Conservation Plan for the Atlantic Pigtoe (*Fusconaia masoni*) in North Carolina

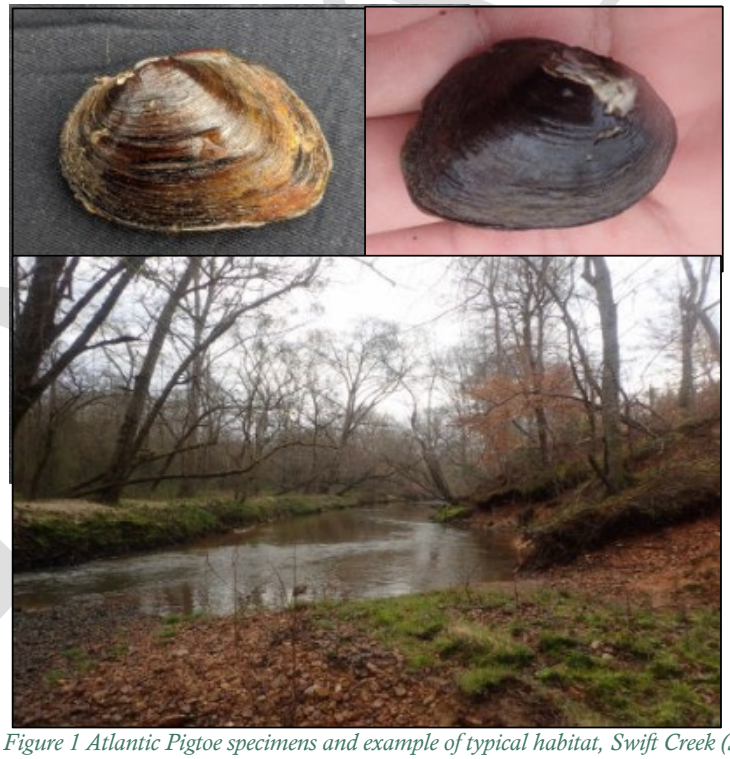

Figure 1 Atlantic Pigtoe specimens and example of typical habitat, Swift Creek (Johnston County, NC). Photo Credit: Michael Fisk, Robert Adams

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NC WILDLIFE RESOURCES COMMISSION

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EXECUTIVE SUMMARY

The North Carolina Wildlife Resources Commission developed this conservation plan to direct management activities for the Atlantic Pigtoe, *Fusconaia masoni,* known in North Carolina from the Roanoke, Tar, Neuse, Cape Fear, and Yadkin-Pee Dee river basins. Historically, this species inhabited waterways from the headwaters to lower reaches of these river basins. The species requires high-quality waterways containing cool, well oxygenated and unpolluted water. Waterways must contain adequate suitable habitat, including constant flow, natural flow regime, unembedded substrate, and stable instream habitat. Direct threats to these species include pollution (chemical and thermal), altered flow conditions, dams, sedimentation, unstable or fragmented habitat, invasive species, and diseases.

The Atlantic Pigtoe is currently petitioned to be federally listed as Threatened and is currently state listed as Endangered. The conservation goal is to prevent the extinction of this species and ensure population viability within North Carolina for the next 100 years. The plan focuses on identifying and reducing threats, promoting population viability, habitat protection, population monitoring, research, and partnerships. Establishing and maintaining partnerships between North Carolina Wildlife Resources Commission staff and other state agencies, federal agencies, universities, non-profit organizations, companies, local governments, and citizens are essential to the implementation of this conservation plan. The management of this species will require collaborative stakeholder efforts to protect sensitive habitats and maintain high-quality water resources throughout North Carolina.

BIOLOGICAL INFORMATION

Portions of this document were pulled directly from the Atlantic Pigtoe Species Status Assessment (SSA) with the permission of the U.S. Fish and Wildlife Service (USFWS 2019).

Description and Taxonomic Classification

The Atlantic Pigtoe, *Fusconaia masoni* belongs to the family Unionidae, and purported subfamily Ambleminae – the most diverse, but also the most imperiled, subfamily of freshwater mussels (Campbell et al. 2005; Campbell and Lydeard 2012). It has been reported in the literature as *Unio subplanus*, *Lexingtonia subplana*, *U. masoni*, or *Pleurobema masoni* (Fuller 1973; Alderman 2003), however the tetragenous nature of marsupial gills (i.e., females use all 4 demibranchs when fully gravid to brood glochidia) places it in the genus *Fusconaia*. It is one of 15 species in the genus *Fusconaia*, one of the most primitive genera, and it is the only representative of the genus along the Atlantic Seaboard (Fuller 1973; Bogan et al. 2003). The species *F. masoni* was described by T.A. Conrad in 1834, with the type specimen from the Savannah River near Augusta, Georgia (Conrad 1834). It was named after one of Conrad's friends, William Mason, an early American conchologist (Conrad 1834). From Burlakova et al. (2012), *F. masoni* appears to be closely related genetically to *F. cerina*, *F. flava*, *F. askewi*, *F. burkei*, and *F. escambia*. Except for *F. flava* (a more wide-ranging species), these taxa are centered in the Gulf of Mexico region.

