Species Status Assessment Report
for the
Atlantic Pigtoe (*Fusconaia masoni*)
Version 1.4

Atlantic Pigtoes from Swift Creek (Neuse), NC (credit: T.Dickinson, Three Oaks Engineering)

June 2021

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

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Valuable peer reviews of a draft of this document were provided by John Alderman (Alderman Environmental Services, Inc.) and Brena Jones (NC Wildlife Resources Commission), and additional review was provided by Jennifer Stanhope (USFWS-Virginia Field Office). We appreciate the time and effort of those dedicated to learning and implementing the SSA Framework, which resulted in a more robust assessment and final report.

Suggested reference:

U.S. Fish and Wildlife Service. 2021. Species status assessment report for the Atlantic Pigtoe (*Fusconaia masoni*). Version 1.4. June, 2021. Atlanta, GA.

Summary of Version Updates

The changes from version 1.0 (December 2016) and 1.1 (February 2017) are minor and do not change the SSA Analysis for Atlantic Pigtoe. The changes were:

1) Changed title of Figure 3-18 from Atlantic Pigtoe Current Representation to Atlantic Pigtoe Current Condition.
2) Revised Section 4.5 to include additional relevant references; restructured to clarify content.
3) Added new references from revised Section 4.5 to References.
4) Removed mention of likelihood of scenario occurrence at 10-year time step due to confusion in initial expert application and subsequent interpretation in report.

The changes from version 1.1 (February 2017) and 1.2 (March 2017) were also minor and do not change the SSA Analysis for Atlantic Pigtoe. The changes were:

1) Revised Section 4.6 to include additional relevant references; added information to clarify content.
2) Added new references from revised Section 4.6 to References.
3) Additional information added to clarify Atlantic Pigtoe diet in section 2.4.

The changes from version 1.2 (March 2017) and 1.3 (April 2019) included minor edits and clarifications suggested from the public comments received on the proposed rule to list Atlantic Pigtoe as a threatened species (83 FR 51570), but they did not change the SSA Analysis. The changes were:

1) Addition of recent survey locations for Sappony Creek, Nottoway River, Little Grassy Creek, Dan River, and Middle Creek (Neuse); updated Figure 3-2.
2) Addition of information provided by Sound Rivers, Inc. regarding monthly flow data comparisons, Section 3.3.1, p.30. [Note: this information was provided during the public comment for the Yellow Lance listing, however it is included in this report because it is relevant to habitats occupied by both Yellow Lance and Atlantic Pigtoe]
3) Included information on TMDLs and the Triennial Review Process in section 4.2.
4) Revised Section 4.5 to include additional relevant references.
5) Removed mention of SmithEnvironment Blog in Section 4.6 under Regulatory Reform in North Carolina.
6) Addition of agriculture BMP and groundwater pumping information in section 4.4.
7) Correction of page numbers for Allan 1995 reference.
8) Additional information provided about uncertainties associated with SLEUTH BAU model in section 5.1.
9) Addition of historical data from museum collections found by NCWRC staff (see Appendix A – Yadkin and Catawba basins).

The changes from version 1.3 (April 2019) and 1.4 (June 2021) included minor edits:

1) Correcting Middle James occurrence data, indicating that it is not currently occupied.
2) Adding information about mussels and sedimentation, including citations, to p.57.
3) Adding information about influence of Asian clams, including citations, to p.59.

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EXECUTIVE SUMMARY

This species status assessment (SSA) reports the results of the comprehensive status review for the Atlantic Pigtoe (*Fusconaia masoni)* (Conrad 1834)), documenting the species' historical condition, and providing estimates of current and future condition under a range of different scenarios. The Atlantic Pigtoe is a freshwater mussel species native to the Atlantic Slope drainage in Virginia, North Carolina, South Carolina, and Georgia. The species occurs in streams and rivers, generally in gravel and coarse sand substrates.

The SSA process can be categorized into three sequential stages. During the first stage, we used the conservation biology principles of resiliency, redundancy, and representation (together, the 3Rs) to evaluate individual mussel life history needs (Table ES-1). The next stage involved an assessment of the historical and current condition of species' demographics and habitat characteristics, including an explanation of how the species arrived at its current condition. The final stage of the SSA involved making predictions about the species' responses to positive and negative environmental and anthropogenic influences. This process used the best available information to characterize viability as the ability of a species to sustain populations in the wild over time.

To evaluate the current and future viability of the Atlantic Pigtoe, we assessed a range of conditions to allow us to consider the species' resiliency, representation, and redundancy. For the purposes of this assessment, populations were delineated using the 12 river basins that Atlantic Pigtoe mussels have historically occupied (i.e., James, Chowan, Roanoke, Tar, Neuse, Cape Fear, Pee Dee, Catawba, Edisto, Savannah, Ogeechee, and Altamaha River basins). Because the river basin level is at a very coarse scale, populations were further delineated using Management Units (MUs). MUs were defined as one or more HUC10 watersheds that species experts identified as most appropriate for assessing population-level resiliency.

Resiliency, assessed at the population level, describes the ability of a population to withstand stochastic disturbance events. A species needs multiple resilient populations distributed across its range to persist into the future and avoid extinction. A number of factors, including (but not limited to) water quality, water quantity, habitat connectivity, and instream substrate, may influence whether Atlantic Pigtoe populations will occupy available habitat. As we considered the future viability of the species, more populations with high resiliency distributed across the known range of the species can be associated with higher species viability. As a species, the Atlantic Pigtoe has limited resiliency, with many of the populations in low or presumed extirpated condition.

Redundancy describes the ability of the species to withstand catastrophic disturbance events; for the Atlantic Pigtoe, we considered whether the distribution of resilient MUs within populations was sufficient for minimizing the potential loss of the species from such an event. The Atlantic Pigtoe historically ranged from the James River Basin in Virginia to the Altamaha River Basin in Georgia, but both the number and distribution of mussel populations occupying that historical range has declined over the past 60 years.

Representation characterizes a species' adaptive potential by assessing geographic, genetic, ecological, and niche variability. The Atlantic Pigtoe has exhibited historical variability in the physiographic regions it inhabited, as well as the size and range of the river systems it inhabited. The species has been documented from small streams to large rivers in multiple physiographic provinces, from the foothills of the Appalachian Mountains through the Piedmont and into the Coastal Plain. Much of the representation of the Atlantic Pigtoe has been lost; physiographic variability has been lost with 76% loss in the Coastal Plain, 67% loss in the Mountains, and 48% loss in the Piedmont, and the remaining occurrences are represented by very few individuals in very few locations.

Together, the 3Rs comprise the key characteristics that contribute to a species' ability to sustain populations in the wild over time (i.e., viability). Using the principles of resiliency, redundancy, and representation, we characterized both the species' current viability and forecasted its future viability over a range of plausible future scenarios. To this end, we ranked the condition of each population by assessing the relative condition of occupied watersheds using the best available scientific information.

The analysis of species' current condition revealed that Atlantic Pigtoe abundance and distribution has declined, with the species currently occupying approximately 40% of its historical range. Most of the remaining populations are small and fragmented, only occupying a fraction of reaches that were historically occupied. This decrease in abundance and distribution has resulted in largely isolated contemporary populations. Evidence suggests that the range reduction of the species corresponds to habitat degradation resulting from the cumulative impacts of land use change and associated watershed-level effects on water quality, water quantity, habitat connectivity, and instream habitat suitability. The effects of climate change (e.g., increasing temperatures, droughts) have begun to be realized in the current Atlantic Pigtoe range and may have contributed to habitat degradation.

