mechanisms was identified as a threat to the Altamaha spinymussel in the final rule. The Altamaha spinymussel is currently protected under sections 7 and 9 of the Endangered Species Act and is protected at the state level by Georgia's Endangered Wildlife Act (EWA).

<u>*Nonpoint Source Pollution*</u>

Sources of nonpoint source pollution that may impact mussel habitat include agricultural runoff, timber operations, urbanization, and road construction, especially when sediment is allowed to enter streams (TNC 2004, p. 8-10). Construction activities that are performed according to Best Management Practices (BMPs) can retain adequate conditions for aquatic ecosystems, however, when BMPs are not followed, these activities can cause impacts to aquatic habitat when compliance, monitoring, and enforcement of these recommendations is poorly implemented. Additionally, Georgia's Erosion and Sediment Control Act exempts commercial forestry activities from the need to acquire permits and meet the minimum requirements of the Erosion and Sediment Control Act (GFC 2009, p. 64). While self-reported compliance rates are high in the state (~95 percent), compliance with BMPs is voluntary and is dependent on education and proper implementation of BMPs to reduce sediment from reaching the Altamaha River. Regulation of nonpoint source pollution is challenging as there are no end-of-pipe sources to monitor and specific discharge permits are not issued.

<u>*Point Source Pollution*</u>

Under the Clean Water Act, point source dischargers are required to obtain discharge permits as part of the National Pollutant Discharge Elimination System (NPDES). The pollutant loads permitted by discharge permits are based on approved water quality standards developed primarily through the results of laboratory-based toxicity testing. Currently, the available toxicity data for freshwater mussels is limited in comparison to other more common test species, including fish and benthic insects. The protectiveness of water quality standards for freshwater mussels is uncertain in instances where mussel toxicity data for a specific pollutant is lacking. As water quality standards are updated using additional data on freshwater mussel pollutant sensitivities, confidence in the protectiveness of water quality standards for freshwater mussels should increase. .

3.5 Factor E: Other natural or man-made factors

Climate Change and Drought

Climate change has the potential to increase vulnerability of the Altamaha spinymussel to random catastrophic events or alter habitat suitability within the species range. The climate in the southeastern United States has warmed about 1°C (about 2 °F) from a cool period in the 1960s and 1970s and is expected to continue to rise (Carter et al. 2014, p. 398-399). Inter-annual variability in precipitation has been increasing over the last several decades, with this region exhibiting either exceptionally wet or exceptionally dry summers (Groisman and Knight 2007, p. 1855; Wang et al. 2010, p. 1009). Various emissions scenarios suggest that, by the end of the 21st century, average global temperatures are expected to increase 0.3 °C to 4.8 °C (0.5 °F to 8.6 °F), relative to the period 1986–2005 (IPCC 2014, p. 10). By the end of 2100, it is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, and it is very likely that heat waves and extreme precipitation events will occur with a higher frequency and intensity (IPCC 2014, p. 15-16). Projections for future precipitation trends in the Southeast are less certain than those for temperature, but suggest that overall annual precipitation will decrease, and that tropical storms will occur less frequently, but with more force (more category 4 and 5 hurricanes) than historical averages (Carter et al. 2014, p. 399). Warmer temperatures and decreased precipitation will increase water temperatures, change runoff regimes, and increase the frequency, duration, and intensity of droughts in the southeastern United States (Poff et al. 2002, p. ii-v). Droughts cause decreases in water flow and dissolved oxygen levels and increases in temperature in stream systems.

The unique life history traits of freshwater mussels make them especially vulnerable to climate-induced changes. For example, freshwater mussels are largely sedentary and have a limited ability to seek refugia from disturbances such as droughts and floods. Additionally, they are thermo-conformers whose physiological processes are constrained by water temperature within species-specific thermal preferences, such that changes in water temperature can lead to shifts in mussel community structure (Galbraith et al. 2010, p. 1176).

Direct effects of drought on the Altamaha spinymussel (e.g., effects of increased surface water temperature, decreased dissolved oxygen levels, increased ammonia levels, decreased habitat area) have not been well-studied range-wide. Indirectly, drought conditions increase access to the riverbed for all-terrain vehicles (ATVs; see next section) for smaller rivers like the Ohoopee, which can directly or indirectly impact spinymussels and their habitat (Stringfellow and Gagnon 2001, p. 3; Keferl 2020, pers. comm.). While the specific tolerances of the Altamaha spinymussel are not well-studied, mussel declines as a direct result of drought have been documented in the Southeastern U.S. (Golladay et al. 2004, p. 494; Haag and Warren 2008, p. 1165). Drought conditions were prevalent in Georgia between 1998 and 2002, between 2006 and 2009, and again between 2011 and 2012, which may have negatively affected the Altamaha spinymussel. In particular, the Ohoopee River and many other streams in the basin suffered reduced flow rates and low water levels in the main channel during summer surveys (Stringfellow and Gagnon 2001, p. 3). Mussels may bury themselves in the river bottom as a mechanism to survive a drought, however during prolonged periods of drought, mortality due to desiccation can be high and may have negatively impacted remaining Altamaha spinymussel populations in the river (Keferl 2019, pers. comm.).

Reduction in local water supplies due to drought is also compounded by increased human demand and competition for surface and ground water resources for power production, irrigation, and consumption (Golladay et al. 2004, p. 504). Withdrawal of surface water within the Altamaha Basin for thermoelectric power generation, public water supplies, commercial industrial uses, and agriculture has a dramatic effect on flow rates (Marella and Fanning 1996, pp. 14-17). Such removals can cause drastic flow reductions and alterations that may strand mussels on sandbars resulting in mortality of individuals and negative impacts to populations. As development pressures continue to grow, water withdrawals are expected to increase.

All-Terrain Vehicles

Recreational use of ATVs in Altamaha spinymussel watersheds can decrease bank stability and lead to gully formation and heavy silt loading into streams, reducing instream water quality rates (TNC 2004, p. 12; Stringfellow and Gagnon 2001, p. 3). During low flow events, vehicles may directly crush mussels if they enter streams where mussel beds occur. During a survey in 2001, Stringfellow and Gagnon (2001, p. 3) observed heavy ATV and four-wheel drive vehicle traffic and high levels of erosion near bridges and homes. Observations on the Ohoopee River during low flow in October of 2006 revealed extensive ATV traffic that destroyed mussel beds (Rickard 2006, personal observation), and slugs of sediments over 2 feet high have been observed moving down the Ohoopee river after storms hit destabilized banks (Keferl 2020, pers. comm.).

Nuisance and Invasive Species

Non-native species such as the flathead catfish and the Asian clam have been introduced to the Altamaha Basin and may be having an adverse effect on spinymussels and other native species.

The flathead catfish has become the dominant predator in the Altamaha River and potential host fish such as bullhead catish species and redbreast sunfish have suffered population declines. If one of these species is the host for the Altamaha spinymussel, its breeding success and recruitment could be reduced.

The Asian clam is a freshwater bivalve that is believed to compete with native mussels for resources such as food, nutrients, and space (Kraemer 1979, pp. 1092, 1094). High densities of Asian clams have been found to negatively affect the survival and growth of juvenile native mussels via disturbance and displacement of young juveniles and possibly through incidental ingestion of glochidia and newly metamorphosed individuals (Strayer 1999, p. 82; Yeager et al. 1999, p. 255). Dense Asian clam populations may deplete the edible suspended particles as well as deplete the benthic food particles ingested by native subadult mussels and starve the native bivalves (Strayer 1999, pp. 79, 83). Further, Asian clam populations can grow rapidly and are prone to rapid die-offs (Sousa et al. 2008, p. 90), which may affect native mussels when decomposition depletes the oxygen supply and produces high levels of ammonia (Strayer 1999, p. 82). Surveys within the Altamaha Basin have found large numbers of Asian clams for more than 25 years (Gardner et al. 1976, pp. 118–124; Stringfellow and Gagnon 2001, p. 2), but it is not clear how they are affecting the Altamaha spinymussel.

Recruitment

Factors such as low effective population size, genetic isolation, relatively low levels of fecundity and recruitment, and limited juvenile survival could all affect the ability of this species to maintain current population levels and to rebound if a reduction in population occurs (e.g., predation, toxic releases or spills, or poor environmental conditions that inhibit successful reproduction). The most recent comprehensive survey efforts for the Altamaha spinymussel, which occurred prior to the 2011 listing, have shown small, fragmented occurrences across its range at numbers below historical survey observations. The probability of successful reproduction in a broadcast spawner such as the Altamaha spinymussel is reduced as the number of sexually mature individuals decreases.

Genetic Diversity

A loss of genetic diversity is also a concern for small, fragmented populations of a species. Isolation of Altamaha spinymussel populations results in limited or no genetic interchange, leading to increased risks of genetic bottlenecks and inbreeding depression, potentially resulting in reduced reproductive output, survivorship, and potential to adapt to future environmental changes.

Host Fish

The specific host fish for the Altamaha spinymussel has not been identified. This lack of information limits the ability to evaluate the current status of and potential threats to the host fish, thus also limiting our understanding of the current and future status of the Altamaha spinymussel.

3.6 Conservation Efforts

Future recovery of the Altamaha spinymussel will depend on conservation efforts to manage threats from: degraded water quality from pollution and land use practices; off-road vehicle use; construction activities; other watershed and floodplain disturbances that release sediments or nutrients into the water, including threats from mining and agriculture; and lack of knowledge regarding reproductive life history.

Several conservation organizations are active in the Altamaha River Basin. The Nature Conservancy (TNC) maintains an office on the Altama Plantation Wildlife Management Area adjacent to the Lower Altamaha River. TNC has aided in the protection of lands within the Altamaha River Basin through acquisitions and the securing of conservation easements on private properties. GDNR owns and manages multiple large priority conservation areas, in the form of wildlife management areas, along the Altamaha and Ocmulgee Rivers. The Altamaha Riverkeeper advocates for the health of the Altamaha River Basin and monitors the environmental quality of waterbodies in the Altamaha River Basin and upland land-based activities that may impact the Altamaha River and its tributaries.

One strategy often employed to bolster declining mussel populations is captive propagation or population restoration via augmentation, expansion, and/or reintroduction efforts. However, attempts to identify the host fish for the Altamaha spinymussel have been unsuccessful. Without more comprehensive knowledge on the reproductive life history of the Altamaha spinymussel, reintroductions would have to be sourced from wild populations, which may not be feasible at this time without negatively impacting the viability of donor populations. Identifying the host fish of the Altamaha spinymussel is thus a critical need for the conservation of this species.

4 POPULATION AND SPECIES NEEDS AND CURRENT CONDITION

As the population is the basic unit of resiliency, which is then scaled up to redundancy and representation at the species level, appropriately defining and delineating populations is a crucial step to assess species viability. After delineating populations, we then assessed the resiliency of each population by synthesizing the best available information about the population and habitat needs of the species. Population resiliency was then scaled up to describe current redundancy and representation for the Altamaha spinymussel range-wide.

4.1 Delineating Populations

For the purpose of this SSA, we delineated four populations of Altamaha spinymussel in accordance with guidance from species experts (Keferl 2019, pers. comm., Rowe 2019, pers. comm.; Wisniewski 2019, pers. comm.). These populations are: Oconee, Ohoopee, Ocmulgee/Altamaha, and Lower Altamaha (*Figure 4-1*). Historically, the entire range of the Altamaha spinymussel was likely connected in a single interbreeding biological population linked by host fish dispersal, but we used the four population units in the SSA to most accurately describe past trends in resiliency, forecast future resiliency, and capture differences in stressors among units.

The upstream and downstream extents of each delineated population were based on species records and expert input. The Oconee population ranges from Mt. Vernon (US 280) downstream to its confluence with the Ocmulgee/Altamaha River. The Ohoopee population ranges from Reidsville downstream to its confluence with the Altamaha River. The Altamaha/Ocmulgee population ranges from Jacksonville (US 440) downstream to Doctortown (US 84), where the Lower Altamaha population begins, which ranges downstream to Darien. The Lower Altamaha population, downstream from Doctortown and Jesup, is considered a separate population from the Ocmulgee/Altamaha population upstream because it represents a contraction in the species range and faces different stressors than upstream, namely a large pulp mill in Jesup that discharges into the river.

For some resiliency factors, we considered the watershed surrounding each delineated population. To delineate these population watersheds, we used HUC10 watershed boundaries, clipped at the uppermost and lowermost reaches of any delineated stream population by HUC12 watershed units (*Figure 4-1*). This clipping impacted only the Ocmulgee/Altamaha and Lower Altamaha population watersheds; the final population watersheds for the Oconee and Ohoopee populations were unaltered from the HUC10 boundaries.

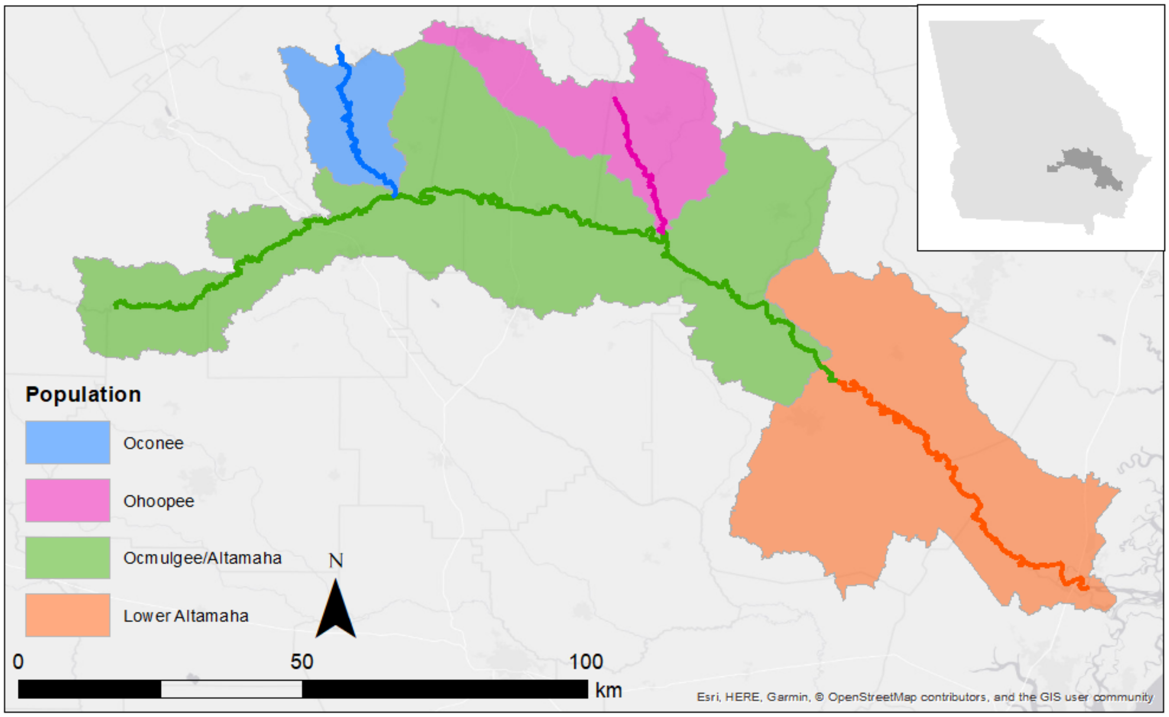

Figure 4-1. Altamaha spinymussel populations (lines) and population watersheds (shaded).

4.2 Population Needs – Resiliency

To assess current resiliency of Altamaha spinymussel populations, we assessed the condition of two population needs: species presence and recruitment, and three habitat needs: water quality, water quantity, and host fish community. These needs that contribute to population resiliency will hereafter be referred to as population and habitat factors, collectively resiliency factors.

4.2.1 Population Factor – Presence

The first population factor is species presence. Altamaha spinymussel populations cannot be resilient where they are not present. The Altamaha spinymussel is very difficult to detect when it is present; detection probability during 2006-2007 surveys of the Altamaha River was estimated to be only 3.7 percent (Meador 2008, p. 55). Because detectability of the species is low, and because comprehensive range-wide surveys have not been completed in the last decade, we considered the population to be extant if any live or freshly dead specimens were observed within the last 20 years (2000 or later; GDNR 2020, n.p.). The observation of Altamaha spinymussel shells from a long-dead individual within the last 20 years did not count towards considering the population extant, as freshwater mussel shells can persist in the environment for years after the mussel dies (Mincy 2012, p. 56-57; Ilarri et al. 2012, p. 12; Wisniewski 2020, pers comm.). It is also possible that shells might have moved through the stream as sediments eroded, such that we cannot be certain that the mussel lived in the same reach in which its shell was later found (Wisniewski 2020, pers comm.). However, in instances when there was no information available to indicate whether an observation was of a live specimen or a remnant shell, we assumed that it was a live individual and counted the observation as a presence. If there were no records of live individuals during the last 20 years, populations were considered presumed extirpated. Because of the low detectability of the species and lack of recent comprehensive surveys, we use the qualifier "presumed" to communicate that the evidence is not strong enough to have absolute certainty that the population is extirpated.

Because of the same limitations (i.e., infrequent surveys, low detectability, mixture of live individuals and remnant shells) in monitoring data, we did not estimate current abundance or trends in abundance other than noting general apparent patterns. Future status assessments for this species can be improved with a new comprehensive survey designed to account for the low detectability of the species (e.g. increased survey effort, repeat site visits in an occupancy framework).

The condition of this factor for each population was classified as follows:

Extant:	Live individuals observed within the last 20 years
Presumed Extirpated:	No live individuals observed within the last 20 years

While extirpated populations do not contribute to current resiliency, they remain important to consider in the SSA when looking to the past to compare historical and current conditions, and when looking forward to determine where opportunities for conservation exist.

4.2.1.1 Presence Assessment by Population

Available information about species presence and monitoring results are summarized below. The available data do not enable a statistically rigorous assessment of trends in abundance over time, but monitoring results appear to indicate a decline in abundance for all populations.