The currently accepted classification is (Integrated Taxonomic Information System 2020):

Phylum: Mollusca
Class: Bivalvia
Order: Unionoida
Family: Unionidae
Subfamily: Ambleminae
Genus: *Fusconaia*
Species: *Fusconaia masoni*

The Atlantic Pigtoe is a small freshwater mussel with a sub-rhomboidal shaped shell. Although larger specimens exist, the Atlantic Pigtoe rarely exceeds 50 mm (2 inches) in length (Wisniewski 2008). Except in headwater stream reaches, where specimens may be elongated, this species is tall relative to its length (Alderman and Alderman 2014). Valves are compressed, the hinge ligament is relatively short and prominent, and the umbo is positioned slightly anterior of the middle of valve and is elevated above the hinge line (Fuller 1973; Wisniewski 2008). The posterior ridge is angular and very distinct. The periostracum is yellow to dark brown and has been described as clothlike or parchmentlike (Fuller 1973), and young individuals may have greenish rays across the entire shell surface. When collected fresh, the nacre in the anterior half of the shell tends to be salmon colored, while nacre in the posterior half tends to be more iridescent (Fuller 1973; Alderman and Alderman 2014). The shell has full dentition with two pseudocardinals in each valve (although the anterior one in the right valve is vestigial) and well-developed lateral teeth (Fuller 1973). In addition to simple papillae, branched and arborescent papillae are often seen on the incurrent aperture (Alderman and Alderman 2014). Salmon colored demibranchs in females are often seen during the spawning season. When fully gravid, females use all four demibranchs to brood glochidia (Fuller 1973).

Life History and Habitat

As is the case with most freshwater mussels, the Atlantic Pigtoe has a unique life cycle that relies on fish hosts for successful reproduction. The Atlantic Pigtoe is a short-term, tachytictic breeder, meaning spawning takes place in the early spring with release of semi-buoyant white to pink-colored conglutinates in the late spring to early summer (C. Eads, North Carolina State University [NCSU], personal communication; Alderman and Alderman 2014). The conglutinates are tubular, and the color varies from white to pink to red depending on the percentage of fertilization, with lower fertilization rates being more red (unfertilized eggs are red; C. Eads, NCSU, personal communication).

Like other species in the Pleurobemini tribe, the Atlantic Pigtoe targets drift-feeding minnow species by releasing pelagic conglutinates (Haag 2012), a highly targeted strategy that decreases encounters with incompatible fish species. Following release from the female mussel, the semi-buoyant conglutinates float and occupy the middle and upper water column where they are targeted by sight-feeding minnows (Wolf 2012). Lab studies by O'Dee and Watters (2000) determined that Bluegill *Lepomis macrochirus* and Shield Darter *Percina peltata* served as host fish for the Atlantic Pigtoe, however more recent host work at White Sulfur Springs National Fish Hatchery (Wolf 2012) found that Rosefin Shiner *Lythrurus ardens*, Creek Chub *Semotilus atromaculatus*, and Longnose Dace *Rhinichthys cataractae* serve as very effective hosts. Additional studies by Eads and Levine (2011) have confirmed that members of the Leuciscidae (formerly Cyprinidae; Tan and Armbruster 2018) family seem to serve as the primary hosts; those tested include the White Shiner *Luxilus albeolus*, Satinfin Shiner *Cyprinella analostana*, Bluehead Chub *Nocomis leptocephalus*, Rosyside Dace *Clinostomus funduloides*, Pinewoods Shiner *Lythrurus matutinus*, Creek Chub, Swallowtail Shiner *Notropis procne*, and Mountain Redbelly Dace *Chrosomus oreas*. This study did not have success with Bluegill or the Chainback Darter *Percina nevisense* (C. Eads, NCSU, personal communication).

Time period for glochidia to complete metamorphosis varies between 8–19 days at 21–22°C and depends on the host fish (Eads and Levine 2011). In captivity in a hatchery/pond setting, age to sexual maturity is approximately 3 years (C. Eads, NCSU, personal communication). Fecundity is uniformly low in most species that have an equilibrium strategy (Haag 2012), and species like Atlantic Pigtoe rely on a consistent, low level of reproductive success to maintain populations. This strategy can allow populations to reach high densities over time in stable habitats, but it also makes them susceptible to habitat disturbances (Wolf 2012). Thus, loss of a small proportion of the Atlantic Pigtoe population when population levels are already low, or a bad recruitment year, can have a dramatic effect on reproductive success (Wolf 2012).

Atlantic Pigtoe demonstrates an "equilibrium life history strategy", which means it is a slow growing and long-lived species with low fecundity (Haag 2012; Alderman and Alderman 2014). As seen in many organisms, this mussel's growth is rapid during the first few years of life but slows with increasing age, as resources are likely diverted to reproduction. Patterns of age structure in healthy Atlantic Pigtoe populations are available for the Nottoway River and Swift Creek (Tar) populations. Shell thin-sectioning conducted by Wolf (2012) yielded a population with multiple age classes ranging from 1–58 years (although the 58-year-old individual was likely an outlier and when removed the age range is 1–33 years). Similarly, a 1991 survey of muskrat middens in Swift Creek (Tar) utilizing an age-length formula developed by Wolf (2012) revealed multiple size classes, ranging from 16–63 mm (age estimates were 1–30+ years; Alderman and Alderman 2014).

The Atlantic Pigtoe is dependent on clean, moderate flowing water with high dissolved oxygen content in creek and riverine environments. Historically, the best populations existed in creeks and rivers with excellent water quality, where stream flows were sufficient to maintain clean, silt-free substrates (Alderman and Alderman 2014). Because this species prefers more pristine conditions, it typically occurs in headwaters and rural watersheds, but not exclusively. It is associated with gravel and coarse sand substrates at the downstream edge of riffles, and less commonly occurs in cobble, silt, or sand-detritus mixtures (Bogan and Alderman 2008; Bogan 2017). Most freshwater mussels, including the Atlantic Pigtoe, are found in aggregations (mussel beds) that vary in size and are often separated by stream reaches in which mussels are absent or rare (Vaughn 2012). Genetic exchange occurs between and among mussel beds via sperm drift, host fish movement, and movement of mussels during high flow events. Theoretically, prior to anthropogenic influence, it is likely that Atlantic Pigtoe mussel beds were distributed contiguously in suitable habitats throughout its known range. The contemporary distribution of Atlantic Pigtoe is patchy, resulting in largely isolated populations and, in turn, potentially limited genetic exchange.