To assess the future condition of the Atlantic Pigtoe, a variety of stressors, including pollution, reduced stream flow, and continued habitat fragmentation, and their (potential) effects on population resiliency were considered. Populations with low resiliency are considered to be more vulnerable to extirpation, which, in turn, would decrease species' level representation and redundancy. To help address uncertainty associated with the degree and extent of potential future stressors and their impacts on species' requisites, the 3Rs were assessed using four plausible future scenarios (Table ES-2). These scenarios were based, in part, on the results of urbanization (Terando et al. 2014) and climate models (International Panel on Climate Change 2013) that predict changes in habitat used by the Atlantic Pigtoe.

An important assumption of the predictive analysis was that future population resiliency is largely dependent on water quality, water flow, and riparian and instream habitat conditions. Our assessment predicted that all currently extant Atlantic Pigtoe populations would experience negative changes to these important habitat requisites; predicted viability varied among scenarios and is summarized below, and in Table ES-3 and Figure ES-1.

Given Scenario 1, the "Status Quo" option, a substantial loss of resiliency, representation, and redundancy is expected. Under this scenario, we predicted that no MUs would remain in high condition, two in moderate condition, six in low condition, and the remaining MUs (20) would be likely extirpated. Redundancy would be reduced with likely extirpation of six out of 14 currently extant MUs; only the Tar Population would retain more than one moderately resilient MU. Representation would be reduced, with only five (42%) of the former river basins occupied, and with extremely limited variability in the Mountains and Coastal Plain, and reduced variability in the Piedmont.

Given Scenario 2, the "Pessimistic" option, we predicted a near complete loss of resiliency, representation, and redundancy. Redundancy would be reduced to two populations (i.e., likely extirpation of 10 populations), and the resiliency of those populations is expected to be low. The majority of MUs are predicted to be extirpated, and of the remaining four MUs, all would be in low condition. Representation is reduced with only 17% of the former river basins occupied, and all Mountain representation and nearly all Coastal Plain representation is lost.

Given Scenario 3, the "Optimistic" option, we predicted slightly higher levels of resiliency, representation, and redundancy in some areas than was estimated for the Status Quo Scenario. Two MUs are predicted to maintain high condition, five are predicted to be in moderate condition, five in low condition, and the remaining 16 MUs are predicted to be likely extirpated. Despite all current populations continuing to persist, only the Tar population would retain moderate levels of resiliency. Existing levels of representation would be maintained.

Given Scenario 4, the "Opportunistic" option, we predicted reduced levels of resiliency, representation, and redundancy. No MUs are predicted to be in high condition, three in moderate condition, five in low condition, and 20 are predicted to be likely extirpated. Redundancy would be reduced by losing 6 MUs compared to current condition. Representation is predicted to be reduced with only six (50%) of the former 12 populations occupied, and with reduced variability in the Mountains, Piedmont, and Coastal Plain.

Table ES-1. Summary results of the Atlantic Pigtoe Species Status Assessment.

3Rs	Needs	Current Condition	Future Condition (Viability)
Resiliency (Large populations able to withstand stochastic events)	• Excellent water quality • Flowing river ecosystems • Suitable substrate: clean, coarse sands and gravels • Multiple occupied management units per population	• 7 (of 12) populations known to be extant • Currently extirpated from 14 of the 28 Management Units • Population status: 1 high resiliency 1 moderate resiliency 5 low resiliency 5 extirpated	Projections based on future scenarios in 50 years: • Status Quo: Threats continue on current trajectory and species maintains current level of response. Seven populations (20 MUs) predicted to be likely extirpated; remaining five populations predicted to have reduced overall resiliency • Pessimistic: higher level of threats and reduced species response. Ten populations (24 MUs) are predicted to be likely extirpated; remaining two (4 MUs) are predicted to have low resiliency • Optimistic: minimal level of threats and optimistic species response. Five populations predicted to remain extirpated; majority of others predicted to maintain existing resiliency condition • Opportunistic: moderate level of threats and selective species response. Six populations are predicted to be likely extirpated; remaining six are predicted to have reduced resiliency
Representation (genetic and ecological diversity to maintain adaptive potential)	• Genetic variation is assumed to exist between river basin populations • Ecological variation exists between small streams and larger rivers, and between physiographic provinces	Compared to historical distribution: • 42% of river basin variability lost; most remaining populations are in low condition • Low genetic representation (due to very low abundances) in remaining populations • Limited physiographic variability in Mountains, Piedmont, and Coastal Plain	Projections based on future scenarios in 50 years: • Status Quo: 58% of River Basin Variability lost; considerable losses in Physiographic Variability in Mountains (83%), Piedmont (69%), and Coastal Plain (90%) • Pessimistic: 83% River Basin Variability lost; severe losses of Physiographic Variability in Mountains (100%), Piedmont (77%), and Coastal Plain (92%) • Optimistic: 42% of River Basin Variability lost; maintain limited Physiographic Variability in Mountains (17%), Piedmont (54%), and Coastal Plain (21%) • Opportunistic: 50% of River Basin Variability lost; considerable losses of Physiographic Variability in Mountains (83%), Piedmont (57%), and Coastal Plain (91%)
Redundancy (number and distribution of populations to withstand catastrophic events)	• Multiple resilient MUs within populations in each area of representation	• Five of the 12 populations are presumed extirpated • Two of the seven extant populations have only one MU currently occupied • 50% of MUs are presumed extirpated • Overall 60% reduction in redundancy across range (32 out of 81 HUCs currently occupied)	Projections based on future scenarios in 50 years: • Status Quo: Five populations expected to persist; 20 of 28 MUs extirpated • Pessimistic: Two populations expected to persist; 24 of 28 MUs extirpated • Optimistic: Seven populations expected to persist; 16 of 28 MUs extirpated • Opportunistic: Six populations expected to persist; 18 of 28 MUs extirpated

Table ES-2. Future scenario and condition category descriptions for each of four scenarios used to predict Atlantic Pigtoe viability.