<u>Oconee</u>

In the Oconee population, the Altamaha spinymussel is currently considered **Presumed Extirpated**.

The species has not been observed in this population since 18 specimens, including 5 juveniles, where collected near Mt. Vernon in 1964 (Johnson et al. 2008, Athearn database). Surveys in this region have been scant however, with only two 2-km stream reaches surveyed for mussels of any species observed in the 1990s, 1 in the 2000s, and 6 in the 2010s (GDNR 2020, n.p.). Surveyed reaches were clustered upstream near Mt. Vernon, and downstream near the confluence with the Ocmulgee River, with no monitoring records for any freshwater mussel species in the intervening ~23-km (14.3-mi) stretch between the two groupings.

Ohoopee

In the Ohoopee population, the Altamaha spinymussel is currently considered **Extant**.

In a survey of the Ohoopee River, Keferl (1981, pp. 12-14) found at least 30 live specimens of the Altamaha spinymussel at seven of eight collection sites, in thinly scattered beds, in the lower 8 km (5 mi) of the river. Spinymussels were not found higher in the watershed, presumably because there are insufficient flows to support this species. By the early 1990s, only two live specimens were found at the same sites (Keferl 1995, pp. 3-6). Stringfellow and Gagnon (2001, p. 6) resurveyed these sites using techniques similar to those used by Keferl (1981), but did not find any live Altamaha spinymussels in the Ohoopee River. In 2005, a live specimen was observed in the Ohoopee River near the confluence with the Altamaha River. Prior to that observation, no live individuals had been observed since 1993. No surveys for the species have been conducted here since 2007, when no specimens were found at 3 sampled sites.

Ocmulgee/Altamaha

In the Ocmulgee/Altamaha population, the Altamaha spinymussel is currently considered **Extant**.

Historically, this population has supported the highest densities of Altamaha spinymussel collections and observations. In the Ocmulgee River in 1962, Athearn made a single collection of 40 live spinymussels downstream of U.S. Highway 341 near Lumber City (Johnson et al. 2008, Athearn database). Researchers collected 19 and 21 live individuals, respectively, during two surveys at Red Bluff (Thomas and Scott 1965, p. 67). In 1986, Stansbery collected 11 live individuals at the U.S. Highway 441 Bridge near Jacksonville, Georgia (Wisniewski 2006, pers. comm.). In the Altamaha River, early surveys at the U.S. Route 301 crossing documented 20 individuals in 1963, 7 in 1965, and 43 in 1970. Sickel sampled seven sites downstream of the U.S. Route 1 bridge in 1967. Sixty spinymussels were collected in one 500-m^2 (5,382-ft^2) site, and an additional 21 spinymussels were collected in a 400-m^2 (4,306-ft^2) site (Sickel 1980, p. 11; Wisniewski 2006, pers. comm.).

The Altamaha spinymussel was last observed in this population in 2011. There were additional limited mussel surveys in this population during 2012, 2015, and 2020 during which other species were observed, but the Altamaha spinymussel was not found. The most recent observations and the only live observations in the 2010s were at the downstream limit of this population between the Ohoopee River and Jesup. Three live individuals were found in 2011 during 16 person-minutes of searching, and live mussels were also found here during numerous surveys in the 2000s. Upstream of the confluence with the Ohoopee River, live individuals have been observed during the 2000s in multiple reaches along the river, but have not been observed during the last decade. Survey effort during the 2010s has been 25 percent of what it was in the 2000s in terms of the number of 2-km (1.2-mi) stream segments surveyed (80 segments in the 2000s, 20 segments in the 2010s for the full length of the Ocmulgee/Altamaha population), so it is likely that the lack of more recent observations in the upstream portion of this population is at least in part due to a lack of survey effort rather than a range contraction. The few reaches in the upper portion of this population that have been surveyed during the 2010s have very little overlap with the known distribution of the Altamaha spinymussel within the river.

Lower Altamaha

In the Lower Altamaha population, the Altamaha spinymussel is currently considered **Presumed Extirpated**.

The earliest observations of the Altamaha spinymussel occurred in this population. Live individuals have not been observed in this population in recent decades, though remnant shells were found during comprehensive surveys in the 1990s. Over a dozen other mussel species were observed distributed throughout the reaches of this population during the same survey, indicating that habitat for freshwater mussels in general exists there. Recent monitoring in this population has been extremely limited; 28 2-km (1.2-mi) stream reaches were surveyed in the 1990s compared to only 4 in the 2000s and 6 in the 2010s.

4.2.1.2 Additional Analysis of Available Monitoring Data

Using the GDNR database, which included data from many of the surveys mentioned above, Wisniewski et al. (2005, entire) conducted a test for a temporal change in sites occupied in the Ocmulgee and Altamaha Rivers between the early 1990s and the early 2000s. Live Altamaha spinymussels were detected at 24 out of 241 sites (10 percent) sampled before 2000 and at 14 of 120 sites (12 percent) sampled after 2000. Although the percentage of sites occupied was not indicative of a decline, an analysis of 39 sites sampled during both time periods showed that the spinymussel was lost from significantly more sites (11 sites) than it colonized (3 sites; Wisniewski et al. 2005, p. 2). This test was imprecise because the failure to detect Altamaha spinymussels when present could have resulted in both false colonizations (species missed during early surveys but detected in recent survey) and false extirpations (species detected during early survey but missed during recent survey). Thus, although the exact number of extirpations and colonizations between the two time periods may not have been accurate, the much higher number of extirpations was suggestive of a decline over this time period.

We repeated this assessment with more current data, and looked at three time periods: the 1990s, the 2000s, and the 2010s (*Table 4-1*). We divided the entire range of the Altamaha spinymussel into 2-km (1.2 mi) reaches. Survey data included absence data; the Altamaha spinymussel was considered absent from a reach if it included records of other mussel species, indicating that it was surveyed and no spinymussels were found, or if a site had a survey record of "No Mollusks", indicating that no mussels of any species were found. This assessment carries the same limitations as the earlier survey, in that it does not incorporate low detectability of the spinymussel, and there is some ambiguity in the data set as to whether some observations were of live individuals or not. Regardless, we summarize the available data here and consider it useful for recognizing general apparent trends in occupancy as well as trends in survey effort over time.

Table 4-1. Number of reaches surveyed and reaches with Altamaha spinymussel present during the last three decades.

	1990s		**2000s**		**2010s**	
Population	**Reaches Surveyed**	**Present *(% of reaches surveyed)***	**Reaches Surveyed**	**Present *(% of reaches surveyed)***	**Reaches Surveyed**	**Present *(% of reaches surveyed)***
Lower Altamaha	28	1 *(3.6%)*	4	0 *(0%)*	6	0 *(0%)*
Ocmulgee/Altamaha	73	23 *(31.5%)*	67	18 *(26.9%)*	8	3 *(37.5%)*
Oconee	2	0 *(0%)*	1	0 *(0%)*	6	0 *(0%)*
Ohoopee	8	3 *(37.5%)*	8	1 *(12.5%)*	0	0 *(NA)*
Total	**111**	**27 *(24.3%)***	**80**	**19 *(23.4%)***	**20**	**3 *(15.0%)***

There were 64 reaches that were surveyed in both the 1990s and 2000s. Of those, the Altamaha spinymussel was detected at 38 percent in the 1990s and 25 percent in the 2000s. Compared to the 1990s, the species was found in 8 new reaches, was apparently lost from 16, and persisted in 8 in the 2000s (*Table 4-2*). With the very limited surveying that has occurred in the 2010s, there are only 8 reaches that were surveyed in both the 2000s and 2010s– 7 reaches in the Ocmulgee/Altamaha population and a single site in the Lower Altamaha. Of these, the Altamaha spinymussel was present in 4 reaches in the Ocmulgee/Altamaha population in the 2000s and 3 in the 2010s, the result of no colonizations, one apparent extinction, and three adjacent sites that persisted. As with the previous assessment, these results, given their limitations, seem to suggest a decline in reaches occupied based on the higher number of extinctions compared to colonizations. Just as importantly, these results demonstrate the need for a new comprehensive survey to better understand the current status of the Altamaha spinymussel throughout its range.

Table 4-2. Summary of 64 sites surveyed both in the 1990s and 2000s.

Population	**Sites Surveyed**	**Present 1990s** *(% of sites surveyed)*	**Present 2000s** *(% of sites surveyed)*	**Colonizations**	**Extinctions**	**Persistence**
Lower Altamaha	2	1 *(50%)*	0 *(0%)*	0	1	0
Ocmulgee/Altamaha	57	21 *(37%)*	15 *(26%)*	7	13	8
Oconee	0	0 *(NA)*	0 *(NA)*	0	0	0
Ohoopee	5	2 *(40%)*	1 *(20%)*	1	2	0
Total	**64**	**24 *(38%)***	**16 *(25%)***	**8**	**16**	**8**

4.2.2 Population Factor – Evidence of Reproduction

The second population factor contributing to resiliency is evidence of reproduction and recruitment; a population consisting of only large old mussels with no successful reproduction and recruitment cannot persist. Unfortunately, very little data are available to assess this critical factor. As described above, detectability for adult Altamaha spinymussels when present is estimated to be very low, 3.7 percent as estimated by Meador (2008, p. 55). The detectability for juveniles is likely lower than adults (Wisniewski 2020, pers. comm). Because of the difficulty of locating juveniles, we do not conclude that reproduction and recruitment are absent in populations where it has not been observed. We classify those populations instead as "unknown" for the status of this factor.

The condition of this factor for each population was classified as follows:

Evidence Present: Evidence of reproduction/recruitment within the last 20 years
Unknown: No evidence of reproduction/recruitment within the last 20 years
Not Applicable: This factor is not applicable for presumed extirpated populations.

To better understand the status of this resiliency factor for future assessments, we suggest that a range-wide survey for the species be conducted and that some survey methods include those that target juvenile age classes. We also stress the need for continued investigation into the host fish for the species, another gap in current understanding of Altamaha spinymussel reproduction. Identifying the host fish could allow host fish abundance and population dynamics to serve as a proxy for potential Altamaha spinymussel reproduction. Where the host fish is rare or absent, juvenile spinymussels are likely to be absent.

4.2.2.1 Presence Assessment by Population

<u>Oconee</u>

As the Oconee population is presumed extirpated, this factor is **Not Applicable**.

<u>Ohoopee</u>

There are no recorded observations of juvenile Altamaha spinymussels in this population within the last 20 years. Given the difficulty in detecting juveniles, the status of reproduction and recruitment in this population is **Unknown**.

<u>Ocmulgee/Altamaha</u>

There is **Evidence Present** of reproduction and recruitment in the Ocmulgee/Altamaha population. Surveys in the Ocmulgee River during the fall of 2000 and 2001 resulted in observation of 11 live Altamaha spinymussels ranging in length from 58 to 106 mm. While none of these included juveniles, the presence of multiple size classes indicates that some recruitment has been occurring during the 10-20 years prior (Skelton et al. 2002, p. 4). Small mussels (down to 34 mm) were also observed during surveys in 2004 in the Altamaha River above Jesup and were likely 2-4 years old (Albanese 2020, pers. comm., Rowe 2020*b*, pers. comm.).

<u>Lower Altamaha</u>

As the Lower Altamaha population is presumed extirpated, this factor is **Not Applicable**.

4.2.3 Habitat Factor – Water Quality

As fully aquatic organisms, water quality is an important component of population resiliency for the Altamaha spinymussel. In the absence of site-specific water quality measurements taken at spinymussel locations within each population, we examined Georgia's 303(d) list of impaired waters, used data available at the subwatershed scale (HUC 12) by the EPA to characterize point source pollution, and assessed land use as a proxy of nonpoint source pollution for each delineated Altamaha spinymussel population.

4.2.3.1 Water Quality: 303(d) list

Each state is mandated by the Clean Water Act to assess the water quality in its waterbodies every two years and submit a list of waters that are impaired so as to not support their designated uses. We examined the results from the most recent assessment in 2018 as they apply to Altamaha spinymussel populations (EPD 2018, entire).

The condition of this factor for each population was classified as follows:

Supporting:	Assessed river segments support designated use
Not Supporting:	Assessed river segments do not support designated use
Unknown:	It is uncertain whether assessed river segments support their designated use because assessment is still pending

The designated use for all segments within the Altamaha spinymussel range is fishing, meaning that water quality was assessed in relation to the river's ability to support fishing and results do not necessarily apply to other uses such as swimming or shellfish health.

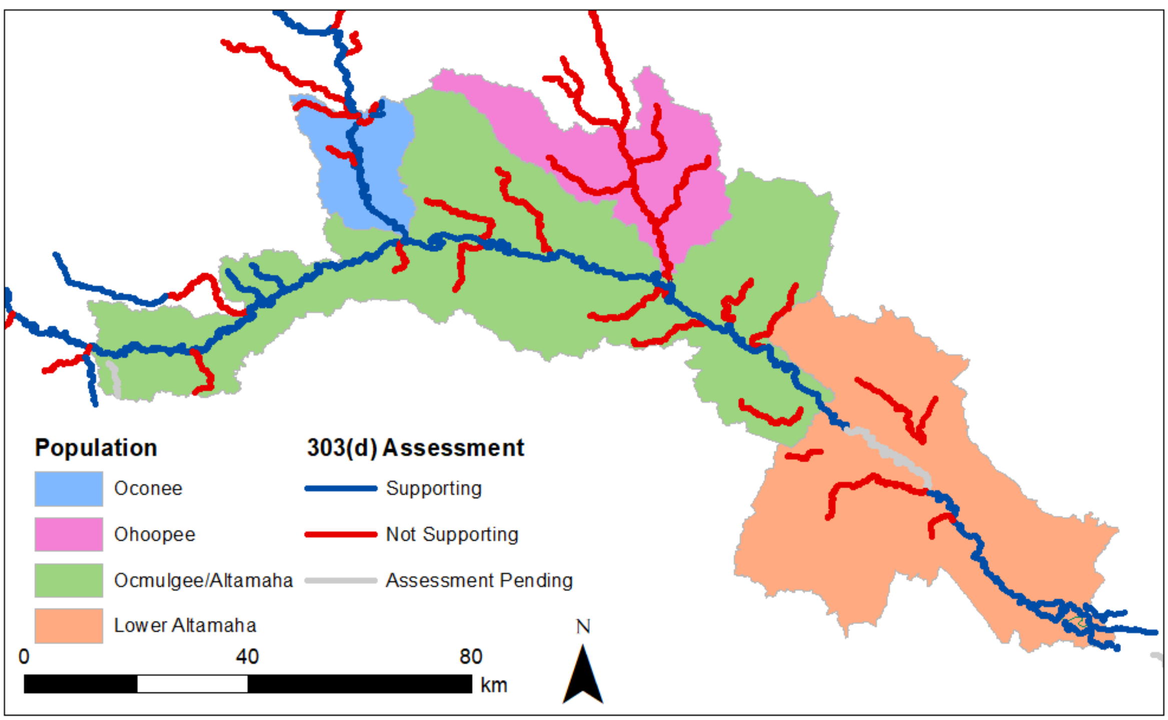

Figure 4-2. Georgia 303(d) status of rivers as of 2018.

Oconee

The river segment making up the Oconee population is classified as **Supporting** its designated use of fishing. Multiple tributaries however are listed as impaired due to fecal coliform bacteria and impacts to fish biota due to nonpoint source or unknown causes.

Ohoopee

The river segments making up the Ohoopee population are classified as **Not Supporting** their designated use of fishing due to mercury levels in fish exceeding human health standards. The upper river segment within the population boundary is also impacted by fecal coliform bacteria. A Total Maximum Daily Load (TMDL) was developed for mercury in 2002 (EPA 2002, entire).

Ocmulgee/Altamaha

The river segments making up the Ocmulgee/Altamaha population are classified as **Supporting** their designated use of fishing. Multiple tributaries however are listed as impaired due to dissolved oxygen levels, fecal coliform bacteria, and impacts to fish biota due to nonpoint source or unknown causes.

Lower Altamaha

The river segments making up the Lower Altamaha population are classified as either **Supporting** their designated use of fishing or **Unknown** because assessment is pending. The segment immediately downstream of the Rayonier paper mill has been pending assessment since 2012. A TMDL for mercury was completed in 2002, and more data need to be collected and evaluated to determine whether the designated use is supported. Specifically, a numeric criterion for color needs to be developed to determine whether water quality standards are being met (EPD 2012, p. A-291). Some tributaries to the Lower Altamaha are listed as impaired due to dissolved oxygen levels.

4.2.3.2 Water Quality: Point Source Pollution

To assess point source pollution in each population, we used the EPA Water Pollutant Loading Tool (https://echo.epa.gov/trends/loading-tool/get-data/watershed-statistics, accessed May 11, 2020) to compile information from Discharge Monitoring Report (DMR) and Toxics Release Inventory (TRI) records about facilities permitted to discharge pollutants into streams in each delineated Altamaha spinymussel population. The DMR and TRI data sources differ in purpose and in the information they collect for the EPA.

DMR

The Clean Water Act requires discharging facilities to obtain a permit from the National Pollutant Discharge Elimination System (NPDES) and submit monthly DMRs to demonstrate compliance with their permit. DMR pollutant reporting also includes general water quality parameters including but not limited to pH, temperature, and total suspended solids, but permitted facilities are only required to submit DMR information about pollutants identified in their NPDES permit (EPA 2014, p. 2). Other pollutants may be discharged that are not included in the DMR reports.

TRI

Toxic chemical use and discharge information is submitted to TRI under the Emergency Planning and Community Right-to-Know Act (EPCRA) to help communities plan for emergencies involving hazardous chemicals (EPA 2014, p. 2). Reported chemicals include over 650 that typically are known to cause significant chronic or acute human health or environmental impacts. Non-chemical pollutants are not reported here. For example, suspended solids may be a significant discharge reported in a facility's DMR, but suspended solids will not be reported to the TRI program because it is not a toxic chemical (EPA 2014, p. 9). Conversely, TRI records may contain information on pollutants not reported in DMRs. Only facilities in certain industrial sectors and with certain types of discharge are required to report to TRI. Within delineated Altamaha spinymussel populations, only two discharging facilities report to TRI. Of those two, one also submits DMRs, and the other only submits to TRI.