Mussels, such as the Atlantic Pigtoe, filter algae, detritus, microscopic animals, and bacteria from the water column (Fuller 1973; Nichols and Garling 2000; Strayer et al. 2004; Haag 2012). Encysted glochidia are nourished by their fish hosts and feed for a period of one to three weeks. Nutrient uptake by glochidia is not well understood, but probably occurs through the microvillae of the mantle (Watters 2020). For the first several months, juvenile mussels partially employ pedal (foot) feeding, extracting bacteria, algae, and detritus from the sediment, although they also may filter interstitial (pore) water (Yeager et al. 1994; Alderman and Alderman 2014). However, their gills are rudimentary and generally incapable of filtering particles (Watters 2007). Adult mussels also can obtain their food by deposit feeding, siphoning in food from the sediment and its pore water and pedal feeding directly from the sediment (Yeager et al. 1994; Vaughn and Hakenkamp 2001). Food availability and quality for the Atlantic Pigtoe in its habitats are affected by habitat stability and connectivity, flow, and water and sediment quality.

Distribution and Population Status

The Atlantic Pigtoe has been documented in all major river basins in the Atlantic coastal drainages from the James River Basin in Virginia south to the Altamaha River Basin in Georgia. Johnson (1970) indicated the southernmost records were from the Ogeechee River Basin, however, recent curation of the H. D. Athearn collection uncovered valid specimens from the Altamaha River. The Atlantic Pigtoe has been documented from multiple physiographic provinces, from the foothills of the Appalachian Mountains through the Piedmont and into the Coastal Plain, in streams ranging in size from lower order streams up to some of the largest Atlantic Slope rivers within the species' range. In North Carolina, the Atlantic Pigtoe has historically been found in the Roanoke, Tar, Neuse, Cape Fear, Pee Dee, and Catawba river basins.

The Atlantic Pigtoe is currently occupying 40% of its historic range (USFWS 2019). Of the three physiographic regions where the species occurs, the most significant declines have occurred in the Coastal Plain and Mountains (USFWS 2019). The remaining populations are small and fragmented. The cumulative impacts of land use change and associated watershed-level effects on water quantity and quality, habitat connectivity, and instream habitat suitability have led to habitat degradation and ultimately declines in abundance and distribution (USFWS 2019). Populations that are small and fragmented are more vulnerable to extirpation.

In North Carolina and throughout the species' range, the Tar Basin supports the most robust population of Atlantic Pigtoe. Historically they have been documented in 15 HUC10s and currently occupy 12 of these (Figure 1). Alderman (1994) documented 18 separate populations and described around half of them as being in poor condition. The other half was split between being good and fair. In the Neuse Basin, the species has been detected in 10 HUC10s and currently occupies 8 of these. The known ranges of the Atlantic Pigtoe in the Roanoke, Cape Fear, and Yadkin Pee Dee are more restricted with 5, 6, and 7 historic occupied HUC10s, respectively. Current HUC10s occupied have been reduced to Roanoke = 3, Cape Fear = 2, and Yadkin Pee Dee = 2 for each basin. There is one observation of Atlantic Pigtoe in the Catawba Basin from the 1800s although this population is considered extirpated. During targeted and non-targeted surveys for Atlantic Pigtoe, typically <10 mussels per site are collected for the upper Tar Basin and upper Neuse Basin while <5 mussels per site are typically found elsewhere. Some exceptions do occur where 38 and 28 individuals have been collected at sites in the Tar and Neuse basins.

Atlantic Pigtoe was considered as threatened in the early 1990s (Williams et al. 1993) and then upgraded to State Endangered effective July 1, 2002 in North Carolina (Bogan 2017). NatureServe classifies the Atlantic Pigtoe as Critically Imperiled (G1) and Vulnerable (S3) in North Carolina (NatureServe 2020, NCNHP 2020). Based on the recent SSA, the Atlantic Pigtoe has been proposed to be listed as Threatened under the Endangered Species Act 1973 (USFWS 2019).

Current conditions of the Tar and Neuse populations characterized by the US Fish and Wildlife Service (USFWS) as high and moderate while the Roanoke, Cape Fear, and Yadkin-Pee Dee populations are characterized as low (USFWS 2019). Factors including urban development, climate change, agricultural practices, forest conversion and management, invasive species, and dams and barriers have impacted Atlantic Pigtoe distribution and abundance (USFWS 2019). For detailed accounts on how these factors have impacted Atlantic Pigtoe refer to the USFWS SSA. Of these factors, urban development and climate change were considered to have the greatest impacts on Atlantic Pigtoe populations. These factors were used to determine future population conditions (up to 50 years) under several management scenarios. These predictions suggest that the Roanoke, Cape Fear, and Yadkin-Pee Dee population may become extirpated while the Tar and Neuse populations will be characterized as having low occupancy and abundance.