			Future Condition Category Descriptions			
Scenario Name	**Climate Future**	**Urbanization**	**Species Condition**	**Water Quality Condition**	**Water Quantity Condition**	**Habitat Condition**
1) Status Quo Scenario	Current Climate effects continue on trend into the future, resulting in increased heat, drought, storms and flooding	Urbanization continues on trend with current levels	Current level of species response to impacts on landscape; current levels of propagation & augmentation and/or translocation capacity	Current level of regulation and oversight, including limited protective WQ[5] standards requirements and utilization of basic technologies for effluent treatment	Current level of regulation and oversight, including sustained IBTs[6] and irrigation withdrawals; current flow conditions	Current level of regulation, barrier improvement/removal projects, and riparian buffer protections
2) Pessimistic Scenario	Moderate to Worse Climate Future (RCP8.5[1])-exacerbated effects of climate change experienced related to heat, drought, storms and flooding	Urbanization rates at high end of BAU[4] model (~200%)	Species response to synergistic impacts on landscape result in significant declines coupled with limited propagation capacity and/or limited ability to augment/reintroduce propagules	Declining water quality resulting from increased impacts, limited regulation and restrictions, and overall reduced protections	Degraded flow conditions resulting from climate change effects, increased withdrawals and IBTs, limited regulation, and overall reduced protections	Degraded instream and riparian habitat conditions from increased impacts, limited regulation, fewer barrier improvement/removal projects, and overall reduced riparian buffer protections
3) Optimistic Scenario	Moderate to Improved Climate Future (trending towards RCP 2.6[2]) resulting in minimal effects of heat, drought, storms and flooding	Urbanization rates realized at lower levels than BAU model predicts (<100%)	Optimistic species response to impacts; targeted propagation and/or restoration efforts utilizing existing resources and capacity	Slightly increased impacts tempered by utilizing improved technologies and implementing protection strategies	Improved flow conditions through increased oversight and implementation of flow improvement strategies	Existing resources targeted to highest priority barrier removals; riparian buffer protections remain intact; targeted riparian connectivity projects; regulatory mechanisms remain the same
4) Opportunistic Scenario	Moderate Climate Future (RCP4.5/6[3]) - some climate change effects experienced; some areas impacted more than others by heat, drought, storms and flooding	Moderate BAU urbanization rates (~100%) realized	Selective improved species response to impacts as a result of targeted propagation and/or restoration efforts utilizing current resources and capacity	Moderate increase in WQ impacts resulting from continued levels of regulation, protection, and technology	Targeted strategies to improve flow conditions in priority areas	Targeted increase in riparian connectivity and protection of instream habitat in priority areas through targeted conservation efforts

[1]Representative concentration pathway 8.5
[2] Representative concentration pathway 2.6
[3] Representative concentration pathway 4.5/6
[4]Business as usual
[5]Water quality
[6]Interbasin transfer

Table ES-3. Predicted Atlantic Pigtoe population conditions under each of four plausible scenarios. Predictions were made using a 50-year time interval.

		Future Scenarios of Population Conditions			
POPULATIONS: Management Units	Current	#1 Status Quo	#2 Pessimistic	#3 Optimistic	#4 Opportunistic
James: Craig Creek Subbasin	Moderate	Low	Likely Extirpated	Moderate	Moderate
James: Mill Creek	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
James: Rivanna	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
James: Upper James	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
James: Middle James	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
James: Appomattox	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Chowan: Nottoway	Moderate	Likely Extirpated	Likely Extirpated	Low	Low
Chowan: Meherrin	Low	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Roanoke: Dan River Subbasin	Low	Likely Extirpated	Likely Extirpated	Moderate	Likely Extirpated
Roanoke: Roanoke	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Tar: Upper/Middle Tar	High	Low	Low	Moderate	Low
Tar: Lower Tar	Low	Low	Likely Extirpated	Low	Likely Extirpated
Tar: Fishing Ck	High	Moderate	Low	High	Moderate
Tar: Sandy-Swift	High	Moderate	Low	High	Moderate
Neuse: Upper Neuse	Moderate	Low	Likely Extirpated	Moderate	Low
Neuse: Middle Neuse	Moderate	Likely Extirpated	Likely Extirpated	Low	Likely Extirpated
Cape Fear: New Hope	Moderate	Low	Likely Extirpated	Low	Likely Extirpated
Cape Fear: Deep River Subbasin	Low	Likely Extirpated	Likely Extirpated	Moderate	Low
Cape Fear: Mainstem	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Cape Fear: Black	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Pee Dee: Muddy	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Pee Dee: Uwharrie/Little	Low	Low	Low	Low	Low
Pee Dee: Goose/Lanes	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Catawba	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Edisto	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Savannah	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Ogeechee	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Altamaha	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated

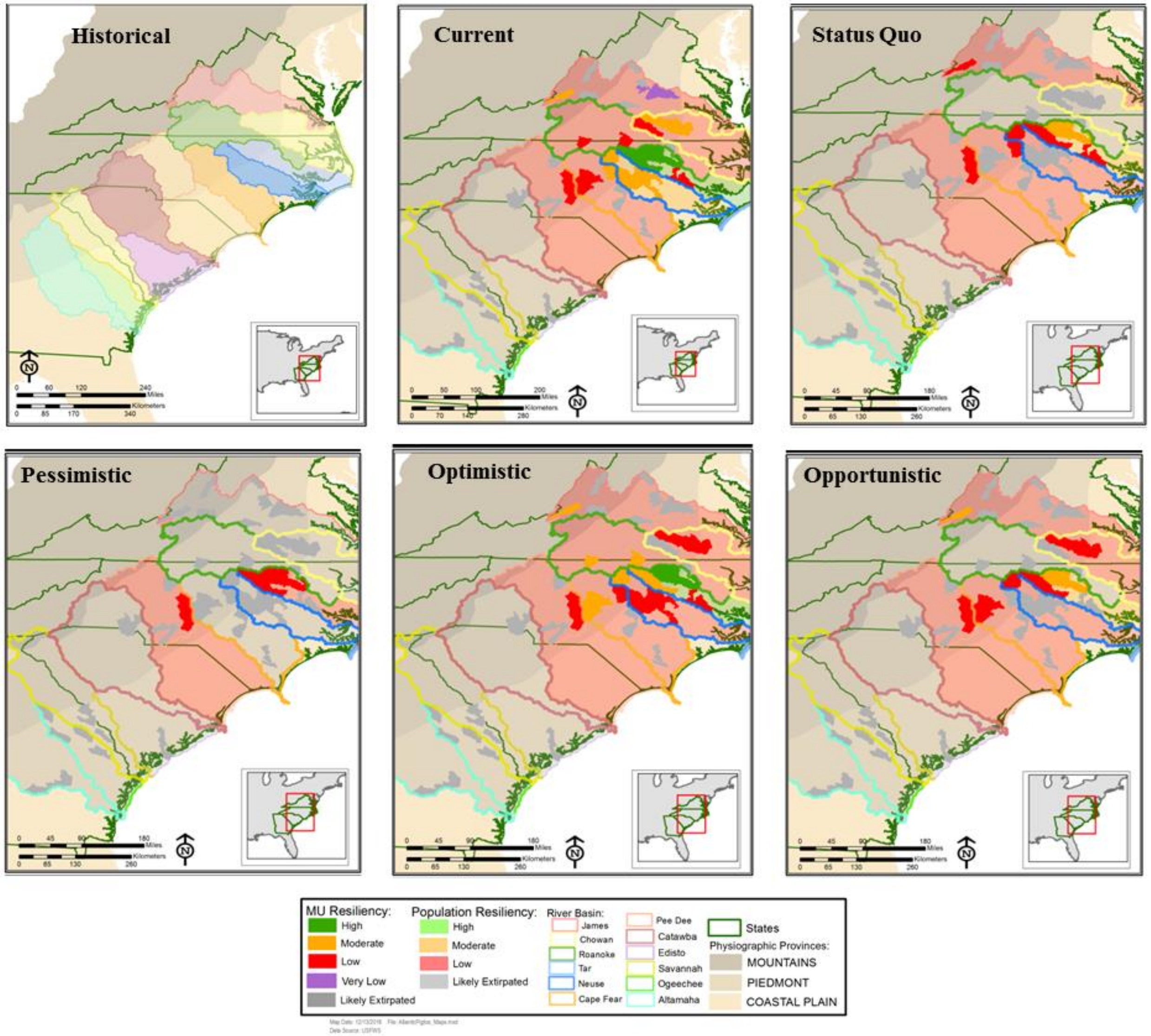

Figure ES-1 Maps of historical range, current condition, and predicted Atlantic Pigtoe population conditions under each scenario (see Table ES-3)