SSA Use of Data

The vast majority of discharging facilities within the Altamaha spinymussel range only have reported DMR data. For those with no DMR data that did have TRI data, we used the TRI data. For those that had both DMR and TRI data, we used in our assessment the data source that reported the highest value for a given metric (continue reading for description of metrics assessed). We did not sum the two data sources together or take an average because although the two data sources report different kinds of information, there may be some overlap in discharged pollutants reported. Because of this, and because neither TRI nor DMRs report on an exhaustive list of possible pollutants, the following point source pollution water quality assessment should be viewed as conservative, acknowledging that pollutant discharge and toxicity may be higher than presented here.

We compiled three metrics that complement each other to provide an overview of point source pollution in each population: the number of discharging facilities, volume of pollutant discharge, and toxicity of discharge. First, the number of dischargers provides information about how widespread pollutants might be. For example, for an identical watershed, amount, and type of discharge, water quality will be impacted across a wider area if the discharge is spread across 10 discharging facilities than if it is concentrated to a single facility. Second, the volume of pollutant discharged is important to consider when assessing impacts on water quality. Similarly, the type and toxicity of the discharge matters; not all pollutants have equal effects on aquatic and human life. The EPA has developed Toxic Weighting Factors for each pollutant, where higher weights indicate higher toxicity per pound of pollutant (EPA 2012, entire). These weights are used to calculate Toxic Weighted Pound Equivalents (TWPEs), a relative measure of the toxicity of discharges. The exact ecological impact that a certain value of TWPEs discharged to the environment will have will vary depending on site specific factors and what organism or ecological indicator the "impact" is measured in reference to. Thus, we cannot say that a TWPE value over a certain threshold will have a specific negative impact on spinymussels, or conversely, that a TWPE value under a certain threshold is safe, but we can use the values to compare relative toxicity across spinymussel populations. It is important to note here that pollutants reported in DMRs that are not specific chemical compounds (e.g. "oil and grease") cannot have toxic weighting factors, and thus cannot have a TWPE, despite having harmful impacts to human and environmental health (EPA 2014, p. 5). Thus, TWPEs reported here represent a conservative estimate of the toxicity of discharges.

These three metrics, the 1) number of dischargers, 2) amount of discharge, and 3) toxicity of discharge, were divided by the area of each population watershed to aid comparison across populations of different sizes, resulting in each metric being converted to a value per square kilometer, and combined to generate a single score for point source pollution for each population. Each metric was weighted equally in this combined score in the absence of any evidence to support weighting them differently. To achieve equal weighting, each of the three metrics were scaled from 0 to 1 by dividing all values by the maximum observed for a given metric. The three scaled metrics for each population were then summed together to generate a single point source pollution score that could range from 0 to 3, with high values indicating worse point source pollution. Importantly, these scores ranked populations relative to each other, not relative to empirical toxic thresholds for the Altamaha spinymussel. Scores were classified as better or worse condition based on the thresholds below. We use these relative terms rather than more absolute terms like good/moderate/poor condition to emphasize that this classification of populations is relative to each other.

The condition of this factor for each population was classified as follows:

Better Condition: Point source pollution score 0 - 1.5
Worse Condition: Point source pollution score 1.5 - 3

We examined these point source pollution metrics from 2007 (the first year available from the reporting tool) to 2019 (the most recent full year of data) but used an average of the last 5 years of data to characterize the current condition. The results were nearly identical using a 10-year average.

The density of discharging facilities in each population watershed was similar among populations, ranging from 0.1 to 0.6 facilities per 100 km^2 (*Figure 4-3*, *Figure 4-4*).

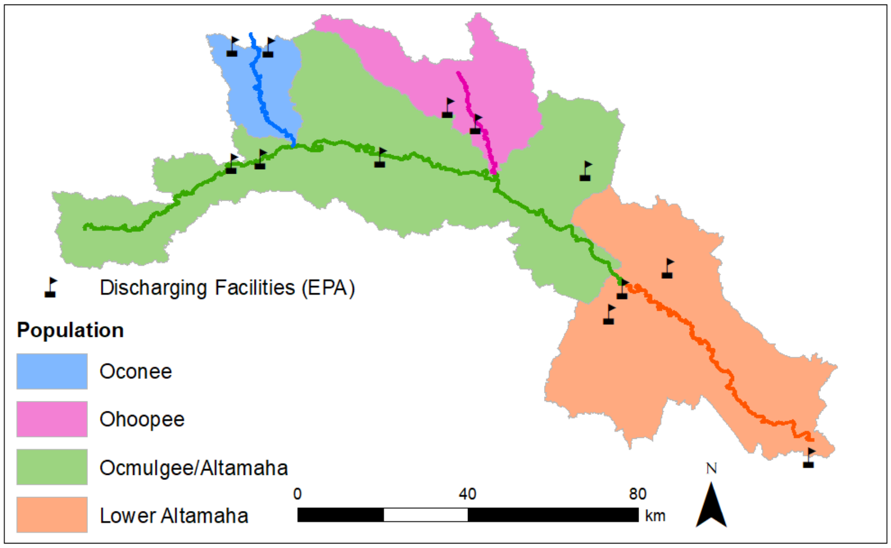

Figure 4-3. Point source pollution discharging facilities reporting to the EPA.

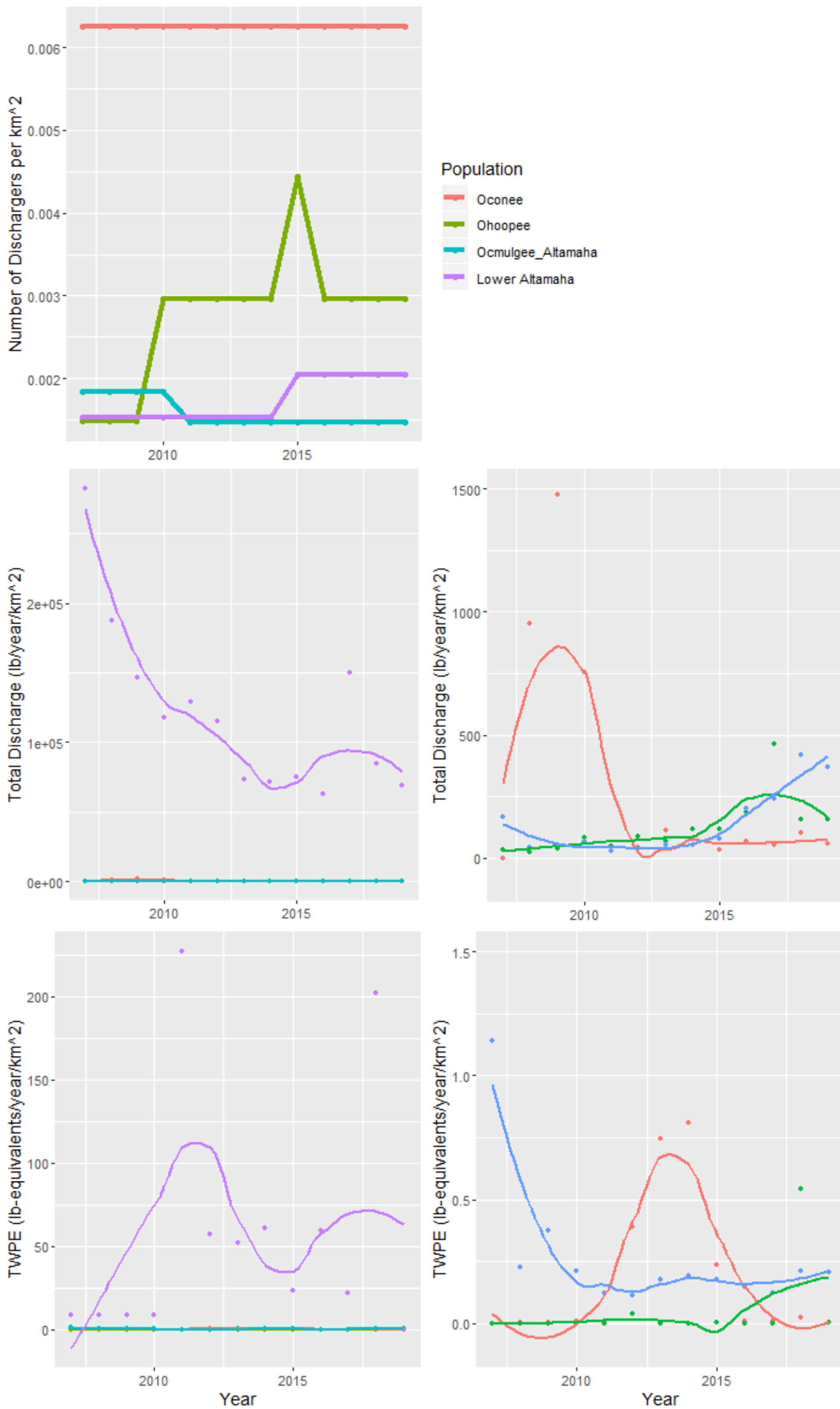

Figure 4-4. Number of discharging facilities, volume of discharge, and toxicity of discharge from reporting facilities in Altamaha spinymussel population watersheds. Graphs in the right column are zoomed in versions of their counterpart on the left.

There was an extensive gap among populations when comparing the volume and toxicity of discharge (*Figure 4-4*, *Table 4-3*). The volume and toxicity of pollutants discharged in the Lower Altamaha River by the Rayonier pulp mill are orders of magnitude higher than the discharges to any of the other population watersheds.

Table 4-3. Raw and scaled discharge metrics and overall point source pollutions score.

	# Discharging Facilities		Pollutant Discharged (lbs/yr)		Toxicity (Toxic Weighted Pound Equivalents/yr)		Overall Score
Population	**Per km^2**	**Scaled**	**Per km^2**	**Scaled**	**Per km^2**	**Scaled**	
Oconee	0.006	1.000	62.8	0.0007	0.057	0.0009	1.002
Ohoopee	0.003	0.520	217.8	0.002	0.111	0.002	0.525
Ocmulgee/Altamaha	0.001	0.235	262.4	0.003	0.173	0.003	0.241
Lower Altamaha	0.002	0.327	88,373.7	1.000	61.249	1.000	2.327

Oconee

The Oconee population watershed currently contains two discharging facilities, sewerage systems for the cities of Mt. Vernon and Glenwood. Although the density of discharging facilities is the highest of all the populations, as there are two facilities within the smallest population watershed, pollutant discharge and toxicity are relatively low. Water quality with regards to point source pollution in this population is considered to be in **Better Condition**.

Ohoopee

The Ohoopee population watershed currently contains two discharging facilities, a farm and a sewerage system for a prison. The density of discharging facilities, the amount of discharge, and toxicity of the discharge are relatively low. Water quality with regards to point source pollution in this population is considered to be in **Better Condition**.

Ocmulgee/Altamaha

The Ocmulgee/Altamaha population watershed currently contains four discharging facilities, sewerage systems for the cities of Hazlehurst, Lumber City, and Glennville, and the Edwin I. Hatch nuclear plant. The density of discharging facilities, the amount of discharge, and toxicity of the discharge are relatively low. Water quality with regards to point source pollution in this population is considered to be in **Better Condition**.

Lower Altamaha

The Lower Altamaha population watershed currently contains four discharging facilities, sewerage systems for the cities of Ludowici, Jesup, and the New Hope Plantation Mobile

Park, and the Rayonier pulp mill. The density of discharging facilities is fairly low, but the amount of discharge and toxicity of the discharge produced by the Rayonier mill are far higher than any elsewhere in the range of the Altamaha spinymussel. Water quality with regards to point source pollution in this population is considered to be in **Worse Condition**.

4.2.3.3 Water Quality: Nonpoint Source Pollution

The final component of water quality that we addressed is nonpoint source pollution. In assessing nonpoint source pollution, we focused primarily on land use. We first narratively discuss the impacts of legacy sediments in the Altamaha Basin. Legacy sediments from historical agricultural practices are believed to be a more significant threat to the health of the river system than nonpoint source inputs from current land uses. We then summarize current levels of land use within each population watershed to set as a baseline for future changes.

Legacy Sedimentation

From 1700 to 1970, agricultural practices, particularly associated with growing cotton, in the Southern Piedmont physiographic province resulted in extreme soil erosion, removing more than 17.8 cm (7 in.) of soil across the landscape (Trimble 1974, p. 1). The Ocmulgee, Oconee, and Ohoopee rivers all drain through the Piedmont and were directly affected by this erosion and resulting sedimentation. In 1938, van der Schalie (p. 56) reported the Altamaha River as being yellow in color, due to the large amount of suspended silt originating from intensive farming and road construction occurring in the headwaters. The sediment from these practices moved into stream channels and valleys, covering most of the original bottomlands (Trimble 1974, p. 26) and is now referred to as legacy sediment (Jackson et al. 2005, p. 3). As a result, stream profiles have been dramatically altered with unstable sediment deposits being dissected and streams being incised with entrained sediment migrating downstream to be deposited in stream channels and floodplains (Trimble 1974, pp. 116-121; Jackson et al. 2005, p. 1). The mobilization of legacy sediments, principally through lateral migration of stream channels and bank erosion is an ongoing threat as it moves downstream covering suitable habitat (Jackson et al. 2005, p. 10). Large-scale sediment movement and deposition may result in increased embeddedness, which would generally decrease habitat quality. Although it is the historical, anthropogenic land use that created the legacy sediment, the volume of legacy sediment still migrating through the Altamaha River Basin is likely a significant threat to the spinymussel. Since 1950, the amount of area in farmland in Georgia has decreased by 57 percent, and associated soil erosion has decreased with it (EPD 2012, p. v). However, it will probably be centuries before the soil eroded during the cotton-farming era fully leaves the system (Jackson et al. 2005, p. 11; McCarney-Castle et al. 2010, p. 412).

Current Land Use

We summarized the current land use within each of the Altamaha spinymussel population watersheds using spatial land cover data from the 2016 National Land Cover Database (NLCD) (Jin et al. 2019, entire), available at a 30 x 30-m resolution (98 x 98 ft). We collapsed the land use classes in the original data set down to 7 classes: 4 natural (water, wetland, forest, and other) and 5 anthropogenic (developed [including roads], cropland, and hay/pasture). For each population, we examined 3 spatial scales, the entire population watershed, a 3,000-ft (914-m) buffer around the river centerline, and a 500-ft (152-m) buffer around the river (*Figure 4-5*). Five hundred feet was chosen as the minimum buffer to approximate a 100-ft buffer from the river's edge, as the Altamaha River itself is several hundred feet across in many places. Depending on the river morphology in any one location, the buffer could extend more or less than 100 feet from the river bank, but was meant to represent the land uses immediately adjacent to the banks of assessed rivers. Most stretches of the assessed rivers flow through wide floodplains of woody wetland, so we created the larger 3,000-ft buffer to begin to represent the land uses adjacent to these wetlands.

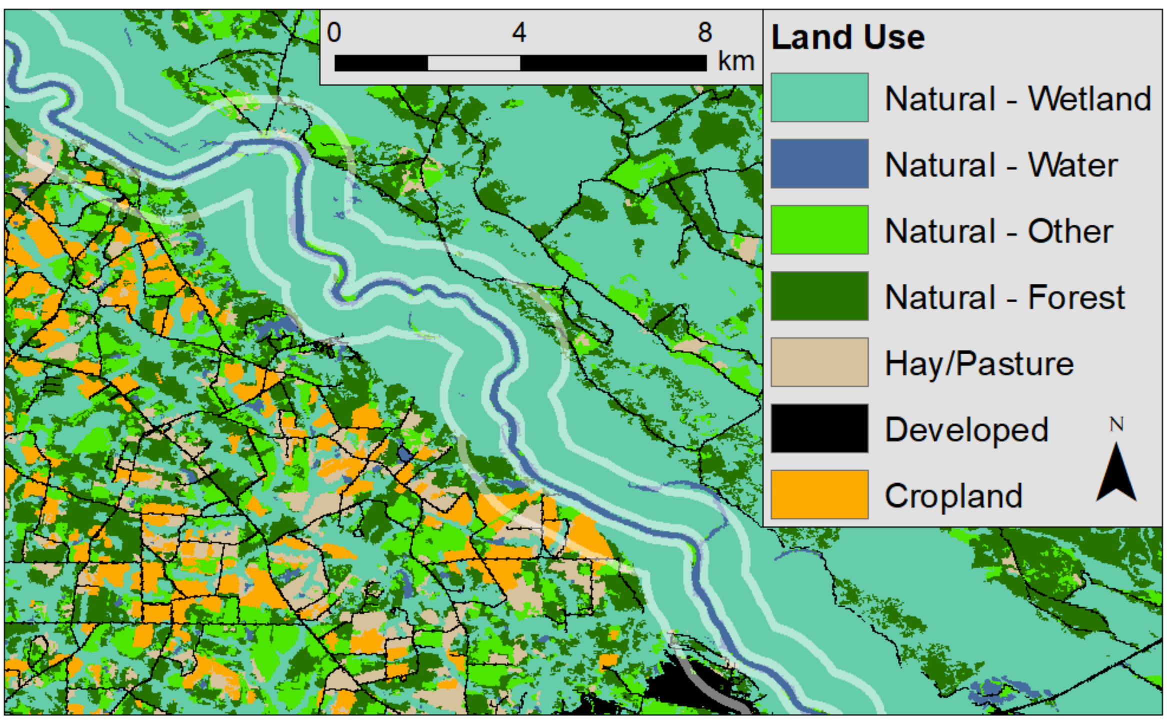

Figure 4-5. Example of multiple buffer distances for examining land use around Altamaha spinymussel rivers. Buffers shown in white.