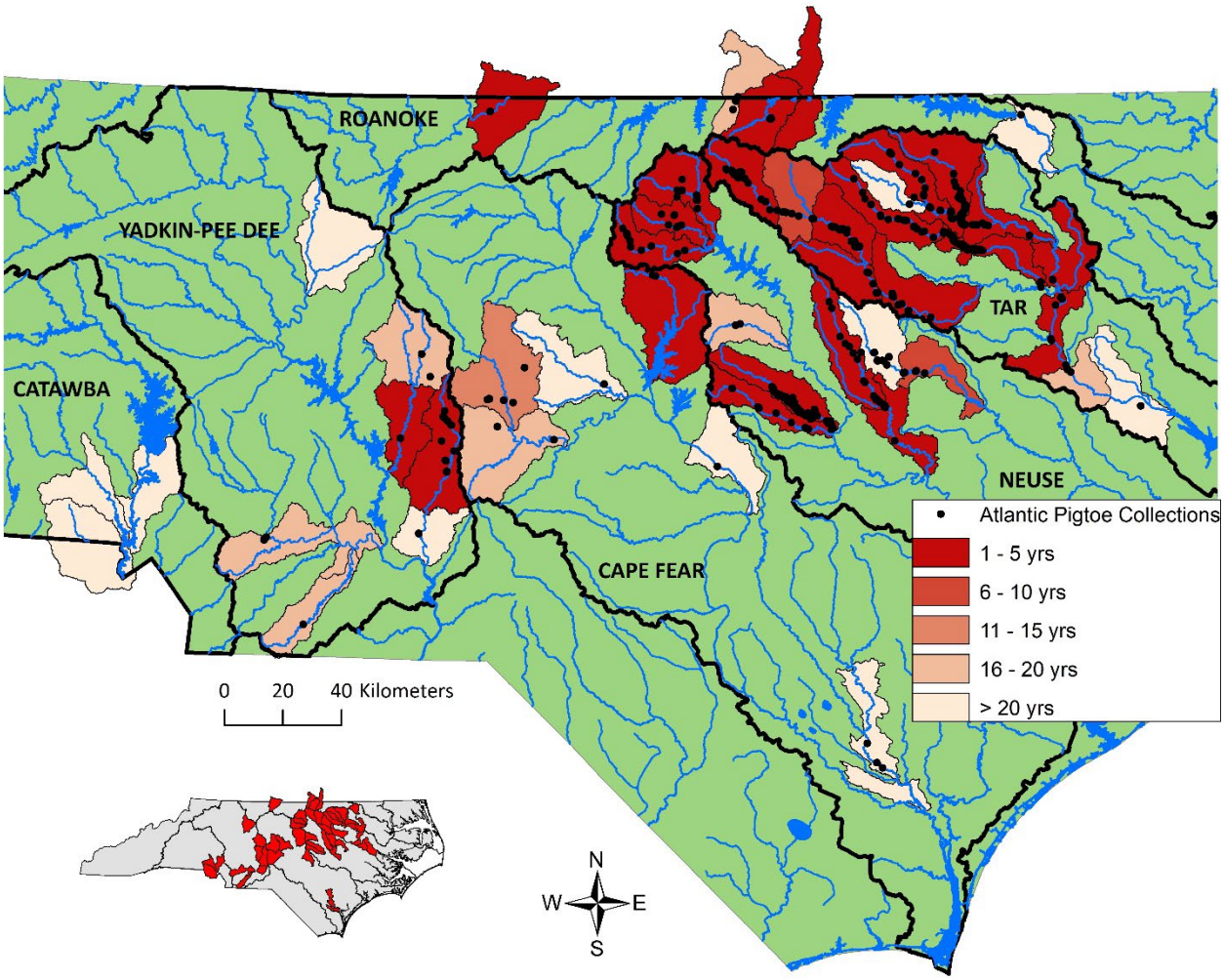
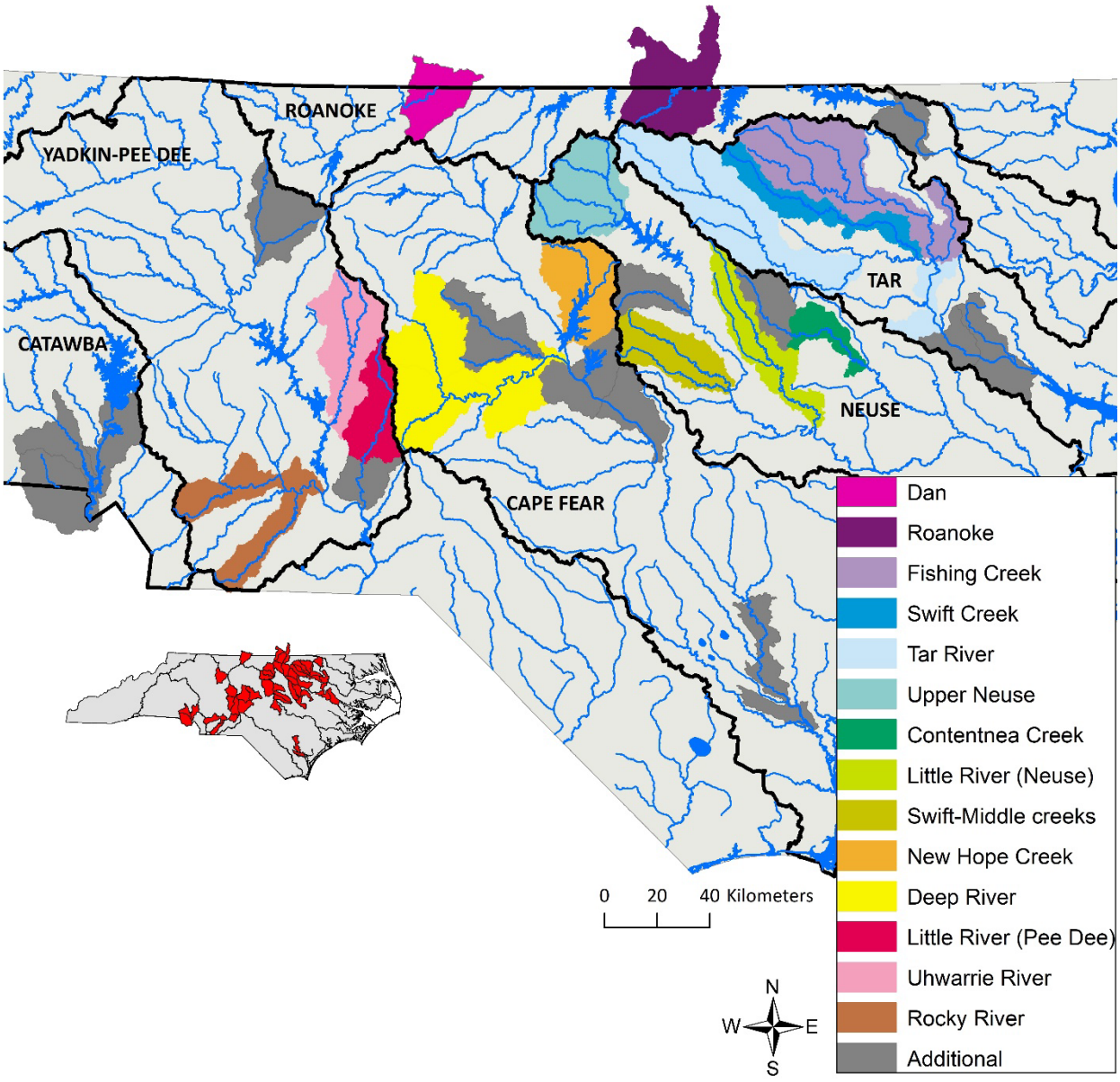