Current Viability Summary

The historical range of the Atlantic Pigtoe included streams and rivers in the Atlantic Slope drainages from the James River Basin to the Altamaha River Basin with the documented historical distribution in 28 MUs within twelve former populations. The Atlantic Pigtoe is presumed extirpated from 54% (15/28) of the historically occupied MUs. Of the remaining 13 occupied MUs, only three (21%) are estimated to be highly resilient, five (36%) are moderately resilient, and five (43%) have low resiliency. Scaling up from the MU to the population level, one of twelve former populations (the Tar Population) was estimated to have high resiliency, one population (the Neuse Population) was estimated to have moderate resiliency, five populations (James, Chowan, Roanoke, Cape Fear, Pee Dee) had low estimated resiliency, and five of the former 12 populations are presumed extirpated, thus eliminating 42%, or the entire southern portion, of the species' range. 71% of streams that remain part of the current species' range are estimated to be in low condition, potentially putting the Atlantic Pigtoe at risk of extirpation. Once known to occupy streams in three physiographic regions, the species has also lost substantial physiographic representation. An estimated 67% loss has occurred in the Mountain watersheds, 48% loss in the Piedmont, and 76% loss in the Coastal Plain watersheds.

Overall Summary

Estimates of current and future resiliency for Atlantic Pigtoe are low, as are estimates for representation and redundancy. The Atlantic Pigtoe faces a variety of threats from declines in water quality, loss of stream flow, riparian and instream habitat fragmentation, and deterioration of instream habitats. These threats, which are expected to be exacerbated by urbanization and climate change, were important factors in our assessment of the future viability of the Atlantic Pigtoe. Given current and future decreases in resiliency, populations become more vulnerable to extirpation from stochastic events, in turn, resulting in concurrent losses in representation and redundancy. Predictions of Atlantic Pigtoe habitat conditions and population factors suggest possible extirpation in up to five of seven currently extant populations. The two populations predicted to remain extant at the end of the predictive time horizon are expected to be characterized by low occupancy and abundance.

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CHAPTER 1 - INTRODUCTION

The Atlantic Pigtoe is a freshwater mussel once found in Atlantic Slope drainages from the James River Basin in Virginia to the Altamaha River Basin in Georgia. The species was petitioned for federal listing under the Endangered Species Act of 1973, as amended (Act), as a part of the 2010 Petition to List 404 Aquatic, Riparian and Wetland Species from the Southeastern United States by the Center for Biological Diversity (CBD 2010, p.532).

The Species Status Assessment (SSA) framework (USFWS 2016a, entire) is intended to be an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA Report to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from Candidate Assessment to Listing to Consultations to Recovery. As such, the SSA Report will be a living document that may be used to inform Endangered Species Act decision making, such as listing, recovery, Section 7, Section 10, and reclassification decisions (the former four decision types are only relevant should the species warrant listing under the Act).

Because the Atlantic Pigtoe SSA has been prepared at the Candidate Assessment phase, it is intended to provide the biological support for the decision on whether to propose to list the species as threatened or endangered and, if so, to determine whether it is prudent to designate critical habitat in certain areas. Importantly, the SSA Report is not a decisional document by the U.S. Fish and Wildlife Service, rather it provides a review of available information strictly related to the biological status of the Atlantic Pigtoe. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of a 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 the species to sustain resilient populations in natural stream ecosystems for at least 50 years. Using the SSA framework (Figure 1.1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its redundancy, representation, and resiliency (USFWS 2016a, entire; Wolf et al. 2015, entire).

- Resiliency is assessed at the level of populations and reflects a species' ability to withstand stochastic events (arising from random factors). Demographic measures that reflect population health, such as fecundity, survival, and population size, are the metrics used to evaluate resiliency. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), and the effects of anthropogenic activities.

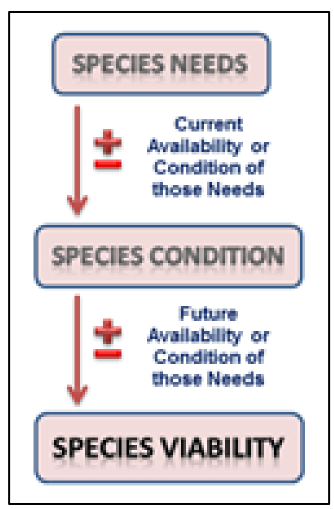


Figure 1-1 Species Status Assessment Framework

- Representation is assessed at the species' level and characterizes the ability of a species to adapt to changing environmental conditions. Metrics that speak to a species' adaptive potential, such as genetic and ecological variability, can be used to assess representation. Representation is directly correlated to a species' ability to adapt to changes (natural or human-caused) in its environment.

- Redundancy is also assessed at the level of the species and reflects a species' ability to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk of such an event across multiple, resilient populations. As such, redundancy can be measured by the number and distribution of resilient populations across the range of the species.

To evaluate the current and future viability of the Atlantic Pigtoe, we assessed a range of conditions to characterize the species' redundancy, representation, and resiliency (together, the 3Rs). This SSA Report provides a thorough account of biology and natural history and assesses the risk of threats and limiting factors affecting the future viability of the species.

This SSA Report includes: (1) a description of Atlantic Pigtoe resource needs at both individual and population levels (Chapter 2); (2) a characterization of the historic and current distribution of resilient populations across the species' range (Chapter 3); (3) an assessment of the factors that contributed to the current and future status of the species and the degree to which various factors influenced viability (Chapter 4); and (4) a synopsis of the factors characterized in earlier chapters as a means of examining the future biological status of the species (Chapter 5). This document is a compilation of the best available scientific information (and associated uncertainties regarding that information) used to assess the viability of the Atlantic Pigtoe.

CHAPTER 2 - INDIVIDUAL NEEDS:
LIFE HISTORY AND BIOLOGY

In this section, we provide basic biological information about the Atlantic Pigtoe, including its physical environment, taxonomic history and relationships, morphological description, and reproductive and other life history traits. We then outline the resource needs of individuals and populations. Here we report those aspects of the life histories that are important to our analyses. For further information about the Atlantic Pigtoe refer to Alderman (2003), Bogan et al. (2003), and Alderman and Alderman (2014).

2.1 Taxonomy

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, p.131; Campbell and Lydeard 2012, p.1). It has been reported in the literature as *Unio subplanus*, *Lexingtonia subplana*, *U. masoni*, or *Pleurobema masoni* (Fuller 1973, p.105; Alderman 2003, p.4-5), 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, p.105; Bogan et al. 2003, p.1).