The amount of land that is developed or in cropland is of particular relevance for nonpoint source pollution. In addition to other impacts on aquatic habitat structure and quality, developed land cover increases runoff into streams, increasing loads of sediments, nutrients, metals, pesticides, and other nonpoint source pollutants (CWP 2003, pp. 27-29). Agricultural land cover can impact water quality and aquatic organisms via increased exposure to chemical fertilizers, pesticides, livestock waste, and sedimentation. The GDNR EPD (2012, p. v) has estimated that 91 percent of the average annual sediment load deposited in the Altamaha Basin comes from row crop agriculture.

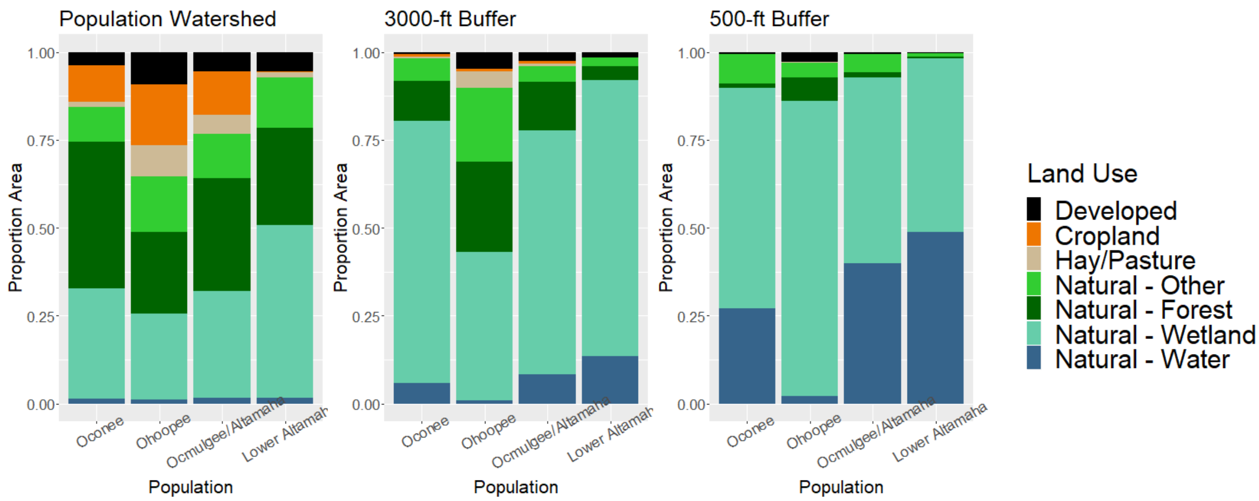

Figure 4-6. Current land use. Natural classes are displayed on the bottom, and anthropogenic on the top.

The proportion of each population watershed in each land use is displayed in *Figure 4-6* (See Appendix A for table of values). Development is not prevalent in any population watershed; development makes up 9 percent of the land area in the Ohoopee population watershed, ranging down to 4 percent in the Oconee population watershed. The majority of the development in the Ohoopee watershed is from Vidalia, Georgia, over 20 km away from the delineated Ohoopee population of Altamaha spinymussel. Hazlehurst and Baxley are the largest developed areas potentially impacting the Ocmulgee/Altamaha population. Jesup is the largest developed area potentially impacting the Lower Altamaha population, with development much closer to the river than other populations. The Impervious Cover Model (Scheuler 1994, entire), widely used in planning and zoning, uses 10 percent impervious cover as a threshold indicating impacted stream habitat (although in reality it is a continuous decline; there would be little difference in impact between 9.9 and 10.1 percent impervious cover). Riley et al. (2005, pp. 1898,1905) found effects of urbanization on amphibians and other aquatic taxa when urbanization reached 8-15 percent of watershed land cover. The levels of development within Altamaha spinymussel watersheds do not surpass these thresholds, so we conclude that current development is not a major threat to stream habitat at this time, though the Ohoopee watershed is approaching that threshold.

There is more variation among populations in the proportion of area in cropland, ranging from 0.4 percent in the Lower Altamaha watershed to 10-13 percent in the Oconee and Ocmulgee/Altamaha watersheds, to a maximum of 17 percent in the Ohoopee watershed. It is uncertain to what extent these levels of agricultural land use contribute nonpoint source pollution of sediments and nutrients to Altamaha spinymussel-occupied streams, especially compared to the impact of legacy sediments from historical agriculture.

The current impacts of agriculture and development are likely mediated by the presence of a riparian buffer of primarily natural vegetation, much of which is protected for conservation, though the potential exists for ditches or small tributaries to transport pollution through these riparian areas. Zooming in to the 500-foot buffer around the river centerline, over 95 percent of the area is in natural land uses, primarily woody wetland. The most amount of development within this narrow buffer area occurs in the Ohoopee population, where 2.9 percent of the buffer area is developed. Within the wider 3,000-foot buffer, the area is still primarily in natural land uses, with forest and other natural land uses joining woody wetland as the top contributing land uses. Cropland does not exceed 1 percent of this area in any population, and development tops out at 4.9 percent in the Ohoopee population. The woody wetland surrounding the Ohoopee River is much narrower compared to the large-river populations, leading to higher amounts of anthropogenic land uses closer to the river.

Over 80,000 hectares within the assessed population watersheds, including over 20,000 hectares within 3,000 feet of the assessed rivers are in conservation, including federal, state, and county lands and private lands managed for conservation under an easement or covenant (*Table 4-4*). The most heavily-protected watershed and riparian area of the four population watersheds is the Lower Altamaha, followed by the Ocmulgee/Altamaha, Oconee, and finally the Ohoopee. These conservation lands provide both current and future protection against land use changes that can increase the inputs of sediments, nutrients, and other nonpoint source pollutants into Altamaha spinymussel-occupied rivers.

Table 4-4. Conservation lands in population watersheds and within a 3,000-foot buffer from assessed rivers.

Population	Hectares in Conservation in Watershed	Percent of Watershed	Hectares in Conservation in 3,000-ft buffer	Percent of Buffer
Oconee	1,363	4.3%	1,055	16.2%
Ohoopee	1,113	1.6%	478	8.7%
Ocmulgee/Altamaha	20,470	7.5%	7,834	26.3%
Lower Altamaha	57,366	29.3%	10,673	80.2%

Nonpoint Source Pollution Summary for All Populations

> In contrast to our assessments of the other water quality and resiliency factors, we did not categorize populations into condition classes for nonpoint source pollution. Rather, we summarize what is known about all of the populations. All populations occur in rivers that drain through the Piedmont and are impacted by legacy sediments moving through the system from historical agricultural practices. It is believed that if sediment loads from current sources are maintained at acceptable levels with no net increase in sediments delivered to the system, impacted streams will recover over time (EPD 2012, p. v). Within each population watershed, less than 10 percent of the land area is developed, indicating that Altamaha spinymussel rivers are not impaired from runoff from impervious surfaces. The percent of land in agriculture ranges from less than 1 percent up to 17 percent. Of the four populations, the Ohoopee population watershed has the highest percent area either developed or in cropland– 26 percent. All populations however are largely surrounded by a buffer of woody wetland, forest, and other natural vegetation, which provides some protection from nonpoint source pollutants. Over 20,000 hectares of this buffer region is in conservation.

4.2.4 Habitat Factor – Water Quantity

We assessed water quantity in Altamaha spinymussel populations to understand how that factor might influence current resiliency and set a baseline to compare against future conditions. The restricted range of the Altamaha spinymussel in the Ohoopee River, which is a small river that is more susceptible to low flows during drought conditions, suggests that water quantity is a limiting factor. Mussel viability during drought is affected by both drought severity and stream size (Gough et al. 2012, p. 2,357). For example, smaller streams are more likely to be intermittent, forcing mussels into shallow pools with little to no flow. Moderate drought can result in the narrowing of mussel habitat, while prolonged drought can cause flow to cease altogether. Mussel growth, reproduction, and survival can be impacted by prolonged drought or low-flow conditions due to a variety of factors including: (1) increased surface water temperature; (2) decreased dissolved oxygen levels; (3) increased ammonia levels due to desiccation; (4) reduction of habitat; and (5) increasing access to the riverbed for ATVs to impact mussels directly via crushing mussel beds or indirectly via bank destabilization and increased erosion (Ganser et al. 2015, p. 1714; Golladay et al. 2004, p. 501-503; Haag and Warren 2008, p. 1173; Stringfellow and Gagnon 2001, p. 3; Keferl 2020, pers. comm.).

However, knowledge of precise sublethal and lethal effects from these impacts is limited. Research about surface water temperature tolerances has been limited to 22 species, approximately 10 percent of the species known to occur in North America (Dimock and Wright 1993, entire; Pandolfo et al. 2010*a*, entire; Archambault et al. 2014, entire; Ganser et al. 2015, entire; Khan et al. 2019, entire). A majority of the limited information that does exists is restricted to species found within the Midwest and southeastern United States. However, there is currently no data to describe the sensitivity of the Altamaha spinymussel to environmental stressors such as temperature, dissolved oxygen, and contaminants (FR 76, 2011-25539). Tolerance to these stressors can be inferred from thermal tolerance or drought research conducted on other, similar mussel species.

Gough et al. (2012, entire) assessed the linkage between physiological tolerance, behavioral response, and survival of three species of freshwater mussels subjected to drought: Pondhorn (*Uniomerus tetralasmus*), rough fatmucket (*Lampsilis straminea*), and giant floater (*Pyganodon grandis*). The authors identified three behavioral strategies used by these species to deal with drought and thermal intolerance. The three strategies observed included tracking (moving to remnant pools during drying events), track and then burrow, and burrowing (Gough et al 2012, p. 2,364). Both pondhorn and rough fatmucket burrowed shallowly in response to a 15-week drought, while giant floater rarely burrowed (Gough et al 2012, p. 2,361). Survival results suggest that drought poses the greatest threat to trackers, while burrowers are the most resistant to drought conditions (Gough et al 2012, p. 2,363). This suggests mussel species capable of burrowing in response to stress may have a greater ability to persist. It is not well understood to what extent Altamaha spinymussel employs these strategies to respond to drought and thermal stress, though Keferl (2020, pers. comm.) has observed that the Altamaha spinymussel buries itself deep in sand during low flow events and also can readily move to deeper water after floods recede.

Given the unknowns about how the Altamaha spinymussel specifically responds to the direct and indirect impacts of low-flow events, we sought to characterize relevant stream flow metrics to describe the relative risk for Altamaha spinymussels in the different populations without setting quantitative thresholds for what is "good", "poor" or other such categories. We compiled streamflow modeling outputs generated by LaFontaine et al. (2019, entire) for the historical time frame from 1952 to 2005 and the future time frame from 2045-2075, with results combined across 13 different climate models (LaFontaine et al. 2019, p. 15). We will revisit the future time frame predictions in the future condition section of the SSA; for the present section we investigated the 1952-2005 outputs. We split these historical outputs into two equally sized time periods to represent more historical conditions (Historical: 1952-1978) and more current conditions (Current: 1979-2005). The hydrologic simulation model used to produce water quantity outputs incorporated physical processes including precipitation, evaporation, transpiration, soil infiltration, and runoff. A limitation of the model is that it only included physical processes and did not include effects of anthropogenic water withdrawal for industrial, municipal, or agricultural use. We examined the following five annual metrics produced by the hydrologic simulation models (LaFontaine et al. 2019, pp. 19-21).

Minimum of 7-day average flow (cubic feet per second [cfs])

This metric is the minimum of a 7-day moving average flow for the year and is used widely to characterize low flow conditions for mussels and aquatic systems in general (Riggs 1985, p. 165; Ries et al. 2016, pp. 709-710; Essington et al. 2011, n.p.; Randklev et al. 2018, p. 5).

Base flow (unitless)

The base flow was calculated as the ratio of the minimum of 7-day average flow (described above) divided by the mean annual flow.

Low flow pulse count 5% (number of events per year)

This metric describes the number of low flow events with flows below a threshold equal to 5 percent of the mean flow value for the entire flow record.

Low flow pulse count 25% (number of events per year)

This metric describes the number of low flow events occurring each year, where a low-flow event is defined as flows below a threshold equal to the 25th percentile for the entire flow record.

Low flow pulse duration 25% (days)

This metric describes the average duration, in days, of low flow events with flows below a threshold equal to the 25th percentile for the entire flow record.

We used these low flow metrics to understand the relative risk from low flow events for the different rivers occupied by the Altamaha spinymussel. The rate at which flows drop during these events is also an important metric that influences whether mussels have time to move to stay in wet habitat or become stranded, but data about this metric were not available in a format allowing for meaningful comparisons between populations.

The results clearly illustrate the difference in hydrology between larger and smaller rivers within the range of the Altamaha spinymussel. Specifically, the Ohoopee River is very different from the Ocmulgee, Altamaha, and Oconee Rivers (*Figure 4-7*). The Ohoopee is the only river that is regularly susceptible to dewatering events, as evidenced by its minimum of 7-day average flows. The median 7-day minimum flows for the three larger rivers between 1952 and 2005 fall between 450 and 950 cfs, while the median 7-day minimum flow for the Ohoopee River is only 21 cfs. The minimum 7-day minimum flow modeled during the same time period varied between 37 and 159 cfs for the 3 larger rivers, and was only 3 cfs for the Ohoopee River. The Ohoopee also differs from the other rivers in that base flow makes up a lower proportion of its typical flow, adding to its susceptibility to low-flow events. While the median base flow for the three large rivers ranges from about 13-16 percent of the average flow, base flow makes up only 6 percent of the average flow in the Ohoopee River. These two metrics, the 7-day minimum flow and base flow, appear to be increasing slightly from the historical time period to the current time period.

The Ohoopee also differs from the other rivers in the number and duration of low flow events, considering low flows both below the 25th percentile of the entire flow record and below 5 percent of the mean flow over the entire flow record. The Ohoopee River typically experiences more than twice as many 25th percentile low flow events per year (median 11 low flow events compared to 4-5 in the other three rivers), but each event typically lasts for shorter durations (median 8 days compared to 18-23 days in the other rivers). Consequently, all four rivers spend about the same amount of days during a year in a low flow condition; multiplying the median number of low flow events by the median duration came out to 91 days for all rivers. Considering low flows below 5% of the mean flow, the median value for all populations was 0 days per year, but the mean and range were much higher for the Ohoopee River than the other populations (mean 1.6 and maximum 15 events per year in the Ohoopee compared to means below 0.13 and maximum of 5 events per year in the other rivers). There was not a clear trend from the historical to current time periods in the number and duration of low flow events, but these values will serve as a baseline against which to compare future predictions.

While the Ohoopee River spends a similar amount of time in a low flow condition as the other populations, that low flow state is lower than the other populations both in terms of the volume of water flowing and the proportion of average flow remaining during low flow events. We believe this puts the Ohoopee River population of Altamaha spinymussels at higher risk than those in the other three populations. We acknowledge that the Ohoopee River is a part of the historical range of the species and it is likely that the species has adapted behaviorally or physiologically to the smaller river conditions that exist there. During extreme low flow events however, the physical conditions present in the Ohoopee River (e.g., temperature, dissolved oxygen, dry riverbeds) present a more stressful environment than the other rivers, and present more opportunities for direct mortality of mussels or habitat degradation via ATV use on dry riverbeds and banks (Stringfellow and Gagnon 2001, p. 3; Keferl 2019, pers. comm.).

The condition of this factor for each population was classified as follows, based on relative comparisons among populations (i.e., not based on empirical quantitative thresholds):

High Risk:	Higher relative risk of direct and indirect impacts to the survival and health of Altamaha spinymussels from low flow events
Low Risk:	Lower relative risk of direct and indirect impacts to the survival and health of Altamaha spinymussels from low flow events

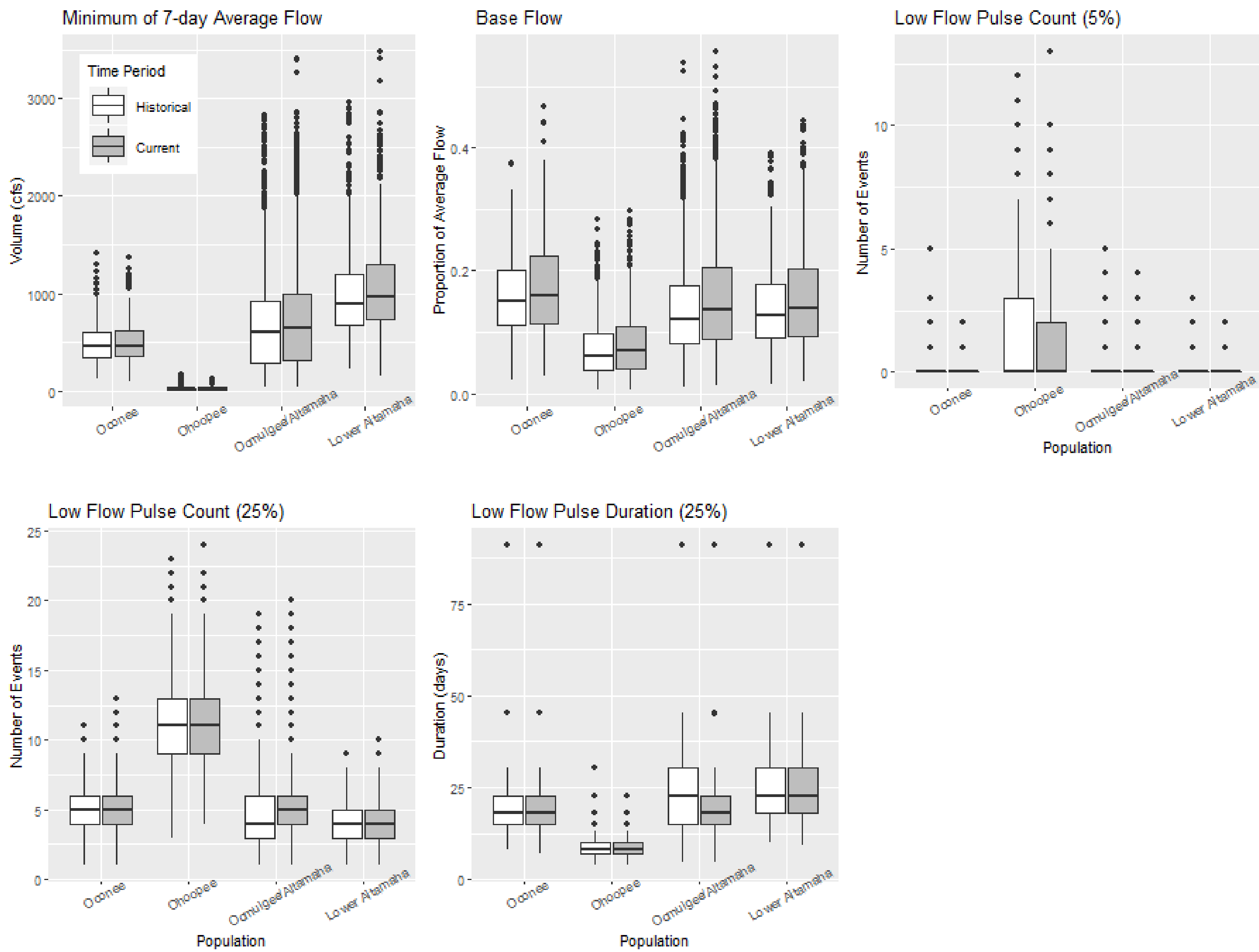

Figure 4-7. Current and historical water quantity metrics for Altamaha spinymussel populations.