FIGURE 1 – Distribution map of the Atlantic Pigtoe within North Carolina depicting 10-digit hydrologic units (colored and categorized based on year of observation) and collection locations (black dots). Locations for historical collections in the Catawba and Muddy Creek (upper Yadkin-Pee Dee) are not known.



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230 ***FIGURE 2****. Management Units (MUs) in the Roanoke, Tar, Neuse, Cape Fear, Yadkin-Pee Dee, and Catawba basins*
231 *depicting 10-digit hydrologic units. Primary MUs are in color, additional augmentation/reintroduction MUs are in grey.*
232 *Descriptions of MUs are in Table 1.*

233

Basin	Management Unit	HUC10s		Category
Roanoke	Dan	301010309		Primary
	Upper Roanoke	301010208	301010407	Primary
		301010209		Primary
		301010701		Additional
Tar	Fishing Creek	302010201	302010205	Primary
		302010202	302010206	Primary

		302010203		Primary
	Swift Creek	302010108	302010107	Primary
	Tar River	302010102	302010104	Primary
		302010106	302010302	Primary
		302010103	302010101	Primary
		302010304		Additional
		302010306		Additional
Neuse	Upper Neuse	302020102	302020103	Primary
		302020101		Primary
	Contentnea Creek	302020304		Primary
		302020301		Additional
	Little River	302020115	302020116	Primary
	Swift/Middle creeks	302020110	302020109	Primary
	Crabtree Creek	302020108		Additional
Cape Fear	Deep River	303000302	303000304	Primary
			0303000306	Primary
	New Hope Creek	303000206		Primary
	Cape Fear River	303000405	0303000401	Additional
	Rocky River	303000305		Additional
	Black River	303000608		Additional
Pee Dee	Little River	304010403		Primary
		304010404		Additional
	Uwharrie River	304010304	304010305	Primary
		304010507	304010506	Primary
	Muddy Creek	304010113		Additional
Catawba	Lower Catawba	305010114	305010115	Additional
		305010206		Additional

TABLE 1.*. Prioritized management units (10-digit hydrologic units) for augmentations. Categories are defined as: Primary) MUs within known range that are considered the best habitat, Additional) MUs within known range to be used if Primary MU targets are exceeded. If Primary and Additional targets are exceeded, then reintroductions will focus within the presumed historical range of the species (not listed below) if suitable habitat exists.*

THREAT ASSESSMENT

Reason for Listing

The Atlantic Pigtoe was originally listed as threatened in North Carolina in 1991 due to perceived rarity and decline. Only the Tar River's Swift Creek population of the Atlantic Pigtoe was considered relatively healthy and the species was considered extremely rare species elsewhere in the state (Adams et al. 1991).

Present and Anticipated Threats

As with all aquatic species, there are many natural and anthropogenic factors that threaten the long-term viability of Atlantic Pigtoe. Extinction and decline of North American unionid bivalves can be linked to impoundment and inundation of riffle habitat throughout the United States. The loss of obligate hosts, coupled with increased siltation, and various types of industrial and domestic pollution have resulted in the rapid decline of the unionid bivalve fauna in North America (Bogan 1993, NCWRC 2015). Dams, both manmade and natural (created by beavers, see Kemp et al. (2012), are a barrier to dispersal of host fish and attached glochidia. Throughout the Neuse and Tar-Pamlico River basins, beavers have continued to build dams and impound an increasing number of river kilometers. Beaver dams not only inundate and alter riffle/run mussel habitat upstream of the dam but also affect mussel populations downstream of the dam by increasing fluctuations in flow regime, decreasing dissolved oxygen levels, and increasing the variability of food quality and quantity (Hoch 2012, Kemp et al. 2012). Wastewater that contains monochloramine and unionized ammonia compounds are acutely toxic and pose a significant threat to all aquatic species, especially mussels. Point source discharges from municipalities may be responsible for glochidial mortality that results in local extirpation of mussels (Goudreau et al. 1993, Gangloff et al. 2009, NCWRC 2015). Impervious surfaces in urbanized watersheds exacerbate high water levels, even during short rainfall events, which can result in flash flooding. These high or flashy flow events contribute to increased sediment loads and erosion, turbidity throughout the water column, and stream bed movements that stress mussel populations (Gangloff et al. 2009, NCWRC 2015). Climate change and development will continue to bring additional stressors that need to be evaluated for mussels. Furthermore, specific pollutants that may be introduced into the aquatic environment, the interactions of pollutants and temperature (from climate change), salinity (related to sea level rise), and lower dilution (from altered flows) will need to be considered (NCWRC 2015). In addition, invasive species such as the Asian Clam, *Corbicula fluminea*, the Flathead Catfish, *Pylodictis olivaris*, and Hydrilla, *Hydrilla verticillata* can create competitive pressures on food resources and habitat availability. These factors can decrease oxygen availability, cause ammonia spikes, alter benthic substrates, impact host fish communities, reduce stream flow, and increase sediment buildup (Belanger 1991, Scheller 1997, NCANSMPC 2015, NCWRC 2015).