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, pp.28-29). It was named after one of Conrad's friends, William Mason, an early American Conchologist (Conrad 1834, p.35). From Burlakova et al. (2012, p.7), *F. masoni* appears to be closely related genetically to *F. cerina*, *F. flava*, *F. askewi*, *F. burkei*, and *F. escambia*. With the exception of *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 2016):

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

2.2 Description

The Atlantic Pigtoe is a small freshwater mussel with a sub-rhomboidal shaped shell. Although larger specimens exist, the Atlantic Pigtoe rarely exceeds 50mm (2 inches) in length (Wisniewski 2008, p.1; Figure 2-1). Except in headwater stream reaches, where specimens may be elongated, this species is tall relative to its length (Alderman and Alderman 2014, p.5). 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 hingeline (Fuller 1973, p.106;

Wisniewski 2008, p.1). 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, p.107), 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, p.107; Alderman and Alderman 2014, p.5). The shell has full dentition with two pseudocardinals in each valve (although the anterior one in right valve is vestigial) and well developed lateral teeth (Fuller 1973, p.107).

In addition to simple papillae, branched and arborescent papillae are often seen on the incurrent aperture (Alderman and Alderman 2014, p.5). Salmon colored demibranchs in females is often seen during the spawning season. When fully gravid, females use all 4 demibranchs to brood glochidia (Fuller 1973, p. 108).

Figure 2-1 Typical Atlantic Pigtoe specimen (credit: J.Alderman).

2.3 Reproduction, including Host Fish Interaction

As is the case with most freshwater mussels, the Atlantic Pigtoe has a unique life cycle that relies on fish hosts for successful reproduction (Figure 2-2):

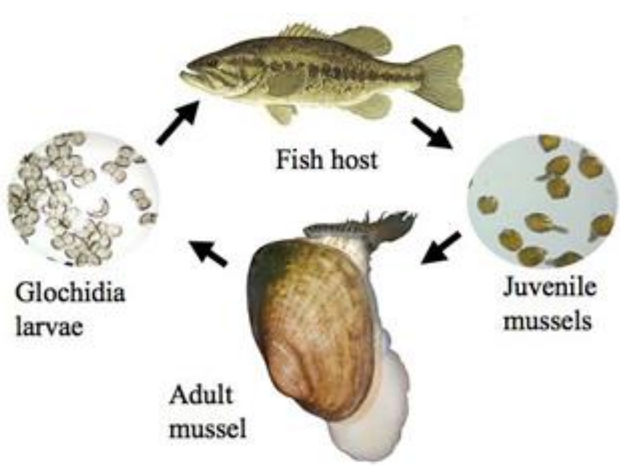


Figure 2-2 Generic illustration of the freshwater mussel reproductive cycle (FMCS 2015)

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 (NCSU) email to S.McRae (USFWS) on 1/13/2016; Alderman and Alderman 2014, p.9; Figure 2-3). The conglutinates are tubular, and the color varies from white to pink to red depending on the percentage of fertilization, with less fertilization being more red (unfertilized eggs are red) (C.Eads (NCSU) email to S.McRae (USFWS) on 1/13/2016).

Figure 2-3 Atlantic Pigtoe conglutinates (credit: C.Eads)

Like other species in the Pleurobemini tribe, the Atlantic Pigtoe targets drift-feeding minnow species by releasing pelagic conglutinates (Haag 2012, p.163), 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 (as referenced in Wolf 2012, p.33).

Lab studies by O'Dee and Watters (2000, p.77) 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, p.52) found that Rosefin Shiner (*Lythrurus ardens*), Creek Chub (*Semotilus atromaculatus*), and Longnose Dace (*Rhynichthys cataractae*) serve as very effective hosts. Additional studies (Eads and Levine 2011, p.12) have confirmed that members of the Cyprinidae 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) email to B.Forbus (USFWS) on 12/2/2016).

Time period for glochidia to complete metamorphosis varies between 8-19 days at 21-22ºC, and depends on the host fish (Eads and Levine 2011, p.11).

2.4 Diet

Mussels, such as the Atlantic Pigtoe, filter algae, detritus, microscopic animals, and bacteria from the water column (Fuller 1974, p. 221; Silverman *et al.* 1997, pp. 1862-1865; Nichols and Garling 2000, pp. 874-876; Strayer *et al.* 2004, pp. 430-431; Haag 2012, p.26). 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 2007, p. 55). 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, pp. 217-221; Alderman and Alderman 2014, p.9). However, their gills are rudimentary and generally incapable of filtering particles (Watters 2007, p. 56). Adult mussels also can obtain their food by deposit feeding, siphoning in food from the sediment and its interstitial (pore) water and pedal feeding directly from the sediment (Yeager *et al.* 1994, pp. 217-221; Vaughn and Hakenkamp 2001, pp. 1432-1438). Food availability and quality for the Atlantic Pigtoe in its habitats are affected by habitat stability and connectivity, flow, and water and sediment quality.

2.5 Age, Growth, Population Size Structure, and Fecundity

Atlantic Pigtoe demonstrates an "equilibrium life history strategy", which means it is a slow-growing and long-lived species with low fecundity (Haag 2012, p.211; Alderman and Alderman 2014, p.9). 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.

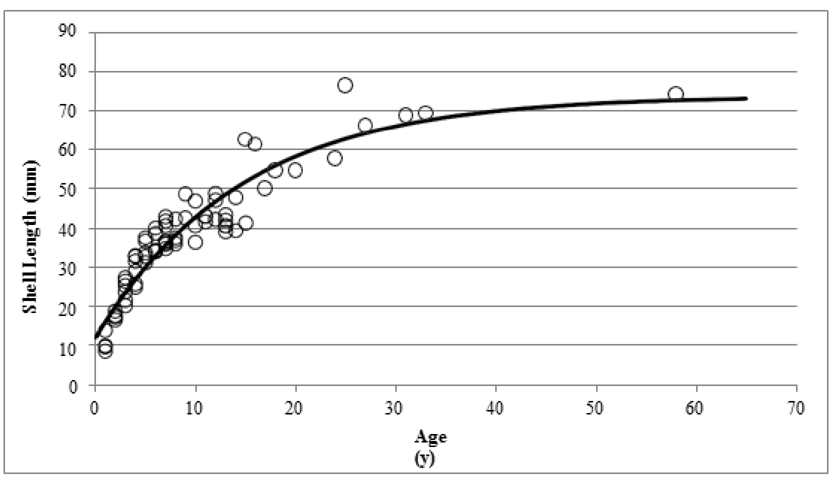


Figure 2-4 Observed (dots) and predicted growth (line) for Atlantic Pigtoe population in the Nottoway River, VA (from Wolf 2012, p.29); 58 year old individual considered an outlier.

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, p.27-29; Figure 2-4) yielded a population with multiple age classes ranging from 1 to 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) revealed multiple size classes, ranging from 16mm to 63mm (approximately ages 1 to 30+ years) (Alderman and Alderman 2014, p.31; Figure 2-5).