4.2.4.1 Water Quantity Assessment by Population

<u>Oconee, Altamaha/Ocmulgee, and Lower Altamaha</u>

> Based on the relatively higher volumes of water flowing during low flow events and higher proportion of average flow comprised of base flow, we considered these three populations to be at **Low Risk** from water quantity issues.

<u>Ohoopee</u>

> Based on the relatively low volumes of water flowing during low flow events and low proportion of average flow comprised of base flow, we considered this population to be at **High Risk** from water quantity issues. There is a high level of uncertainty about the physiological tolerances of the Altamaha spinymussel and behaviors they may exhibit to reduce their exposure to conditions at their tolerance limits. However, conditions in the Ohoopee River during low flow events are more extreme than the other populations and are assumed to be more physiologically stressful to mussels and more likely to invite other threats like ATV usage through mussel habitat.

4.2.5 Habitat Factor – Host Fish Community

The final habitat factor contributing to resiliency is the health of the host fish community. Unfortunately, the host fish for the Altamaha spinymussel is unknown. Host fish trials have been conducted, but have been inconclusive (see Section 2.2: Life History). No glochidia have successfully transformed into juveniles during host fish trials, though glochidia did encyst onto numerous fish species including redbreast sunfish, bluehead chub, flat bullhead, pirate perch, largemouth bass, eastern mosquitofish, and lake sturgeon (Johnson 2004, p. 3; Johnson 2012, p. 739). Due to this uncertainty, we did not assess each population in terms of host fish health other than to say that for every Altamaha spinymussel population, the health of the host fish population is **Unknown**. Below we describe the general current state of the fish community in the Altamaha Basin.

Most of the common diadromous fish species in the Altamaha Basin have been stable or slightly increasing during the last few decades, and there is no evidence that the Rayonier pulp mill represents a barrier to migration; common species are abundant above and below the mill (Harrison 2020, pers. comm.). In recent history, bullhead species have declined significantly in response to the introduction of flathead catfish in the 1970s (Harrison 2020, pers. comm.). Flat bullhead is one of the species that Altamaha spinymussel glochidia encysted on, but did not metamorphize into juveniles during host fish trials. Redbreast sunfish, another potential host, have also declined since the introduction of flathead catfish, but they are still common (Harrison 2020, pers. comm.).

4.2.6 Current Resiliency

We combined all of the resiliency factors to generate an overall habitat condition score and an overall resiliency score (*Table 4-5*). To generate the overall habitat conditions score, the condition categories for each habitat factor were converted to a numeric value of -1 for categories indicating worse conditions (i.e., not supporting, worse condition, high risk, highlighted in orange in *Table 4-5*), +1 for categories indicating better conditions (i.e., supporting, better condition, low risk; highlighted in green in *Table 4-5*), and 0 for categories providing no or uncertain information (no color highlights in *Table 4-5*). These values were summed to generate the overall habitat score, which provides a relative ranking of habitat among the four populations based on available data. Future assessments can provide more accurate scoring by filling in some of the unknown information like the identity and population conditions of the host fish for the Altamaha spinymussel or the finalization of 303(d) assessment for the Lower Altamaha population. Future assessments may also weight the different habitat factors differently; for example, the health of host fish populations, necessary for persistence, should be weighted more heavily than each water quality factor in the overall habitat score.

Table 4-5. Altamaha spinymussel resiliency factors and overall resiliency.

	Population Factors		**Habitat Factors**					**Overall Habitat Score**	**Overall Resiliency**
			Water Quality						
Population	**Presence**	**Evidence of reproduction**	**303(d) list**	**Point Source**	**Nonpoint Source**	**Water Quantity**	**Host Fish Community**		
Oconee	Presumed Extirpated	NA	Supporting	Better	All impacted by legacy sediments. Low levels of development, risk from agriculture partially mediated by riparian buffer.	Low Risk	Unknown	+3	**Presumed Extirpated**
Ohoopee	Present // Likely Declining	Unknown	Not Supporting	Better		High risk		-1	**Low**
Ocmulgee/ Altamaha	Present // Likely Declining	Evidence Present	Supporting	Better		Low Risk		+3	**Moderate**
Lower Altamaha	Presumed Extirpated	NA	Unknown	Worse		Low Risk		0	**Presumed Extirpated**

Overall resiliency was informed by both population and habitat factors. First, if a population was presumed extirpated, that condition was carried over as the overall resiliency score. A population cannot be resilient, even in excellent habitat, if there is no population. For extant populations, available data indicate that populations are declining in abundance and distribution. A new range-wide survey and subsequent statistical analysis would provide more confidence in population trends, but given current evidence that all extant populations are declining, we designated no populations as highly resilient. Resiliency refers to the ability of populations to withstand stochastic demographic and environmental events, and neither of the two declining Altamaha spinymussel populations currently have a high ability to do so. Extant populations were thus classified as having either moderate resiliency or low resiliency based on the overall habitat score. A positive habitat score resulted in a moderate resiliency rank while a zero or negative habitat score resulted in a low resiliency rank.

Using these criteria, the Oconee and Lower Altamaha populations are **Presumed Extirpated** and have no resiliency. Their overall habitat scores indicate that the habitat in the Oconee population is in better condition than the Lower Altamaha, which can be relevant for future restoration or reintroduction efforts.

The Ohoopee population, which is listed as non-supporting on Georgia's 303(d) list and is at higher risk from low flow events has **Low Resiliency**.

The Ocmulgee/Altamaha population has **Moderate Resiliency** based on scoring well in terms of water quality and quantity.

4.3 Species Needs -- Redundancy and Representation

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).

4.3.1 Current Redundancy

Redundancy improves with increasing numbers of populations distributed across the species range, and connectivity (either natural or human-facilitated) that allows connected populations to "rescue" each other after catastrophes. Potential catastrophic events that could eliminate or severely reduce population resiliency include but are not limited to: drought, chemical spills, and invasive species impacting the Altamaha spinymussel or its host fish.

Current redundancy for the Altamaha spinymussel is low. Two of the 4 historical populations are presumed extirpated. The two remaining populations are not connected along one single linear path (*Figure 4-8*), meaning that localized upstream catastrophic impacts like chemical spills in one population will not cause the extinction of the entire species. However, the low resiliency of the

Ohoopee population limits its ability to serve as a refugia or source population for recolonization should the Ocmulgee/Altamaha population face a catastrophic event.

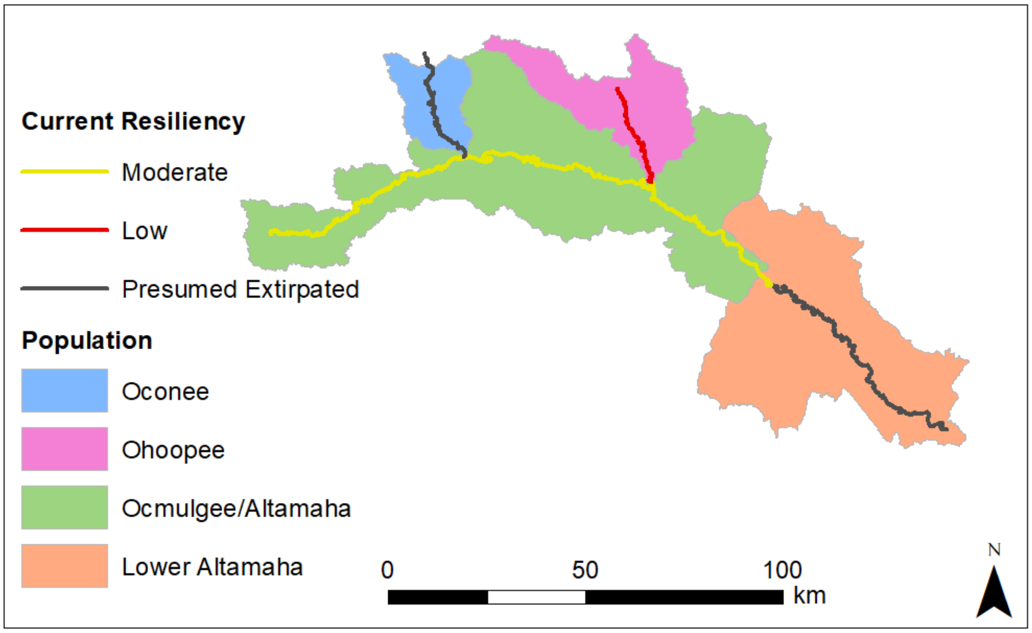

Figure 4-8. Current resiliency of Altamaha spinymussel populations.

4.3.2 Current Representation

Representation refers to the breadth of genetic and environmental diversity within and among populations that contributes to the ability of the species to respond and adapt to changing environmental conditions over time. Maintaining resilient populations across the range of variation within the species will increase the amount of variation within the species on which natural selection can act, increasing the chances that the species will persist in a changing world.

Since the Altamaha spinymussel is a narrow ranging endemic, occupies similar environmental conditions across its range, and genetic information on the species is lacking, one representative unit was used to describe all occurrences of the Altamaha spinymussel. It is possible that genetic differences exist among the populations of Altamaha spinymussel, however, we do not have adequate data to support delineating representative units at this time; additional research could inform a change in representative units in the future.

It is possible that the population in the Ohoopee River could represent a small river "type" of the species, which otherwise historically exists only in larger rivers (Rowe 2019, pers. comm.; Wisniewski 2019, pers. comm.). Whether this difference in habitat in the Ohoopee River has led to genotypic or phenotypic differences compared to other historical populations of Altamaha spinymussel is unknown.

Because the Altamaha spinymussel is a narrow-ranging endemic species and we have no evidence for multiple representative units, current representation is inherently low.

5 FUTURE CONDITIONS AND VIABILITY

We have assessed the needs of the Altamaha spinymussel (Chapter 2), factors influencing those needs (Chapter 3), and the current condition of those needs (Chapter 4). In this chapter we assess the future condition of the Altamaha spinymussel under multiple plausible scenarios, and describe future viability of the species in terms of resiliency, redundancy, and representation.

5.1 Future Scenarios Approach

There is a high degree of uncertainty in the current condition of the species, including its abundance, population trends, how much reproduction and recruitment are occurring, what the host fish is, and consequently what the status of the host fish population is. Because of this uncertainty, we explored future scenarios projected out to two different time frames. Scenarios were projected out a maximum of 50 years (to 2070), with an intermediate time step in 20 years (2040) to explore conditions in which the species might go extinct within that time frame.

Given the estimated life span of the similar species, if reproduction and recruitment are limited, possibly due to host fish declines, abundance of Altamaha spinymussels will continue along its apparent decline and the species will likely be extinct or functionally so within 20 years. If however, reproduction and recruitment are occurring and apparent declines in abundance are at least partially due to low detectability and a lack of recent surveys, the species will still persist within 20 years.

If the species has gone extinct within 20 years, there is no reason to explore scenarios further into the future. Given that the species persists over the next 20 years, we then explore scenarios 50 years in the future. The structure of future scenarios is summarized in *Figure 5-1*, and scenarios are detailed in the following sections.

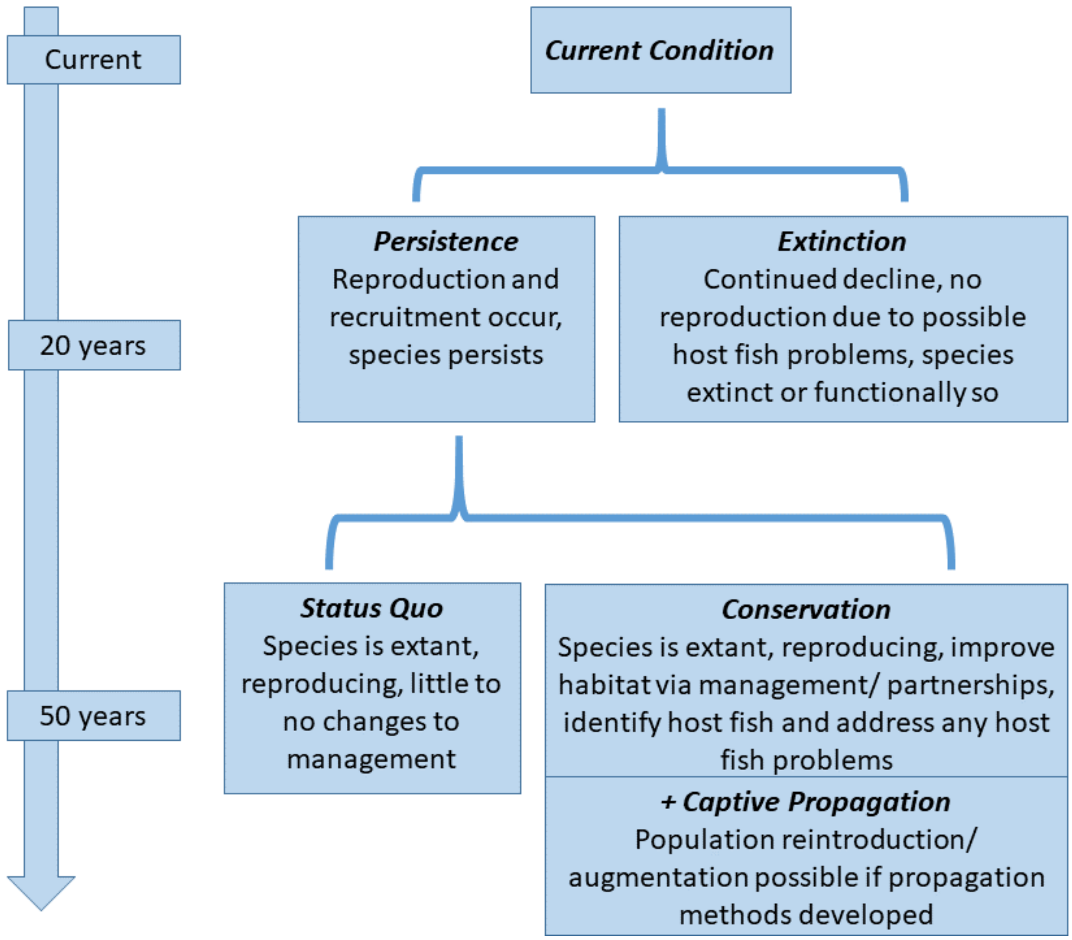

Figure 5-1. Altamaha spinymussel future scenarios

Future climate change, land use change, and changes in water quantity are related to each other and are likely to occur similarly across all scenarios. In the next sections, we provide a range of plausible future conditions for these factors to be applied across all scenarios.

5.1.1 Climate Change

It is challenging to predict with high certainty how the climate will change in the future and the precise effects that those changes will have on Altamaha spinymussels. For example, we do not at this time understand the thermal tolerance of the species or have predictions of how increased water withdrawal from a growing population will interact with climate changes. While we could not predict with certainty every aspect of how the Altamaha spinymussel will respond to climate change, different climate scenarios were incorporated into our future predictions of land use (which influences nonpoint source pollution) and water quantity.

In order to predict future changes in climate, scientists rely on climate model simulations that are driven by assumptions about future human population growth, changes in energy generation and land use, socio-economic development, and technology change. The Intergovernmental Panel on

Climate Change (IPCC) Fifth Assessment Report (AR5), published in 2014, presents the most recent climate findings based on a set of scenarios that use Representative Concentration Pathways (RCPs). There are four RCPs, identified by the amount of radiative forcing (i.e., the change in energy in the atmosphere due to greenhouse gases) reached by 2100: one high pathway (RCP 8.5); two intermediate stabilization pathways (RCP 6.0 and RCP 4.5); and one low trajectory pathway (RCP 2.6) selected from the range of climate scenarios present in the climate literature (van Vuuren et al. 2011, pp. 11, 20). Prior to the development of the RCP scenarios, the IPCC developed Special Report Emissions Scenarios (SRES). One of the main differences between RCP and SRES climate projections is that RCPs start with atmospheric concentrations of greenhouse gases and SRESs start with a narrative story about socioeconomic processes that lead to a given future (Nakićenović et a. 2000, p. 3). Although the SRES projections are not as used widely today, these two approaches (SRES or RCP) are not inconsistent. Rather, they both present plausible and consistent pictures of how future human activities may affect climate. The RCP 4.5 scenario is comparable to the SRES B1 scenario and the RCP 8.5 scenario is comparable to the SRES A2 scenario (van Vuuren et al. 2011, pp. 17, 20; *Figure 5-2*). The model that we used to forecast land use into the future was based upon SRES scenarios, while the water quantity projection models we used were based upon RCP scenarios. For both factors, land use change and water quantity change, we provided a high and low climate change impact projection based on the RCP 8.5/SRES A2 and RCP 4.5/SRES BI scenarios, respectively. In presenting this range, our purpose is to provide bounds on the range of plausible outcomes, and we do not imply that an outcome in the middle of the range is the most likely outcome.