Historic and Ongoing Conservation Efforts

Prior to 2009, North Carolina Wildlife Resources Commission (NCWRC) staff conducted general surveys for the species throughout its range in North Carolina. In 2009, NCWRC partnered with NCSU to propagate Atlantic Pigtoes and augment existing populations. An augmentation plan for four species including Atlantic Pigtoe was developed in 2010 (Eads and Levine 2010) and potential broodstock sources were identified. The following year, host fish trials were conducted and grow-out techniques refined (Eads and Levine 2011). The trials found that multiple species of Cyprinids are suitable host fish (see background above) and floating baskets in small impoundments can be used as grow-out facilities to reach stocking size (Levine et al. 2012). After the completion of these studies, in September and October of 2015, 370 Atlantic Pigtoes were stocked into Fishing (5 sites) and Little Fishing creeks (4 sites). Follow-up snorkel surveys were conducted at eight of nine augmentation reaches in 2016. Fishing Creek monitoring surveys were completed at each of the five reaches between July and September 2016. A total of 68 live (31%) Atlantic Pigtoes were recaptured at the augmentation locations. Growth among the recaptured mussels in Fishing Creek was minimal (mean = 0.8 mm, standard deviation [SD] = 0.3 mm). Little Fishing Creek monitoring surveys were

completed at three of four reaches in August 2016. A total of 19 live (13%) Atlantic Pigtoes and one shell were recaptured in Little Fishing Creek. The mussels in Little Fishing Creek exhibited minimal growth (mean = 1.1 mm, SD = 0.8 mm). Since 2016, non-targeted surveys have recaptured six individuals in 2018 and one individual in 2019 in Little Fishing Creek. Mean growth of the 2018 recaptures was 5.9 mm, SD = 9.2 mm and the one individual recaptured in 2019 grew 4.8 mm since being released in 2015. Given the life history characteristics of the Atlantic Pigtoe and the low productivity of Fishing and Little Fishing Creeks, the slow observed growth is expected. Since 2017, targeted surveys for Atlantic Pigtoe have been conducted throughout its range in North Carolina. The NCWRC, in conjunction with Georgia Southern University, is currently examining genomic data for the species. The goal of the genetic monitoring and research is to maximize genetic diversity in the augmented and reintroduced populations, while minimizing outbreeding and inbreeding depressions, and the loss of unique alleles.

The objectives of the genetic study are to:

1. Describe the genetic diversity within and among wild populations,
2. Identify unique single nucleotide polymorphisms that describe the effective population size in the wild and in the hatchery,
3. Evaluate the genetic diversity of progeny within the hatchery, and
4. Evaluate the genetic diversity of any augmented populations.

CONSERVATION GOALS

Overarching Goal

To prevent the extinction of Atlantic Pigtoe and promote population viability (i.e., multiple age classes and wild recruitment) within North Carolina for the next 100 years.

Objectives

The primary conservation strategy is to promote habitat protection and maintain the best populations of Atlantic Pigtoe throughout its range in North Carolina.

1) Promote habitat protection and maintain populations of Atlantic Pigtoe within Management Units (MUs). Management Units will be defined based on hydrologic units (i.e., HUC10s; Table 1; Figure 2).
2) Maintain an ark population of Atlantic Pigtoe from each river basin.
3) Utilize captive propagation and/or translocations to augment or establish populations of Atlantic Pigtoe where appropriate habitat exists (pending approval from the Habitat, Nongame and Endangered Species Committee of the NCWRC).
4) Establish connectivity and gene flow between existing and established populations by either translocating individuals or removing barriers.

CONSERVATION ACTIONS

Habitat Protection and Habitat Management

Protecting habitat integrity, including hydrology, is crucial for species survival. Comments on permit reviews should stress minimizing inputs that include chemical pollutants such as herbicides,

pesticides, pharmaceuticals, and industrial compounds, as well as thermal plumes, sediment and nutrients carried by storm water. NCWRC Habitat Conservation Division staff will recommend that all permits issued within basins where Atlantic Pigtoe occur implement the recommendations of the NCWRC's *Guidance Memorandum to Address and Mitigate Secondary and Cumulative Impacts to Aquatic and Terrestrial Wildlife Resources and Water Quality* (NCWRC 2002). Forestry activities should incorporate forest practice guidelines (FPGs), or best management practices (BMPs) as required by certifying organizations such as those of the Sustainable Forestry Initiative/Forest Stewardship Council/American Tree Farm System certification standards. Restoration of habitat should be prioritized for primary HUCs and should focus on the protection of riparian habitat and associated uplands (Table 1, Figure 2).

The NC Wildlife Action Plan (NCWRC 2015) lists priority 12-digit HUCs by watershed. NCWRC staff will encourage acquisition of riparian lands in these priority HUCs that occur within the 10-digit HUCs listed in Figure 2 of this document. Acquisitions can include both fee simple ownership and conservation easements. Ideally these lands would be in the vicinity of other conservation lands such as NCWRC game lands, NC State Parks, National Forests, or lands managed by a local land trust.