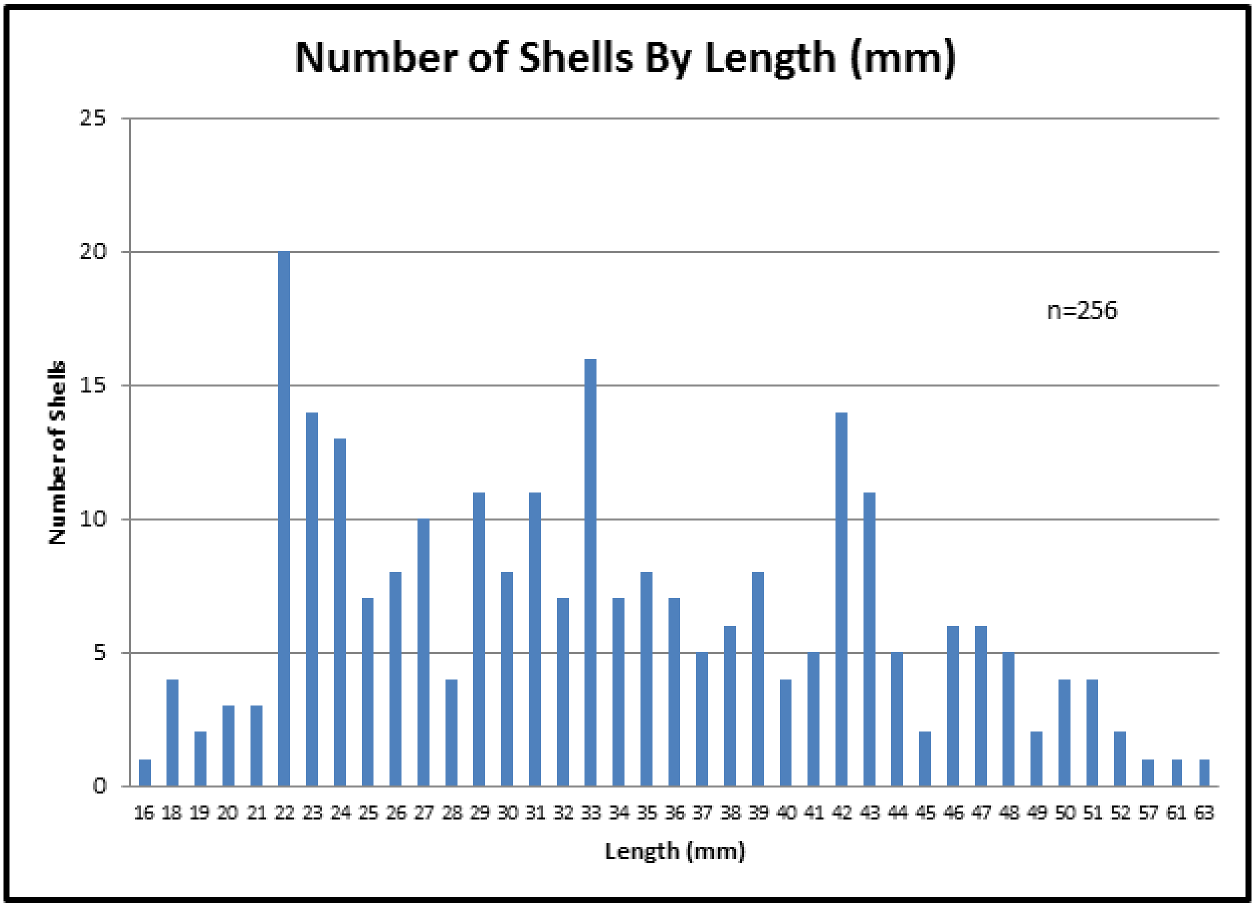


Figure 2-5 Size-frequency distribution of the Swift Creek (Tar) Atlantic Pigtoe population, August 1991 (from Alderman and Alderman 2014, p.31).

In captivity in a hatchery/pond settting, age to sexual maturity is approximately 3 years (C.Eads (NCSU), pers. comm.). Fecundity is uniformly low in most species that have an equilibrium strategy (Haag 2012, p.211), 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, p.33). 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, p.33).

2.6 Habitat

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, p.8). Because this species prefers more pristine conditions, it typically occurs in headwaters and rural watersheds. 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, p.30).

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, p. 983). 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. As we discuss in more detail below, the contemporary distribution of Atlantic Pigtoe is patchy, resulting in largely isolated populations and, in turn, potentially limited genetic exchange.

Table 2.1 Life history and resource needs of the Atlantic Pigtoe.

Life Stage	Resources and/or circumstances needed for INDIVIDUALS to complete each life stage	Resource Function (BFSD*)	Information Source
Fertilized Eggs - early spring	• Clear, flowing water • Sexually mature males upstream from sexually mature females • Appropriate spawning temperatures • Presence of gravid females	B	- Berg et al. 2008, p.397 - Haag 2012
Glochidia - late spring to early summer	• Clear, flowing water • Just enough flow to attract drift feeding minnows • Presence of Host Fish for attachment	B, D	- Levine et al. 2011, p.3 - Haag 2012

Juveniles
- excystment from host fish to ~20mm shell length
	• Clear, flowing water
	• Host fish dispersal
	• Appropriate interstitial chemistry
	  - Low salinity (~0.9ppt)
	  - Low ammonia (~0.7 mg/L)
	  - Low levels of copper and other contaminants
	  - Dissolved oxygen >4 mg/L
	• Appropriate substrate for settlement
	• Adequate food availability
		F, S	- Dimmock and Wright 1993
			- Sparks and Strayer 1998, p.132
			- Augspurger et al. 2003, p.2574
			- Augspurger et al. 2007, p.2025
			- Strayer and Malcom 2012

Adult - >20mm shell length	• Clear, flowing water • Appropriate substrate (silt-free gravel and stable, coarse sand • Adequate food availability (phytoplankton and detritus) High Dissolved oxygen (>3mg/L) Water temperature <35°C	F, S	- Yeager et al. 1994, p.221 - Nichols and Garling 2000, p.881 - Chen et al. 2001, p.214 - Spooner and Vaughn 2008, pp.308,315

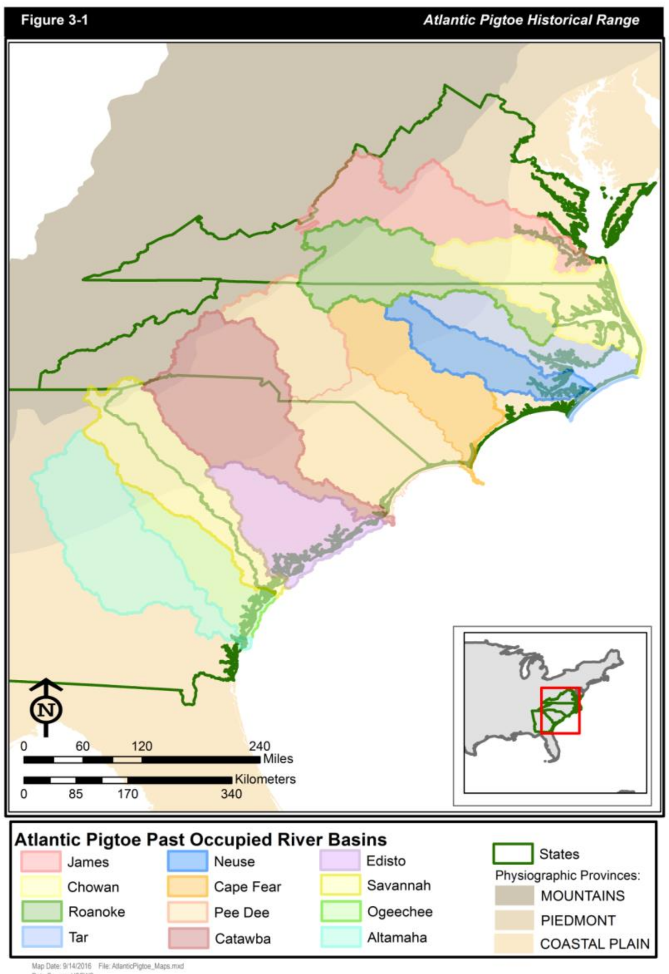
* B=breeding; F=feeding; S=sheltering; D=dispersal

CHAPTER 3 – POPULATION AND SPECIES NEEDS AND CURRENT CONDITION

In this chapter we consider the Atlantic Pigtoe's historical distribution, its current distribution, and the factors that contributed to the species current condition. We first review the historical information on the range and distribution of the species. Next we evaluate species' requisites to consider their relative influence to Atlantic Pigtoe resiliency, representation, and redundancy. Through the lens of the 3Rs, we then estimate the current condition of Atlantic Pigtoe populations.