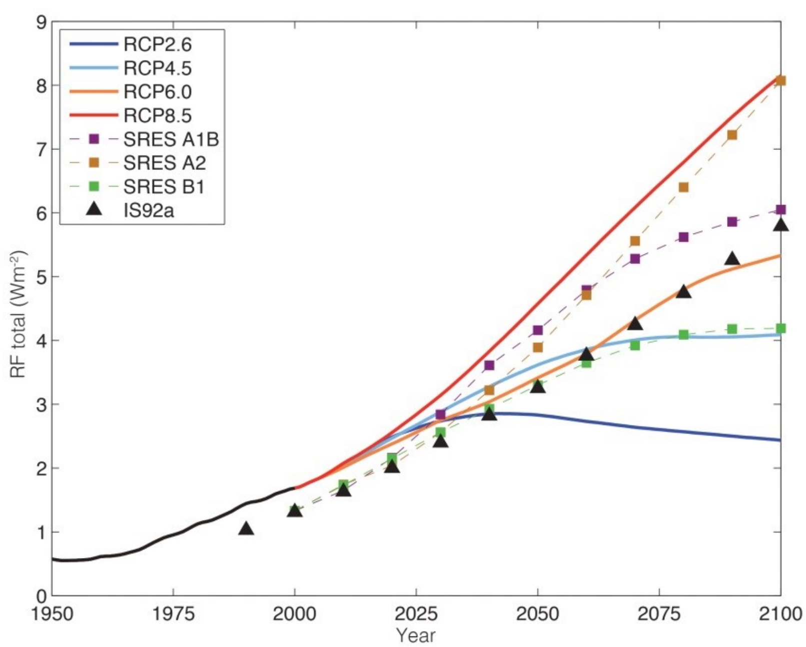

Figure 5-2. Historical and projected future anthropogenic radiative forcing (RF; the change in energy in the atmosphere due to greenhouse gases) under different scenarios, relative to the preindustrial period (about 1765; Cubasch et al. 2013, p. 146).

5.1.2 Land Use Change

To assess future changes in nonpoint source pollution, we summarized changes in land use within each of the Altamaha spinymussel population watersheds. Land cover data were compiled from the USGS FORE-SCE (FOREcasting SCEnarios of Land-use Change) model (Sohl et al. 2018, data release). This data set was selected because it provides future predictions of land use in annual time steps out to 2100 based on multiple future SRES scenarios. We extracted results for SRES A2 and B1 to bound plausible future outcomes The modeling time frame for this data set was 2006-2100, meaning that 2020 (current) results were modeled predictions also based on SRES scenarios as opposed to a common starting point.

Note that this land cover data set is different from that used in the current condition assessment. We used NLCD data for the current condition because the resolution of the data (30 x 30 meters; 98 x 98 feet) was much smaller than the FORE-SCE data (250 x 250 meters; 820 x 820 feet), providing a more accurate picture of current land use. The FORE-SCE model, though it has a lower spatial resolution, offers annual predictions of land use into the future, which is not available with the NLCD data. Consequently, in presenting FORE-SCE land cover data for future assessments, we rely more heavily on the patterns of predicted land use change than the precise area of land predicted to be in each land cover class. To aid interpretation, we collapsed land cover classes down to 4 relevant categories: natural (including forests, wetlands, open water, and other natural land cover types), cropland, pasture/hay, and developed. Other extractive uses like forestry clearcuts and mining were excluded from the following figures to aid interpretation and because values were low, but raw values for all land cover classes in the original data set are provided in tabular form in Appendix B.

At the watershed scale, the amount of land in development and hay/pasture are predicted to be low and stable across all populations and scenarios, while the amounts of natural lands and croplands are more variable (*Figure 5-3*). Under the B1 climate scenario, the amount of natural land and cropland are predicted to remain fairly stable or show a slight conversion of agricultural land back to natural land cover. Under the A2 climate scenario, natural lands are predicted to decrease in favor of cropland (or developed land in the Lower Altamaha watershed). This loss of natural land cover in this scenario is predicted to be slight in the Lower Altamaha watershed, slightly more pronounced in the Oconee and Ocmulgee/Altamaha watersheds, and most pronounced in the Ohoopee watershed where the amount of land in natural land cover and cropland are predicted to be nearly equivalent by 2070. Within the 3,000-foot buffer from Altamaha spinymussel rivers, all populations are predicted to retain stable and high amounts of natural land cover and low amounts of anthropogenic land uses, with the exception of the Ohoopee where a slight conversion of natural lands to cropland is predicted in the A2 scenario (*Figure 5-4*).

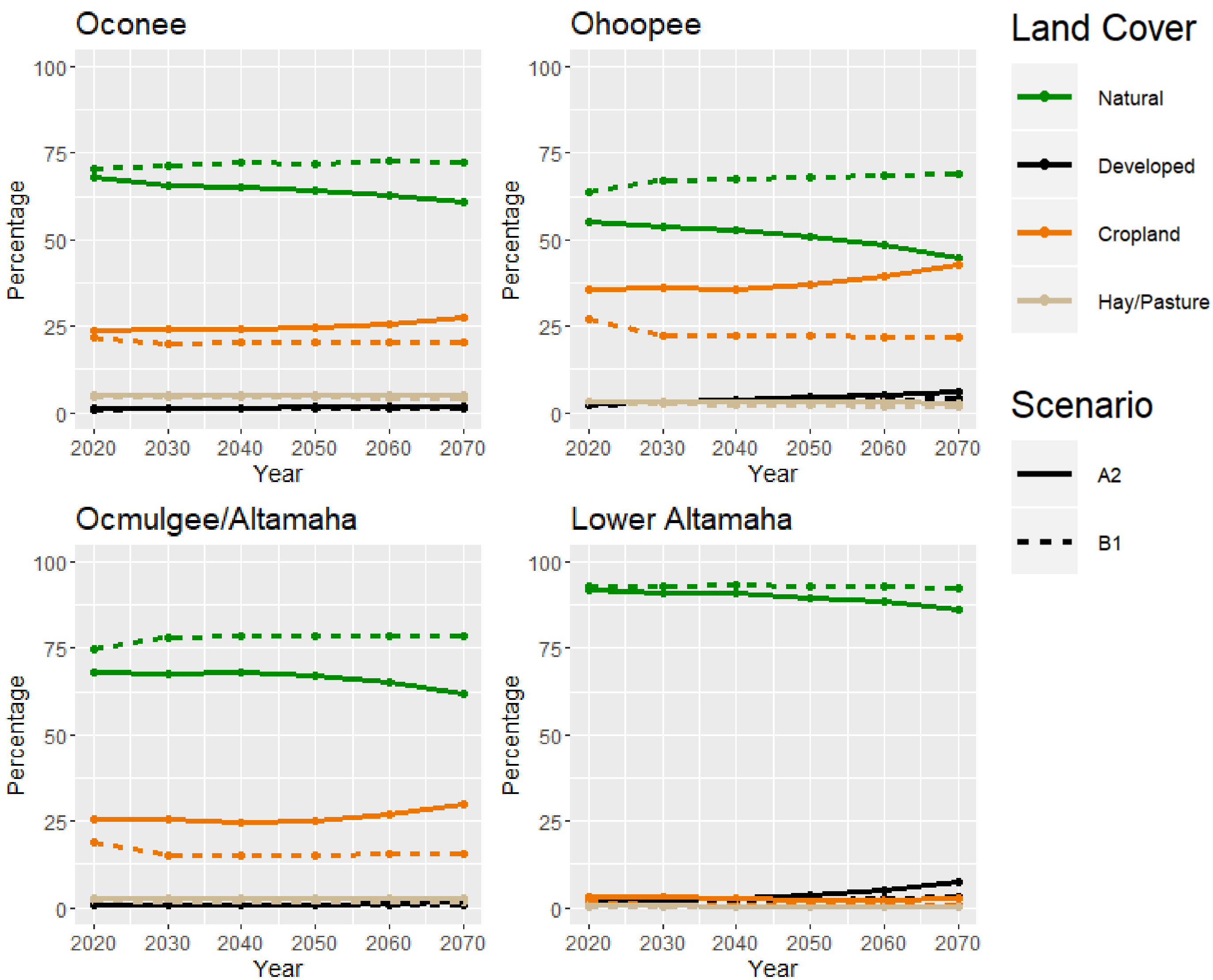

Figure 5-3. Predicted land use at the watershed scale for the A2 and B1 climate scenarios.

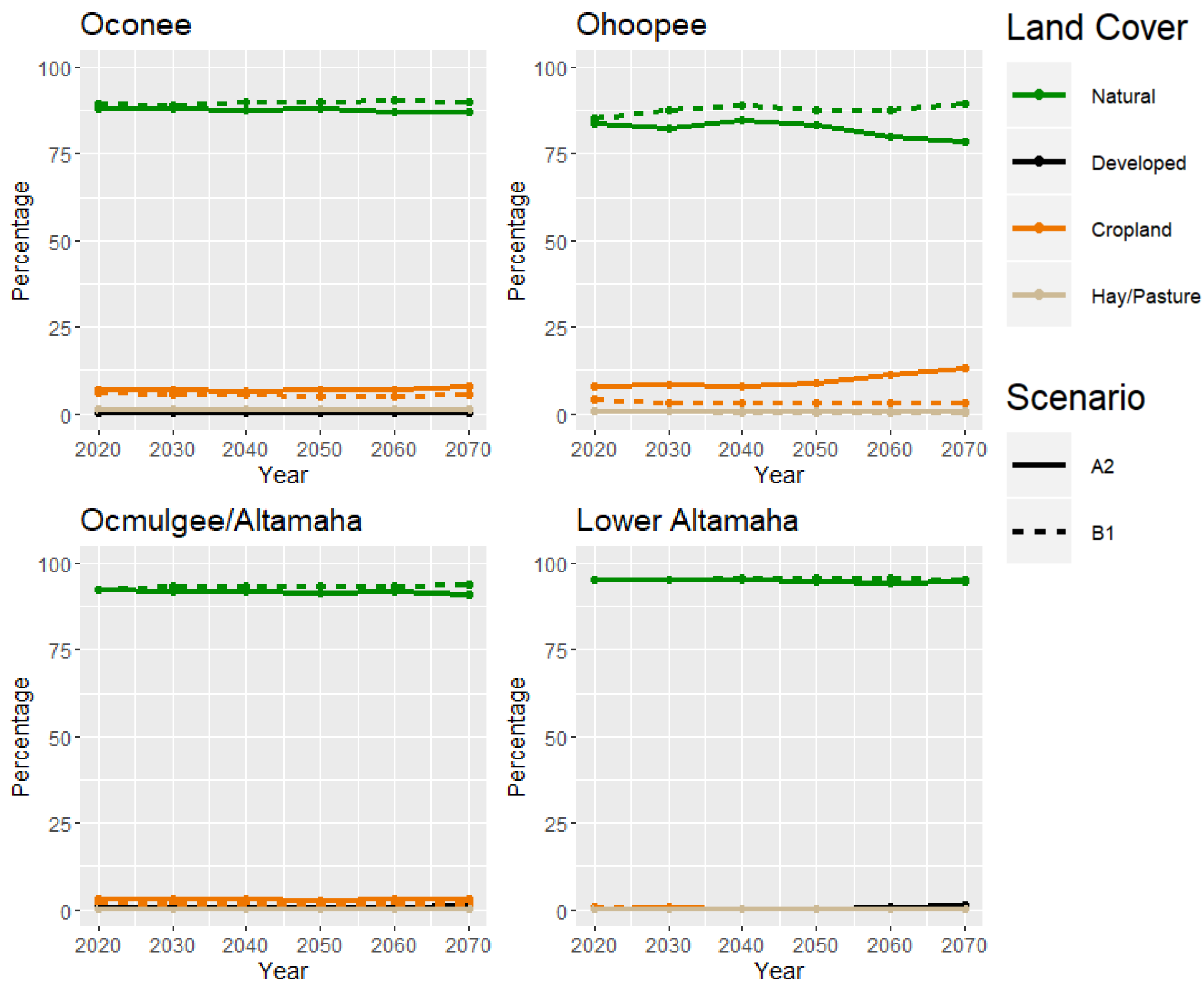

Figure 5-4. Predicted land use at the 3,000-foot river buffer scale for the A2 and B1 climate scenarios.

For the current condition assessment, the implications of current land use on nonpoint source pollution (i.e., runoff of sediments, chemicals, and nutrients from impervious surfaces and agricultural fields) were largely unknown. It is believed that the mussel community is being influenced primarily by legacy sediments from historical agricultural practices, and the impact to Altamaha spinymussel populations from current development or agricultural practices is unknown. This holds for the future condition; we cannot conclude in absolute terms what impact predicted land use changes will have on the viability of Altamaha spinymussel populations, especially compared to ongoing impacts from legacy sedimentation, which is expected to impact affected streams for centuries to come (Jackson et al. 2005, p. 11; McCarney-Castle et al. 2010, p. 412). In relative terms however, the Ohoopee River faces the highest risk of additional impacts from land use change under more aggressive climate change and associated socio-economic possible futures, with a greater magnitude of land use change than other populations that extends closer to the riverbank than in the other populations. The three other populations may face some loss of natural land cover at the watershed scale, but impacts will continue to be buffered by a riparian buffer composed heavily of natural vegetation.

5.1.3 Water Quantity

To assess future water quantity, we used to same modeling outputs as in the current condition (LaFontaine et al. 2019, entire), which provided annual predictions for the time frame 2045-2075. We extracted results for two climate scenarios, RCP 4.5 and RCP 8.5 to bound plausible future outcomes and compared these against the historical and current states.

Results indicated that risk to the Altamaha spinymussel from low flow events will likely be lower than or similar to the current condition in the future (*Figure 5-5*, Appendix C). Under both modeled climate scenarios, minimum 7-day flow is predicted to increase in the Ocmulgee/Altamaha and Lower Altamaha populations and not change appreciably in the Oconee and Ohoopee populations. The portion of flow made up of base flow is predicted to increase in all populations. The frequency of low flow events under the 25^{th} percentile of the flow record is predicted to increase slightly in the Oconee and Ohoopee populations, but the frequency of events under 5% of the mean is predicted to fall for the Ohoopee population.

There were few differences between the two climate scenarios. Minimum flows and the portion of flow made up of base flow were predicted to increase more in the RCP 8.5 scenario than the RCP 4.5 scenario. The frequency and duration of low flow events did not differ appreciably between the two climate scenarios with the exception of the Lower Altamaha population, where low flow events under the 25^{th} percentile of the flow record were predicted to occur more often but for a shorter period of time in the RCP 8.5 scenario than the RCP 4.5 scenario.

We assessed the current condition of this resiliency factor by classifying populations relative to each other as either high risk or low risk from low flow events. For the future condition, these classifications are not expected to change for any population. The Ohoopee population, even with increasing minimum flows and base flow, is still predicted to face a very different low flow event regime than the other three populations, though there is evidence that the risk could be lessened with increased flows in the future. One limitation of the water quantity model used is that it is based only on physical mechanisms related to climate and terrain and does not incorporate withdrawal of water for human uses, which might increase as human populations increase. Also, the available data did not allow for seasonal evaluation of drought/low flow conditions. Lower than normal flows occurring during time periods that are typically wet may be more detrimental to the Altamaha spinymussel if they occur during a critical life stage (reproduction, etc.). Future models that incorporate both physical and anthropogenic mechanisms and seasonal fluctuations could provide more accurate predictions of future water quantity, and its impact on the Altamaha spinymussel, and should be investigated if/when they are developed.

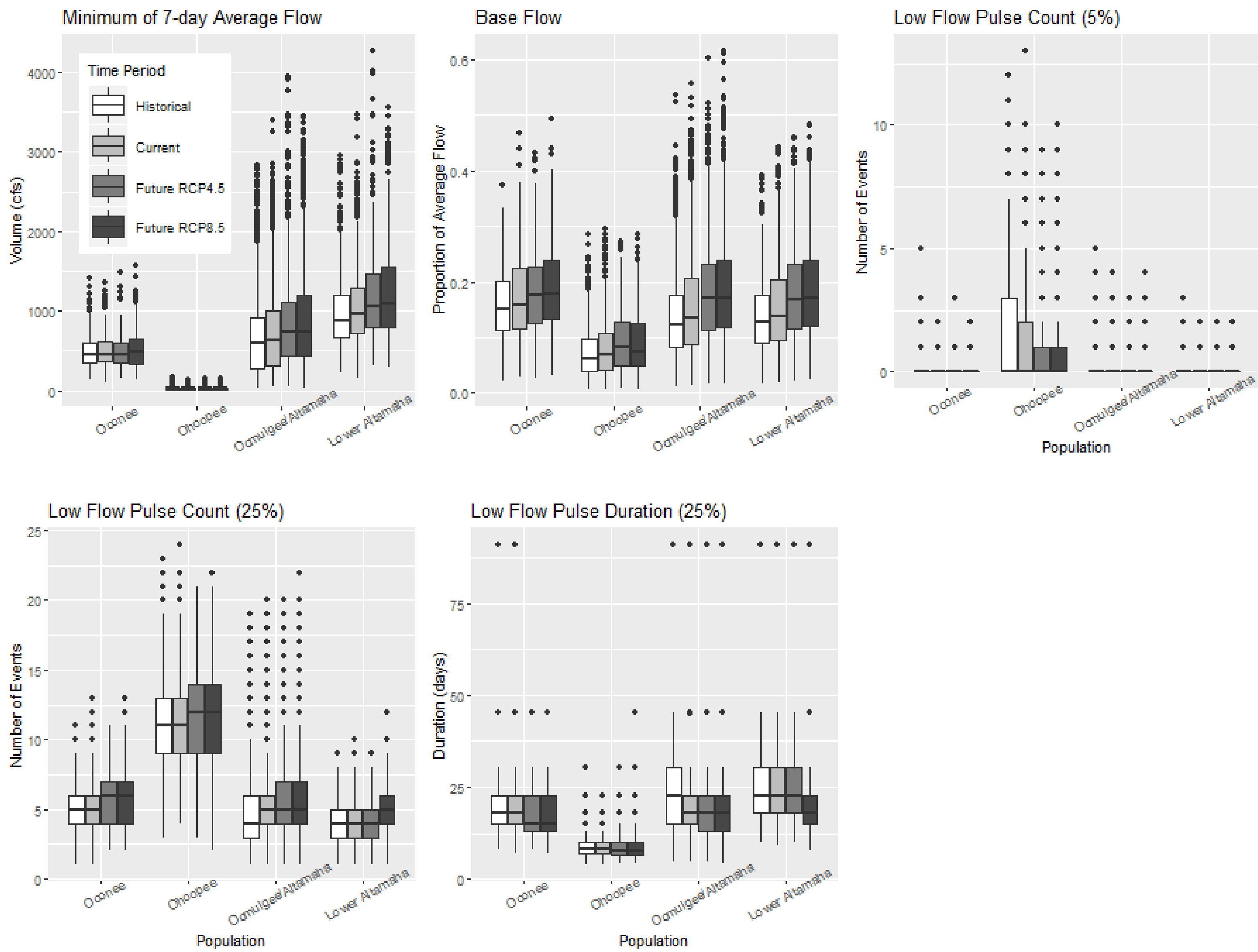

Figure 5-5. Future water quantity predictions under two climate scenarios (RCP 4.5 and RCP 8.5) compared to current and historical simulated values.