Population Management

Atlantic Pigtoe populations may be enhanced by augmenting existing populations with propagated individuals. Propagated mussels may also be reintroduced into areas that were historically occupied where suitable habitat exists. To minimize any real or perceived regulatory burden associated with the federal Endangered Species Act, a stakeholder cooperative agreement, such as Safe Harbor, will be established prior to reintroduction into an unoccupied area. Augmentations will be prioritized as follows:

a. All primary river basin MUs (Table 1, Figure 2).
b. Additional augmentation areas within the known range of Atlantic Pigtoe (Table 1; Figure 2), if propagation efforts exceed primary MU needs.
c. Introduction of Atlantic Pigtoe into areas within the presumed historical range, if propagation efforts exceed MU needs. Ideally located in areas with reduced likelihood of anthropogenic threats.

Incentives (Tax Break)

The NCWRC will encourage private landowners within Atlantic Pigtoe watersheds to participate in the Wildlife Conservation Lands program. This program reduces tax assessment for landowners with 20-800 qualifying acres, including early successional habitat, managed under a written wildlife habitat conservation agreement that addresses needs of species designated as state endangered, threatened, or special concern and is administered by NCWRC.

Monitoring and Research

1. Monitor Atlantic Pigtoe populations every 2–5 years within each MU to assess survival, abundance, population structure, recruitment, and genetic diversity.
2. Conduct Atlantic Pigtoe focused surveys within the Roanoke and Chowan River basins to assess presence or absence of the species.

3. Develop captive propagation techniques to maximize yield, genetic diversity, and post release survival.
4. Determine locations for establishing Atlantic Pigtoe populations and monitor the success of population establishment.
5. Determine the genetic diversity and number of genetically distinct populations of Atlantic Pigtoe throughout its range.
6. Develop microsatellite markers or similar genetic tagging techniques to determine age structure, parentage, and hatchery contribution to wild stock.
7. Conduct surveys for host fish abundance, population structure, and recruitment within each MU.
8. Develop techniques to reduce the abundance of Asian Clam.
9. Determine the known historical range of Atlantic Pigtoe by verifying the identification of specimens held in museum collections.
10. Determine the impact of Flathead Catfish and other invasive species on Atlantic Pigtoe host fish populations.

Education and Outreach

Staff will continue to develop publications and reports as well as highlight conservation efforts through channels such as the NC Chapter of the American Fisheries Society and the Freshwater Mollusk Conservation Society. Results of research and monitoring projects will be presented at professional and non-technical meetings. Coordination with the Wildlife Education staff to promote education and awareness of the Atlantic Pigtoe and efforts to conserve the species and its habitat will be important to disseminate information about the species.

Regulations

Take or possession of this species without a valid permit is currently prohibited under NC law and administrative code (15A NCAC 10I .0102) and is considered a Class 1 misdemeanor (§ 113 337b). Due to difficulties in identifying mussels, some level of incidental take may occur but is not assumed to be significant. Currently, individuals with a valid fishing license can harvest up to 200 mussels per day, but only within specified impounded waters where Atlantic Pigtoe usually do not occur (NCWRC 2021).

LITERATURE CITED

Adams, W. F., R. G. Biggins, E. P. Keferl, J. M. Alderman, H. J. Porter, and A. S. Van Devender. 1991. A Report on the Conservation Status of North Carolina's Freshwater and Terrestrial Molluscan Fauna. Report submitted to NC Wildlife Resources Commission, Raleigh, NC.

Alderman J. M. 1994. Statuses of State Listed Freshwater Mussel Populations in North Carolina. Proceedings of the Annual Conference of Southeastern Association Fish and Wildlife Agencies 48:350–356.

Alderman, J. M. 2003. Status and Distribution of *Fusconaia masoni* and *Elliptio lanceolata* in Virginia. USFWS Grant Agreement:1148-401 81-99-G-113.

Alderman, J. M. and J. D. Alderman. 2014. DRAFT 2014 Atlantic Pigtoe Conservation Plan. Prepared for Virginia Department of Game and Inland Fisheries. Richmond, VA.

Belanger, S. E. 1991. The effect of dissolved oxygen, sediment, and sewage treatment plant discharges upon growth, survival and density of Asiatic clams. Hydrobiologia 218:113–126.

Bogan, A. E. 1993. Freshwater bivalve extinctions (Mollusca: Unionoida): a search for causes. American Zoologist 33:599–609.

Bogan, A. E. 2017. Workbook and key to the freshwater bivalves of North Carolina. North Carolina Freshwater Mussel Conservation Partnership, Raleigh, NC.

Bogan, A. E. and J.M. Alderman. 2008. Workbook and Key to the Freshwater Bivalves of South Carolina. Revised Second Edition.

Bogan, A. E., M. Raley, and J. Levine. 2003. Determination of the systematic position and relationships of the Atlantic Pigtoe, *Fusconaia masoni* (Conrad, 1834) (Mollusca: Bivalvia: Unionidae) with distributions in Virginia, North and South Carolina, and Georgia. USFWS Final Report.

Burlakova, L. E., D. Campbell, A. Y. Karatayev, and D. Barclay. 2012. Distribution, genetic analysis and conservation priorities for rare Texas freshwater molluscs in the genera Fusconaia and Pleurobema (Bivalvia: Unionidae). Aquatic Biosystems 8:1–15.

Campbell, D. C., J. M. Serb, J. E. Buhay, K. J. Roe, R. L. Minton, and C. Lydeard. 2005. Phylogeny of North American amblemines (Bivalvia, Unionoida): prodigious polyphyly proves pervasive across genera. Invertebrate Biology 124:131–164.

Campbell, D. C. and C. Lydeard. 2012. Molecular systematics of *Fusconaia* (Bivalvia: Unionidae: Ambleminae). American Malacological Bulletin 30:1–17.