3.1 Historical Range and Distribution

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. Johnston (1970, p.302) indicated the southernmost records were from the Ogeechee River Basin, however, recent curation of the H.D. Athearn collection uncovered valid specimens from the



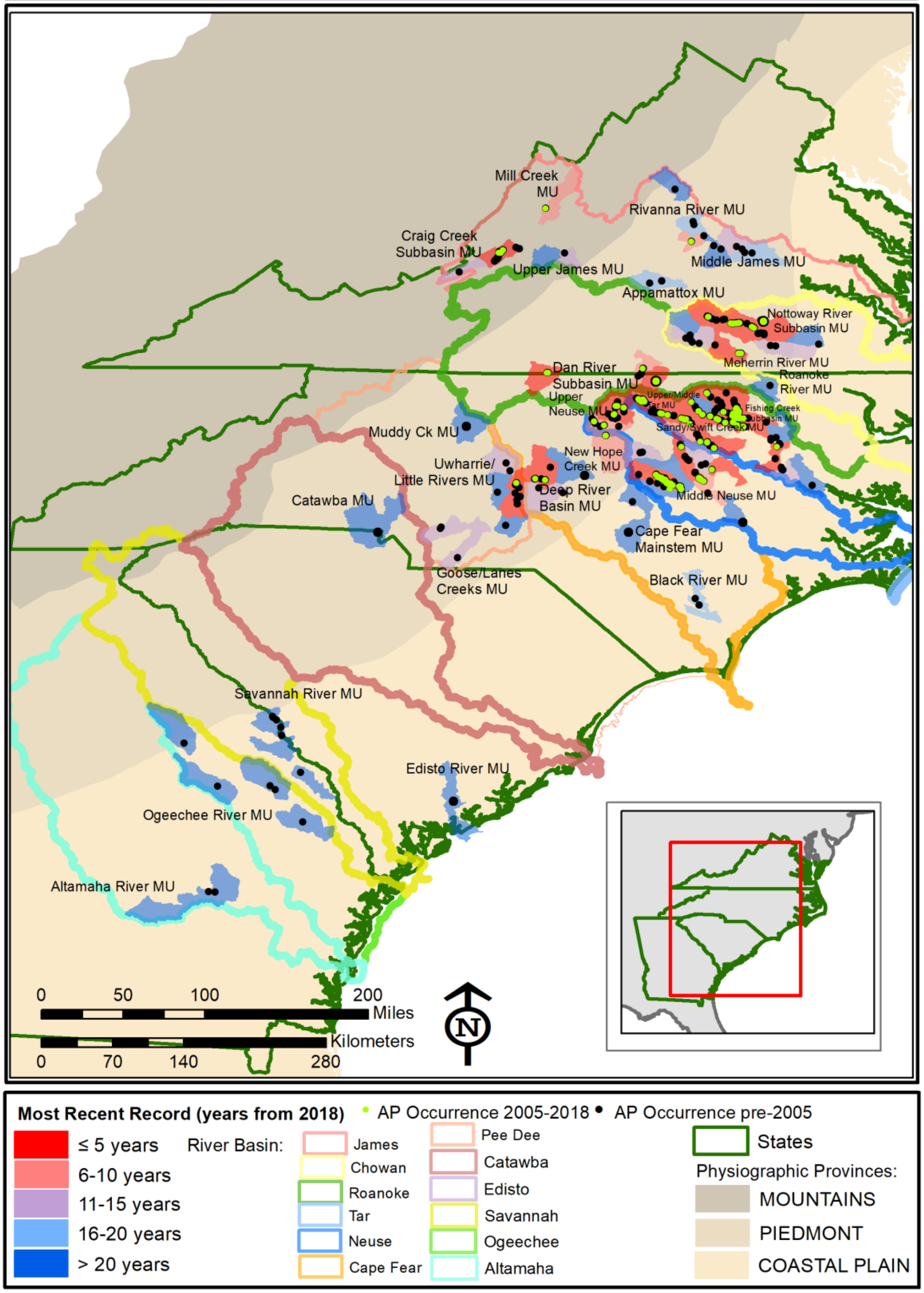
Altamaha River (NCSM 54068). The Atlantic Pigtoe has been documented from multiple physiographic provinces, from the foothills of the Appalachian Mountains through the Piedmont and into the Coastal Plain, in streams ranging in size from < 1 m wide up to some of the largest Atlantic Slope rivers within the species' range.

3.2 Current Range and Distribution

For the purposes of this assessment, populations were delineated using the twelve river basins that Atlantic Pigtoe mussels have historically occupied. This includes the James, Chowan, Roanoke, Tar, Neuse, Cape Fear, Pee Dee, Catawba, Edisto, Savannah, Ogeechee, and Altamaha River basins, and from here forward, we will use these terms to refer to populations (e.g., Tar population). Of twelve historical populations, seven populations have observations in the last 10 years, though the majority of occurrences were limited to a single location within the river basin. The Atlantic Pigtoe is presumed extirpated from the southern portion of the range.

Because the river basin level is at a very coarse scale, populations were further delineated using management units (MUs). MUs were defined as one or more HUC10 watersheds that species experts identified as most appropriate for assessing population-level resiliency (see Section 3.3; Appendix A). Range-wide species occurrence data were used to create "occurrence heat maps" that discretize HUC10 watersheds into 5-year increments based on the date of observed occurrences (see GADNR 2016a; Appendix B). These heat maps display recent observed occurrences using various shades of red, while older observed occurrences are displayed in various shades of blue (e.g., Figure 3-2). Documented species occurrences are included to show distribution within HUC10s. Throughout this section, heat maps are used to characterize the historic and current distribution of Atlantic Pigtoe among MUs for each of twelve populations.