5.2 Future Scenarios – 20 Year Time Frame

There is a great deal of uncertainty in the current trend in abundance of the Altamaha spinymussel due to low detection probabilities and the lack of recent comprehensive surveys, though available data do indicate population declines. Additionally, because the host fish is unknown, the status of the host fish population is unknown, contributing additional uncertainty about the status of the spinymussel. Given this uncertainty about the population status, within 20 years, the Altamaha spinymussel could plausibly follow either of two possible trajectories at the species level, persistence near present levels of abundance or extinction. Given the time necessary to implement conservation measures and observe results, it is unlikely that the species will increase appreciably within 20 years.

For this intermediate 20-year time step, we focused primarily on the population factors of presence and evidence of reproduction, although the habitat factor of host fish community is closely related to evidence of reproduction.

5.2.1 Persistence

In this scenario, we assumed that apparent declines in abundance and distribution in extant populations were at least partially due to low detectability and a lack of recent surveys, and that the species naturally occurs at low densities and will continue to do so into the future. We assumed that populations that are currently presumed extirpated are in fact extirpated, and that the status of the unknown host fish is not limiting to the spinymussel, or that any limitations can be identified and alleviated such that reproduction and recruitment of juvenile mussels continues.

Within this scenario of persistence at the species level, we identified 2 plausible scenarios at the population level within 20 years. Both extant populations could remain extant with stable but low abundance of spinymussels. Alternately, the Ocmulgee/Altamaha population could persist while the Ohoopee population goes extinct due to the habitat threats that contribute to its current low resilience. There has only been a single observation of an Altamaha spinymussel in the Ohoopee River since the 1990s, it is listed on the 303(d) list as not supporting due to high levels of mercury, and more frequent low flow events make this population more susceptible to direct and indirect mortality and habitat degradation from ATVs. The Ohoopee population has previously been thought to be extinct, and given the threats facing it, it is not unreasonable to predict that this population might go extinct within 20 years even if there are no limiting host fish problems at the species level.

Table 5-1. Population factors under the 20-year Persistence scenario.

	Population Factors	
Population	**Presence**	**Evidence of reproduction**
Oconee	Extirpated	NA
Ohoopee	Present at low density or Extirpated	Evidence Present or NA
Ocmulgee/Altamaha	Present at low density	Evidence Present
Lower Altamaha	Extirpated	NA

5.2.2 Extinction

In this scenario, we assumed that apparent declines in abundance and distribution in extant populations were driven by actual declines of the Altamaha spinymussel in response to habitat threats and/or threats facing the host fish that limit spinymussel reproduction and recruitment. Under this scenario, both extant populations are likely to be extinct or functionally so within 20 years as adult mussels die off without reproduction and recruitment to replace them. The Ohoopee population, where just a single mussel has been observed since the 1990s, will likely go extinct first, followed later by the Ocmulgee/Altamaha population, which currently hosts a larger, though still rare, population.

Table 5-2. Population factors under the 20-year Extinction scenario.

	Population Factors	
Population	**Presence**	**Evidence of reproduction**
Oconee	Extirpated	NA
Ohoopee	Extirpated	NA
Ocmulgee/Altamaha	Extirpated	NA
Lower Altamaha	Extirpated	NA

5.3 Future Scenarios– 50 Year Time Frame

Given that the species persists, we explored two primary scenarios on a 50 year time frame (to 2070): Status Quo and Conservation. While the 20-year scenarios focused on population factors, these 50-year scenarios assume that population factors favor species persistence. Population factors not favoring species persistence led to the 20-year Extinction scenario, a dead-end scenario with no reason to continue to project out to 50 years. These 50-year scenarios instead focus on habitat factors. There is uncertainty currently about whether the host fish can be identified and protocols can be developed for captive propagation, so we generated an additional add-on to the Conservation scenario that includes captive propagation under the assumption that these challenges can be addressed within the next 50 years.

5.3.1 Status Quo

This scenario assumes that conditions in the Altamaha Basin continue for the next 50 years along their present trajectory. Conservation actions that are already in place were assumed to continue, but were not increased or new projects initiated. Under the Status Quo scenario, the population factors of presence and evidence of reproduction were held constant from the 20-year Persistence scenario.

Water Quality

The 303(d) listing status for populations were assumed to remain the same as the current condition with the exception of the Ohoopee River. The Oconee and Ocmulgee/Altamaha were assumed to continue to support the designated use of fishing, and the Lower Altamaha was held at "Unknown" to reflect uncertainty in current conditions related to the Rayonier paper mill effluent and uncertainty about whether the condition is likely to improve in the future. The Ohoopee was predicted to improve from "Not Supporting" to "Supporting" within 50 years. The Ohoopee was listed as impaired due to elevated mercury levels in fish, and it is estimated that 99% of the mercury load received by the river comes from atmospheric deposits (EPA 2002, p.2). The Clean Air Act and the Environmental Protection Agency (EPA) have developed multiple regulations, including many in the 2010s, a decade after the Ohoopee River was listed as impaired, intended to decrease the amount of mercury emitted to the air by coal- and oil-fired power plants, municipal and industrial waste incinerators, and other facilities (EPA 2019, n.p.). Therefore we believe it is plausible and likely that the amount of mercury being deposited into the Ohoopee River from atmospheric sources can be reduced over a 50-year period such that it can be delisted from the 303(d) list.

In this scenario, the point source pollution condition remained the same as the current condition for all populations.

Changes in nonpoint source pollution were modeled as changes in land cover as described in Section 5.1.2. The Ohoopee River is predicted to lose more natural land cover in favor of cropland than the other populations, but the absolute impact of predicted changes in land cover on water quality for any population are unknown, considering the legacy sedimentation that will continue to impact these rivers well beyond the forecasting window of this report and rivers are buffered by natural vegetation.

Water Quantity

Water quantity changes were modeled as described in Section 5.1.3, resulting in no categorical changes to this factor compared to the current condition.

Host Fish Community

In this scenario, we assumed that the status of the host fish community within the Altamaha Basin is suitable to support the persistence of the species.

Overall Resiliency

Compared to the current condition, resiliency is not predicted to change under this scenario for 3 out of 4 populations (*Table 5-3*). The Oconee and Lower Altamaha populations will remain extirpated. The Ocmulgee/Altamaha population will have no change in resiliency. Although the host fish community habitat factor improves from "Unknown" to "Suitable" compared to the current condition, this change reflects a predicted improvement in our understanding rather than an actual improvement in resiliency. The future condition of the Ohoopee population in this scenario is uncertain resulting from uncertainty in whether it is likely to persist past the 20-year intermediate time horizon. If the population persists, resiliency is expected to improve as a result of improvements in water quality that lead to its removal from the 303(d) list. If current resiliency is so low that the population does not persist past 20 years, the population will remain extirpated in 50 years.

Table 5-3. Resiliency factors under the 50-year Status Quo scenario. The evidence of reproduction factor is omitted from this table, but is reproduction and recruitment are assumed to occur in all non-extirpated populations.

		Habitat Factors					**Overall Resiliency**
Population		**Water Quality**			**Water Quantity**	**Host Fish**	
	Presence	**303(d) list**	**Point Source**	**Nonpoint Source**			
Oconee	Extirpated	Supporting	Better	Land use changes as modeled, minimal change from current, Ohoopee most at risk in future, all still impacted by legacy sediments and mediated by buffer	Low Risk	Suitable	**Extirpated**
Ohoopee	Present at low density or Extirpated	Supporting	Better		High risk		**Improvement or Extirpated**
Ocmulgee/ Altamaha	Present at low density	Supporting	Better		Low Risk		**No Change**
Lower Altamaha	Extirpated	Unknown	Worse		Low Risk		**Extirpated**

5.3.2 Conservation

In this scenario, we assumed that new conservation measures will be initiated and existing efforts will be increased to improve the status of the Altamaha spinymussel and its habitat. Such efforts can and should include:

- Maintenance of stream habitat and riparian buffers within the species' current and historical range, including physical improvements where needed
- Use education or regulation to limit ATV access to streambeds at or near mussel beds during low flow events
- Promote voluntary stewardship as a practical and economical means of reducing nonpoint source pollution on private lands
- Encourage and support community-based watershed stewardship planning and action
- Conduct basic research on the Altamaha spinymussel and its host fish and apply the results towards management and protection of its habitat
- Develop methodology for maintaining and propagating Altamaha spinymussels in captivity to enable reintroductions and population augmentation
- Monitor population and habitat conditions through a regular survey schedule

In terms of resiliency habitat factors (*Table 5-4*), we have indicated no specific changes compared to the Status Quo scenario, reflecting that for most populations, there are no clear smoking guns at this time as to what is causing the apparent population declines. In the instances where habitat factors do indicate threats to the Altamaha spinymussel (e.g., high risk from low flows in the Ohoopee River, point source pollution in the Lower Altamaha River), these are unlikely to change even in a Conservation scenario. Despite no explicit changes to the status of habitat factors, the above listed conservation measures are likely to improve resiliency of extant populations via improvements in habitat fostered by land managers and the public, a potential decrease in the threat of ATVs to the Ohoopee population, and increased understanding of Altamaha spinymussel biology and their population status.

Table 5-4. Resiliency factors under the 50-year Conservation scenario. The evidence of reproduction factor is omitted from this table, but is reproduction and recruitment are assumed to occur in all non-extirpated populations.

<table>
<tr><th></th><th></th><th colspan="5">Habitat Factors</th><th>Overall Resiliency</th></tr>
<tr><th rowspan="2">Population</th><th></th><th colspan="3">Water Quality</th><th>Water Quantity</th><th>Host Fish</th><th></th></tr>
<tr><th>Presence</th><th>303(d) list</th><th>Point Source</th><th>Nonpoint Source</th><th></th><th></th><th></th></tr>
<tr><td>Oconee</td><td>Extirpated</td><td>Supporting</td><td>Better</td><td rowspan="4">Land use changes as modeled, minimal change from current, Ohoopee most at risk in future, all still impacted by legacy sediments</td><td>Low Risk</td><td rowspan="4">Suitable</td><td>Extirpated</td></tr>
<tr><td>Ohoopee</td><td>Present & increases or Extirpated</td><td>Supporting</td><td>Better</td><td>High risk</td><td>Improvement or Extirpated</td></tr>
<tr><td>Ocmulgee/ Altamaha</td><td>Present & increases</td><td>Supporting</td><td>Better</td><td>Low Risk</td><td>Improvement</td></tr>
<tr><td>Lower Altamaha</td><td>Extirpated</td><td>Unknown</td><td>Worse</td><td>Low Risk</td><td>Extirpated</td></tr>
</table>

The listed conservation actions include developing captive propagation methods to enable future reintroductions and/or population augmentation. However, there is no guarantee that these efforts will be successful. Such efforts over the last 2 decades have not been successful. Assuming that no populations are reintroduced or augmented from captive stock, overall resiliency for the Altamaha spinymussel in this scenario is predicted to be as follows. The Oconee and Lower Altamaha populations will still be extirpated. If the Ohoopee population persists past 20 years, its resiliency is predicted to improve, and resiliency for the Ocmulgee/Altamaha population is predicted to improve.

5.3.3 + Captive Propagation

If efforts to propagate the Altamaha spinymussel in captivity are successful, this paves the way for increases in resiliency and redundancy as captive-bred mussels can be used to reintroduce populations where they have been extirpated and/or augment populations where distributions have contracted or abundances are low. At this point, we do not outline a reintroduction or augmentation strategy in terms of which populations to augment or reintroduce, how many mussels to introduce, etc. Prior to any future introductions, detailed plans for propagation and reintroduction should be developed. Further, reintroduction should only take place after threats have been identified and ameliorated and habitat has been deemed suitable. We also stress the importance of monitoring augmented or reintroduced populations to determine whether the strategy is successful and to identify ways to improve methods to further improve recovery outcomes.

5.4 Future Resiliency

Within 20 years, it is possible that the Altamaha spinymussel could be extinct or functionally so if apparent population declines continue and reproduction and recruitment are unable to keep pace with adult mortality. However, if apparent declines are instead due at least in part to limited surveys and low detectability, and reproduction and recruitment are occurring, the species is likely to persist, though at low densities, in 1-2 populations beyond 20 years. The Ocmulgee/Altamaha population is likely to persist in this scenario, but there is uncertainty whether the Ohoopee population will persist as apparent densities are very low and the population was previously believed to have been extirpated but for the observation of a single spinymussel in 2005.

Given that the species does not go extinct within 20 years, the Ohoopee population has opportunities to improve in resiliency under both the Status Quo and Conservation 50-year scenarios. The Ocmulgee/Altamaha population is likely to see no change in resiliency under the Status Quo scenario, but resiliency will improve under the Conservation scenario. The biggest increases in resiliency across multiple populations will occur if methods are successfully developed to propagate the Altamaha spinymussel in captivity and then use captive-bred mussels to reintroduce or augment populations in the wild. Without captive propagation, the two populations currently presumed extirpated will most likely remain so.

5.5 Future Redundancy

Under the 20-year extinction scenario, redundancy will decline from 4 historical populations and 2 current populations to no remaining populations. If the species as a whole does not go extinct within 20 years, only 1-2 populations are predicted to remain after 50 years. The only way to increase redundancy compared to the current condition is with reintroductions from a successful captive propagation program. Based on our current knowledge of the biology and threats to the species, it is unlikely that the conservation actions included in the Conservation scenario without captive propagation are sufficient to enable natural recolonization of extirpated populations. However, increased research over the coming decades could reveal other conservation actions that target specific threats that are as yet undiscovered.

5.6 Future Representation

As for the current condition, the Altamaha spinymussel is a narrow-ranging endemic species and we have no evidence for multiple representative units given the state of our current knowledge. Thus, future representation under all scenarios remains inherently low.

This concludes our assessment of Altamaha spinymussel needs, current, condition, and future condition. There is a high degree of uncertainty in both the current and future condition of the species. Future assessments of this species' current and future condition can be improved by conducting a new range-wide survey for the species to better understand current abundance, *habitat type utilization, and population trends, and increased research into its life history, especially its host fish. If populations are truly declining, as they appear to be based on available monitoring data, we need to better understand the threats driving this decline in order to develop specific conservation actions to counteract them.*

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APPENDIX A

Table A1. Current land use in Altamaha spinymussel population watersheds and river buffers.

Land Use	Population	Population Watershed		3,000-foot Buffer		500-foot Buffer	
		Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
Cropland	Lower Altamaha	811.3	0.4	233.4	0.8	0.5	0.0
	Ocmulgee/Altamaha	34073.6	12.5	38.0	0.6	0.2	0.0
	Oconee	3336.3	10.4	28.4	0.5	0.2	0.0
	Ohoopee	11643.8	17.2	0	0	0	0
Developed	Lower Altamaha	10668.5	5.4	205.0	1.5	7.8	0.3
	Ocmulgee/Altamaha	14725.2	5.4	732.5	2.5	36.0	0.6
	Oconee	1185.2	3.7	39.2	0.6	7.0	0.6
	Ohoopee	6182.4	9.1	266.6	4.9	30.8	2.9
Hay/Pasture	Lower Altamaha	2704.9	1.4	1.5	0.0	0.2	0.0
	Ocmulgee/Altamaha	14932.2	5.5	199.7	0.7	2.2	0.0
	Oconee	439.8	1.4	26.2	0.4	0.4	0.0
	Ohoopee	6064.5	9.0	257.0	4.7	1.8	0.2
Natural - Forest	Lower Altamaha	54144.5	27.6	518.8	3.9	11.8	0.5
	Ocmulgee/Altamaha	87210.8	32.0	4045.8	13.6	89.5	1.6
	Oconee	13328.9	41.6	667.4	10.3	14.4	1.1
	Ohoopee	15800.2	23.4	1411.8	25.8	73.0	6.8
Natural - Other	Lower Altamaha	27779.4	14.2	342.7	2.6	23.6	0.9
	Ocmulgee/Altamaha	34194.1	12.5	1360.1	4.6	286.4	5.0
	Oconee	3193.2	10.0	375.4	5.8	94.3	7.5
	Ohoopee	10667.1	15.8	1149.0	21.0	44.2	4.1
Natural - Water	Lower Altamaha	3389.0	1.7	1792.6	13.5	1266.8	48.9
	Ocmulgee/Altamaha	4426.8	1.6	2421.0	8.1	2284.1	39.8
	Oconee	483.6	1.5	342.2	5.3	306.6	24.4
	Ohoopee	839.0	1.2	49.7	0.9	23.4	2.2
Natural - Wetland	Lower Altamaha	96297.2	49.2	10457.6	78.5	1279.5	49.4
	Ocmulgee/Altamaha	82819.2	30.4	20483.0	68.8	3038.5	52.9
	Oconee	10015.8	31.3	4350.0	67.0	710.5	56.5
	Ohoopee	16410.9	24.3	2306.9	42.2	897.1	83.8

APPENDIX B

Table B1. Land use in Altamaha spinymussel population watersheds and river buffers in 2020 and 2070 under two climate scenarios.