Conrad, T. A. 1834. New fresh water shells of the United States: with coloured illustrations, and a monograph of the genus Anculotus of Say: also a synopsis of the American Naiades. Academy of Natural Sciences, Philadelphia, PA.

Eads, C. and J. Levine. 2010. Development of a Plan for Population Augmentation for four North Carolina Freshwater Mussel Species. Final Report submitted to NC Wildlife Resources Commission, Raleigh, NC.

Eads, C. and J. Levine. 2011. Refinement of Growout Techniques for Four Freshwater Mussel Species. Final Report submitted to NC Wildlife Resources Commission, Raleigh.

Fuller, S. L. H. 1973. *Fusconaia masoni* (Conrad 1834) (Bivalvia: Unionacea) in the Atlantic drainage of the southeastern United States. Malacological Review 6:105–117.

Gangloff, M. M., L. Siefferman, W. Seesock, and E. C. Webber. 2009. Influence of urban tributaries on freshwater mussel populations in a biologically diverse piedmont (USA) stream. Hydrobiologia 636:191–201.

Goudreau, S. E., R. J. Neves, and R. J. Sheehan. 1993. Effects of wastewater treatment plant effluents on freshwater mollusks in the upper Clinch River, Virginia, USA. Hydrobiologia 252:211–230.

Haag, W. 2012. North American Freshwater Mussels: Natural History, Ecology, and Conservation. Cambridge University Press, Cambridge, NY.

Hoch, R. A. 2012. Beaver and Mill Dams Alter Freshwater Mussel Habitat, Growth, and Survival in North Carolina Piedmont Streams. Master's thesis. Appalachian State University, Boone, North Carolina.

Integrated Taxonomic Information System. 2020. ITIS Standard Report Page: Fusconaia masoni http://www.itis.gov (Accessed 11/25/2020).

Johnson, R. I. 1970. The systemic and zoogeography of the Unionidae (Mollusca: Bivalvia) of the southern Atlantic Slope. Bulletin of the Museum of Comparative Zoology, Harvard University 140:263–449.

Kemp, P. S., T. A. Worthington, T. E. L. Langford, A. R. J. Tree, and M. J. Gaywood. 2012. Qualitative and quantitative effects of reintroduced beavers on stream fish: Impacts of beaver on freshwater fish. Fish and Fisheries 13:158–181.

Levine, J., C. Eads, L. Borst, and C. Osborn. 2012. Assessment of ponds in the North Carolina Piedmont as a nutritional resource for rearing freshwater mussels for population augmentation. Final Report submitted to USFWS, Raleigh, NC.

NatureServe. 2020. NatureServe Explorer [web application]. NatureServe, Arlington, Virginia. Available https://explorer.natureserve.org/. (Accessed: December 31, 2020).

NCANSMPC (North Carolina Aquatic Nuisance Species Management Plan Committee). 2015. North Carolina Aquatic Nuisance Species Management Plan. Raleigh, North Carolina.

NCNHP (Natural Heritage Program). 2020. Natural Heritage Program List of Rare Species 2020. NC Department of Natural and Cultural Resources Raleigh, NC.

NCWRC (North Carolina Wildlife Resources Commission). 2015. North Carolina Wildlife Action Plan. Raleigh, North Carolina.

NCWRC (North Carolina Wildlife Resources Commission). 2021. North Carolina inland fishing, hunting, and trapping digest 2020–2021.

Nichols, S. J. and D. Garling. 2000. Food-web dynamics and trophic-level interactions in a multispecies community of freshwater unionids. Canadian Journal of Zoology 78:871–882.

O'Dee, S. H. and G. T. Watters. 2000. New or confirmed host identifications for ten freshwater mussels. Proceedings of the Conservation, Captive Care, and Propagation of Freshwater Mussels Symposium, 1998, pages 77–82.

Scheller, J. L. 1997. The effect of dieoffs of Asian clams (*Corbicula fluminea*) on native freshwater mussels (Unionidae). Master's Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Strayer, D. L., Downing, J. A., Haag, W. R., King, T. L., Layzer, J. B., Newton, T. J., and S. J. Nichols. 2004. Changing perspectives on pearly mussels, North America's most imperilled animals. BioScience, 54:429–439.

Tan M., and J. W. Armbruster. 2018. Phylogenetic classification of extant genera of fishes of the order Cypriniformes (Teleostei: Ostariophysi). Zootaxa 4476:006–039

USFWS. 2019. Species Status Assessment Report for the Atlantic Pigtoe (*Fusconaia masoni*) Version 1.3. Species Status Assessment Reports. Atlanta, GA.

Vaughn, C. C. 2012. Life history traits and abundance can predict local colonization and extinction rates of freshwater mussels. Freshwater Biology 57:982–992.

Vaughn, C. C., and C. C. Hakenkamp. 2001. The functional role of burrowing bivalves in freshwater ecosystems. Freshwater Biology, 46:1431–1446.

Watters, G.T. 2000. Freshwater mussels and water quality: A review of the effects of hydrologic and instream habitat alterations. Proceedings of the First Freshwater Mollusk Conservation Society Symposium, 1999. pp. 261–274. Ohio Biological Survey.

Williams, J. D., Warren, M. L., Cummings, K. S., Harris, J. L., and Neves, R. J. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries, 18:6–22.

Wisniewski, J. M. 2008. Species Account: Atlantic Pigtoe. Georgia Department of Natural Resources, Athens, GA.

Wolf, E. D. 2012. Propagation, Culture, and Recovery of Species at Risk Atlantic Pigtoe. Virginia Tech Conservation Management Institute, Project No. 11–108.

Yeager, M. M., D. S. Cherry, and R. J. Neves. 1994. Feeding and burrowing behaviors of juvenile rainbow mussels, *Villosa iris* (Bivalvia: Unionidae). Journal of the North American Benthological Society 13:217–222.