				Population Watershed		3,000-foot Buffer	
Land Use	**Population**	**Scenario**	**Year**	**Area (ha)**	**Percent**	**Area (ha)**	**Percent**
Barren	Lower Altamaha	A2	2020	56.3	0.0	6.3	0.0
			2070	56.3	0.0	6.3	0.0
		B1	2020	56.3	0.0	6.3	0.0
			2070	56.3	0.0	6.3	0.0
	Ocmulgee/Altamaha	A2	2020	175.1	0.1	25.0	0.1
			2070	175.1	0.1	25.0	0.1
		B1	2020	175.1	0.1	25.0	0.1
			2070	175.1	0.1	25.0	0.1
	Oconee	A2	2020	12.5	0.0	12.5	0.2
			2070	12.5	0.0	12.5	0.2
		B1	2020	12.5	0.0	12.5	0.2
			2070	12.5	0.0	12.5	0.2
	Ohoopee	A2	2020	61.4	0.1	NA	NA
			2070	61.4	0.1	NA	NA
		B1	2020	61.4	0.1	NA	NA
			2070	61.4	0.1	NA	NA
Cropland	Lower Altamaha	A2	2020	6072.5	3.1	60.1	0.5
			2070	5048.7	2.6	64.0	0.5
		B1	2020	3354.9	1.7	79.8	0.6
			2070	1615.9	0.8	47.6	0.4
	Ocmulgee/Altamaha	A2	2020	69264.9	25.4	927.3	3.1
			2070	81246.9	29.8	1000.1	3.4
		B1	2020	51031.5	18.7	695.0	2.3

				Population Watershed		3,000-foot Buffer	
Land Use	**Population**	**Scenario**	**Year**	**Area (ha)**	**Percent**	**Area (ha)**	**Percent**
			2070	42602.7	15.6	490.0	1.6
	Oconee	A2	2020	7577.8	23.7	443.8	6.8
			2070	8775.4	27.4	502.3	7.7
		B1	2020	6898.5	21.6	376.8	5.8
			2070	6502.3	20.3	343.9	5.3
	Ohoopee	A2	2020	23963.3	35.4	428.2	7.8
			2070	29050.5	42.9	722.0	13.2
		B1	2020	18300.1	27.1	231.1	4.2
			2070	14860.7	22.0	169.7	3.1
Deciduous Forest	Lower Altamaha	A2	2020	6156.8	3.1	126.5	1.0
			2070	3734.8	1.9	92.3	0.7
		B1	2020	5891.7	3.0	120.3	0.9
			2070	3687.7	1.9	98.5	0.7
	Ocmulgee/Altamaha	A2	2020	20918.0	7.7	861.4	2.9
			2070	17673.4	6.5	788.3	2.6
		B1	2020	22576.4	8.3	877.2	2.9
			2070	22351.8	8.2	877.8	3.0
	Oconee	A2	2020	2762.2	8.6	191.8	3.0
			2070	2289.2	7.2	177.7	2.7
		B1	2020	3010.1	9.4	207.2	3.2
			2070	3281.9	10.3	210.0	3.2
	Ohoopee	A2	2020	5203.3	7.7	604.0	11.0
			2070	3917.0	5.8	524.6	9.6
		B1	2020	5708.8	8.4	550.3	10.1
			2070	5867.0	8.7	664.3	12.1
Developed	Lower Altamaha	A2	2020	3146.3	1.6	25.0	0.2

				Population Watershed		3,000-foot Buffer	
Land Use	**Population**	**Scenario**	**Year**	**Area (ha)**	**Percent**	**Area (ha)**	**Percent**
			2070	14218.5	7.3	148.5	1.1
		B1	2020	2901.9	1.5	25.0	0.2
			2070	6255.2	3.2	72.0	0.5
	Ocmulgee/Altamaha	A2	2020	1635.0	0.6	184.8	0.6
			2070	4129.2	1.5	300.3	1.0
		B1	2020	1571.4	0.6	184.8	0.6
			2070	2218.3	0.8	225.1	0.8
	Oconee	A2	2020	336.9	1.1	12.5	0.2
			2070	570.8	1.8	12.5	0.2
		B1	2020	314.0	1.0	12.5	0.2
			2070	420.9	1.3	12.5	0.2
	Ohoopee	A2	2020	1789.1	2.6	41.6	0.8
			2070	4161.0	6.2	41.6	0.8
		B1	2020	1629.5	2.4	41.6	0.8
			2070	2828.7	4.2	41.6	0.8
Evergreen Forest	Lower Altamaha	A2	2020	100522.2	51.3	1662.3	12.5
			2070	96471.5	49.2	1727.7	13.0
		B1	2020	97808.5	49.9	1281.1	9.6
			2070	102297.4	52.2	1352.3	10.2
	Ocmulgee/Altamaha	A2	2020	99027.3	36.3	3493.3	11.7
			2070	89340.9	32.8	3392.0	11.4
		B1	2020	113617.8	41.7	3221.9	10.8
			2070	123916.2	45.5	3556.6	12.0
	Oconee	A2	2020	10409.2	32.5	495.5	7.6
			2070	8973.2	28.0	439.3	6.8
		B1	2020	10652.3	33.3	497.6	7.7

				Population Watershed		3,000-foot Buffer	
Land Use	**Population**	**Scenario**	**Year**	**Area (ha)**	**Percent**	**Area (ha)**	**Percent**
			2070	10986.0	34.3	524.6	8.1
	Ohoopee	A2	2020	21656.5	32.0	1635.8	29.9
			2070	16853.4	24.9	1501.1	27.4
		B1	2020	26232.3	38.8	1708.9	31.2
			2070	29503.5	43.6	1820.5	33.3
Hay/Pasture Land	Lower Altamaha	A2	2020	1221.7	0.6	36.1	0.3
			2070	617.8	0.3	25.0	0.2
		B1	2020	713.4	0.4	23.6	0.2
			2070	324.6	0.2	12.5	0.1
	Ocmulgee/Altamaha	A2	2020	6997.9	2.6	59.8	0.2
			2070	6724.6	2.5	59.8	0.2
		B1	2020	6073.7	2.2	53.6	0.2
			2070	4246.5	1.6	37.5	0.1
	Oconee	A2	2020	1601.3	5.0	90.8	1.4
			2070	1560.9	4.9	74.0	1.1
		B1	2020	1530.3	4.8	84.5	1.3
			2070	1327.5	4.1	65.8	1.0
	Ohoopee	A2	2020	2238.2	3.3	44.2	0.8
			2070	1824.6	2.7	41.1	0.8
		B1	2020	2046.9	3.0	38.1	0.7
			2070	1279.2	1.9	21.9	0.4
Herbaceous Wetland	Lower Altamaha	A2	2020	4316.1	2.2	809.9	6.1
			2070	4178.9	2.1	799.7	6.0
		B1	2020	4341.1	2.2	809.9	6.1
			2070	4334.9	2.2	809.9	6.1
	Ocmulgee/Altamaha	A2	2020	311.3	0.1	106.3	0.4

				Population Watershed		3,000-foot Buffer	
Land Use	**Population**	**Scenario**	**Year**	**Area (ha)**	**Percent**	**Area (ha)**	**Percent**
			2070	311.3	0.1	106.3	0.4
		B1	2020	323.8	0.1	106.3	0.4
			2070	342.6	0.1	106.3	0.4
	Oconee	A2	2020	38.7	0.1	18.8	0.3
			2070	38.7	0.1	18.8	0.3
		B1	2020	44.9	0.1	25.0	0.4
			2070	44.9	0.1	25.0	0.4
	Ohoopee	A2	2020	25.0	0.0	6.3	0.1
			2070	25.0	0.0	6.3	0.1
		B1	2020	25.0	0.0	6.3	0.1
			2070	25.0	0.0	6.3	0.1
Mechanically Disturbed Private	Lower Altamaha	A2	2020	4284.5	2.2	28.7	0.2
			2070	6599.3	3.4	6.3	0.0
		B1	2020	6263.7	3.2	34.9	0.3
			2070	5815.2	3.0	37.2	0.3
	Ocmulgee/Altamaha	A2	2020	8568.5	3.1	171.0	0.6
			2070	10816.0	4.0	337.7	1.1
		B1	2020	9077.5	3.3	357.0	1.2
			2070	8247.5	3.0	135.8	0.5
	Oconee	A2	2020	630.9	2.0	39.5	0.6
			2070	1386.5	4.3	44.0	0.7
		B1	2020	618.8	1.9	31.3	0.5
			2070	499.6	1.6	34.6	0.5
	Ohoopee	A2	2020	2025.4	3.0	204.0	3.7
			2070	2198.6	3.3	210.6	3.9
		B1	2020	2317.4	3.4	332.7	6.1

				Population Watershed		3,000-foot Buffer	
Land Use	**Population**	**Scenario**	**Year**	**Area (ha)**	**Percent**	**Area (ha)**	**Percent**
			2070	1800.2	2.7	165.7	3.0
Mining	Lower Altamaha	A2	2020	181.3	0.1	63.0	0.5
			2070	168.8	0.1	57.2	0.4
		B1	2020	187.5	0.1	63.0	0.5
			2070	150.0	0.1	44.7	0.3
	Ocmulgee/Altamaha	A2	2020	143.8	0.1	22.9	0.1
			2070	137.5	0.1	41.7	0.1
		B1	2020	137.5	0.1	22.9	0.1
			2070	256.0	0.1	22.9	0.1
	Oconee	A2	2020	18.8	0.1	NA	NA
			2070	35.1	0.1	4.2	0.1
		B1	2020	12.5	0.0	NA	NA
			2070	0	0	0	0
	Ohoopee	A2	2020	18.8	0.0	NA	NA
			2070	6.2	0.0	NA	NA
		B1	2020	12.3	0.0	NA	NA
			2070	6.1	0.0	NA	NA
Mixed Forest	Lower Altamaha	A2	2020	9199.3	4.7	105.5	0.8
			2070	6788.8	3.5	99.3	0.7
		B1	2020	8866.1	4.5	111.8	0.8
			2070	6475.2	3.3	93.2	0.7
	Ocmulgee/Altamaha	A2	2020	18244.3	6.7	524.2	1.8
			2070	14820.3	5.4	437.9	1.5
		B1	2020	19231.6	7.1	499.9	1.7
			2070	18187.0	6.7	468.4	1.6
	Oconee	A2	2020	1948.5	6.1	113.7	1.7

				Population Watershed		3,000-foot Buffer	
Land Use	**Population**	**Scenario**	**Year**	**Area (ha)**	**Percent**	**Area (ha)**	**Percent**
			2070	1638.0	5.1	121.1	1.9
		B1	2020	2096.7	6.6	130.7	2.0
			2070	1964.8	6.1	119.0	1.8
	Ohoopee	A2	2020	4477.0	6.6	331.4	6.1
			2070	3352.8	5.0	260.7	4.8
		B1	2020	4893.2	7.2	342.2	6.3
			2070	4669.7	6.9	342.3	6.3
Shrubland	Lower Altamaha	A2	2020	25.0	0.0	NA	NA
			2070	31.3	0.0	NA	NA
		B1	2020	25.0	0.0	NA	NA
			2070	25.0	0.0	NA	NA
	Ocmulgee/Altamaha	A2	2020	18.8	0.0	18.8	0.1
			2070	18.8	0.0	18.8	0.1
		B1	2020	18.8	0.0	18.8	0.1
			2070	18.8	0.0	18.8	0.1
Water	Lower Altamaha	A2	2020	3250.1	1.7	1573.9	11.8
			2070	3275.1	1.7	1579.7	11.9
		B1	2020	3281.3	1.7	1573.9	11.8
			2070	3349.0	1.7	1585.9	11.9
	Ocmulgee/Altamaha	A2	2020	4509.7	1.7	2627.6	8.8
			2070	4503.4	1.7	2632.8	8.8
		B1	2020	4572.4	1.7	2640.1	8.9
			2070	4654.8	1.7	2652.6	8.9
	Oconee	A2	2020	381.3	1.2	311.2	4.8
			2070	381.3	1.2	311.2	4.8
		B1	2020	381.3	1.2	317.5	4.9

				Population Watershed		3,000-foot Buffer	
Land Use	**Population**	**Scenario**	**Year**	**Area (ha)**	**Percent**	**Area (ha)**	**Percent**
			2070	387.5	1.2	323.7	5.0
	Ohoopee	A2	2020	637.4	0.9	83.9	1.5
			2070	631.1	0.9	83.9	1.5
		B1	2020	680.9	1.0	96.4	1.8
			2070	705.9	1.0	96.4	1.8
Woody Wetland	Lower Altamaha	A2	2020	56710.5	29.0	8406.2	63.1
			2070	53952.9	27.5	8297.6	62.3
		B1	2020	61451.0	31.4	8774.1	65.9
			2070	60756.1	31.0	8743.3	65.7
	Ocmulgee/Altamaha	A2	2020	41739.2	15.3	19797.2	66.5
			2070	41656.2	15.3	19679.0	66.1
		B1	2020	43146.3	15.8	20117.2	67.6
			2070	44336.7	16.3	20202.8	67.9
	Oconee	A2	2020	6162.1	19.3	4577.5	70.5
			2070	6218.4	19.4	4590.0	70.7
		B1	2020	6308.1	19.7	4611.9	71.0
			2070	6452.0	20.2	4635.9	71.4
	Ohoopee	A2	2020	5252.8	7.8	1927.9	35.2
			2070	5266.5	7.8	1915.4	35.0
		B1	2020	5440.3	8.0	1959.7	35.8
			2070	5734.7	8.5	1978.5	36.2

APPENDIX C

Table C1. Simulated values for water quantity metrics over four time periods: Historical (1952-1978), Current (1979-2005), and Future (2045-2075) under two climate scenarios: RCP 4.5 and RCP 8.5.

		7-day Minimum Flow (cfs)		Base Flow (unitless)		Low Flow Pulse Count 5%		Low Flow Pulse Count 25%		Low Flow Pulse Duration 25% (days)	
Population	**Time Period**	**Mean (SD)**	**Median**	**Mean (SD)**	**Median**	**Mean (SD)**	**Median**	**Mean (SD)**	**Median**	**Mean (SD)**	**Median**
Oconee	Historical	492.0 (204.4)	452.5	0.16 (0.07)	0.15	0.06 (0.39)	0	5.2 (2.0)	5	20.4 (9.7)	18.2
	Current	508.6 (219.2)	457.4	0.17 (0.08)	0.16	0.02 (0.17)	0	5.5 (2.0)	5	19.5 (10.9)	18.2
	Future RCP 4.5	486.8 (195.9)	453.0	0.18 (0.08)	0.18	0.02 (0.20)	0	5.9 (2.0)	6	17.9 (7.9)	15.2
	Future RCP 8.5	516.3 (234.2)	481.7	0.19 (0.08)	0.18	0.02 (0.17)	0	5.9 (2.0)	6	17.5 (6.9)	15.2
Ohoopee	Historical	24.5 (15.9)	20.7	0.08 (0.05)	0.06	1.79 (2.47)	0	11.0 (3.4)	11	9.1 (3.2)	8.3
	Current	25.4 (16.4)	21.9	0.08 (0.05)	0.07	1.36 (2.08)	0	11.3 (3.5)	11	9.0 (3.3)	8.3
	Future RCP 4.5	25.8 (16.4)	21.8	0.09 (0.06)	0.08	0.97 (1.78)	0	11.7 (3.2)	12	8.5 (2.9)	7.6
	Future RCP 8.5	25.6 (17.5)	21.0	0.09 (0.05)	0.08	1.05 (1.88)	0	11.9 (3.3)	12	8.4 (3.2)	7.6
Ocmulgee/ Altamaha	Historical	666.8 (470.7)	604.4	0.14 (0.08)	0.12	0.16 (0.53)	0	4.8 (2.5)	4	24.5 (14.1)	22.8
	Current	713.3 (504.9)	639.0	0.15 (0.09)	0.14	0.09 (0.38)	0	5.2 (2.5)	5	21.7 (11.3)	18.2
	Future RCP 4.5	812.3 (519.2)	734.2	0.18 (0.09)	0.17	0.03 (0.20)	0	5.6 (2.6)	5	19.9 (9.5)	18.2
	Future RCP 8.5	858.6 (579.8)	744.8	0.19 (0.09)	0.17	0.03 (0.21)	0	5.7 (2.6)	5	19.4 (9.4)	18.2
Lower Altamaha	Historical	991.0 (464.9)	884.5	0.14 (0.07)	0.13	0.12 (0.42)	0	4.0 (1.6)	4	27.4 (15.1)	22.8
	Current	1058.9 (505.4)	969.6	0.16 (0.08)	0.14	0.04 (0.21)	0	4.4 (1.6)	4	24.3 (11.7)	22.8
	Future RCP 4.5	1169.7 (515.9)	1049.3	0.18 (0.08)	0.17	0.03 (0.20)	0	4.5 (1.6)	4	23.5 (11.1)	22.8
	Future RCP 8.5	1225.2 (583.7)	1096.2	0.19 (0.09)	0.17	0.02 (0.16)	0	4.8 (1.7)	5	21.9 (9.6)	18.2