Figure 3-2 ***Atlantic Pigtoe Current Distribution***

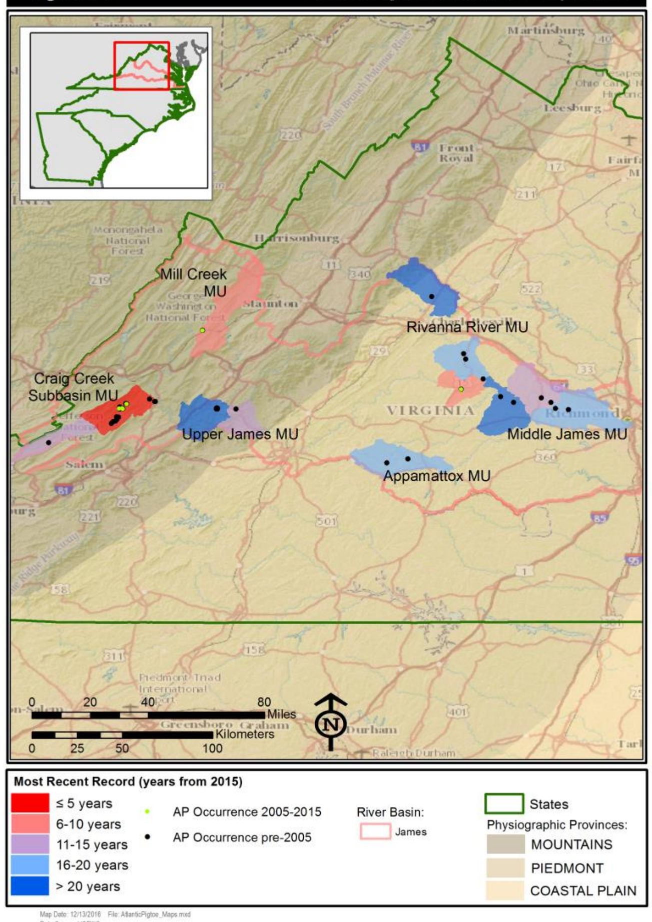


VIRGINIA

3.2.1 James River Population

Basin Overview: The James River is mostly contained completely within the state of Virginia and has a drainage area of approximately10,265mi^2, draining nearly ¼ of the state (VDGIF 2015, p.148). The headwaters (Potts Creek) originate along the Virginia/West Virginia state line; the Jackson and Cowpasture rivers flow through the Alleghany and Blue Ridge Mountains and join to form the James River near Iron Gate, VA and then flows east through the Piedmont and into the Coastal Plain of Virginia where it drains into the Chesapeake Bay at Hampton Roads, VA. Major tributaries include Craig Creek, and the Jackson, Cowpasture, Maury, Tye, Chicahominy, Rivanna, and Appomattox rivers. The James River connects Lynchburg, Richmond, and Newport News, thus making it an important east-west transportation route (Radford University 2014). The James River Basin and its tributaries have excess nutrients and sediment, pollutants that cause a wide variety of problems in the river and streams and serve as indicators of other forms of pollution such as bacteria and toxins (JRA 2015, entire). Sources of these types of pollution are wastewater, agricultural runoff, and urban stormwater runoff (JRA 2015, entire). Based on the 2011 National Land Cover Data, the James River Basin has approximately 11% developed area, 14% agriculture, 4% wetlands, 5% grassland, and 63% forest. Development and population growth are centered around Lynchburg, Richmond, Petersburg, and Norfolk, VA.

Figure 3-3 Atlantic Pigtoe James River Population



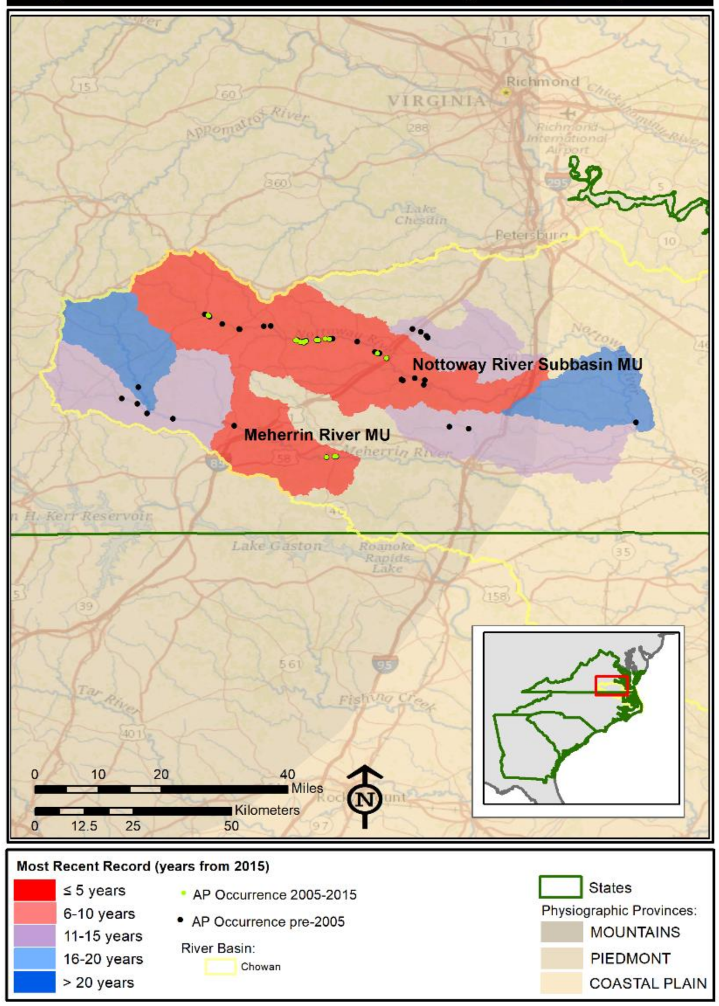
Update: pink HUC in Middle James MUs should be purple

The James River Population consists of six MUs, hereafter referred to as the Craig Creek Subbasin, Mill Creek, Rivanna River, Upper James River, Middle James River, and Appamattox River. The majority of surveys described the abundance of Atlantic Pigtoes as "rare", however a few surveys in the Craig Creek Subbasin in the mid-2000s had some "common" abundances with up to 50 individuals observed and documentation of reproduction (e.g., "juveniles present") as recent as 2006 (see Appendix A). The Rivanna River MU was once considered a stronghold for the species, but Atlantic Pigtoes have not been seen in that MU for 18 years (Alderman and Alderman 2014, p.21).

3.2.2 Chowan River Population

Basin Overview: The Chowan River Basin has a drainage area of approximately 4,800mi^{2}with over 3,200 miles of rivers and streams. The Chowan River headwaters, which include the major tributaries the Meherrin, Nottoway, and Blackwater rivers, originate in southeastern Virginia, and the Chowan River forms at the North Carolina-Virginia border where the Blackwater and Nottoway rivers meet. The Chowan River then flows southeast across the Coastal Plain of North Carolina broadening to nearly two miles wide where it meets the Albemarle Sound near Edenton, NC. In the past decade, the Nottoway River suffered from several seasonal low flow events which not only caused very low dissolved oxygen conditions, but also decreased food delivery because of minimal flows; furthermore, increased predation rates on potential host fishes were concentrated into low-flow refugia (VDGIF 2010, p.12). The Emporia Dam on the Meherrin River provides water to the city of Emporia, VA and is also used for hydroelectric power generation (VDGIF website 2016). Based on the 2011 National Land Cover Data,the Chowan River Basin has approximately 14% developed area, 26% agriculture, 2% wetlands, 1% grassland, and 53% forest.   While predominantly grassland and forest, some development and population growth are centered around Emporia and Franklin, VA and Murfreesboro, NC.

Figure 3-4 Atlantic Pigtoe Chowan Population

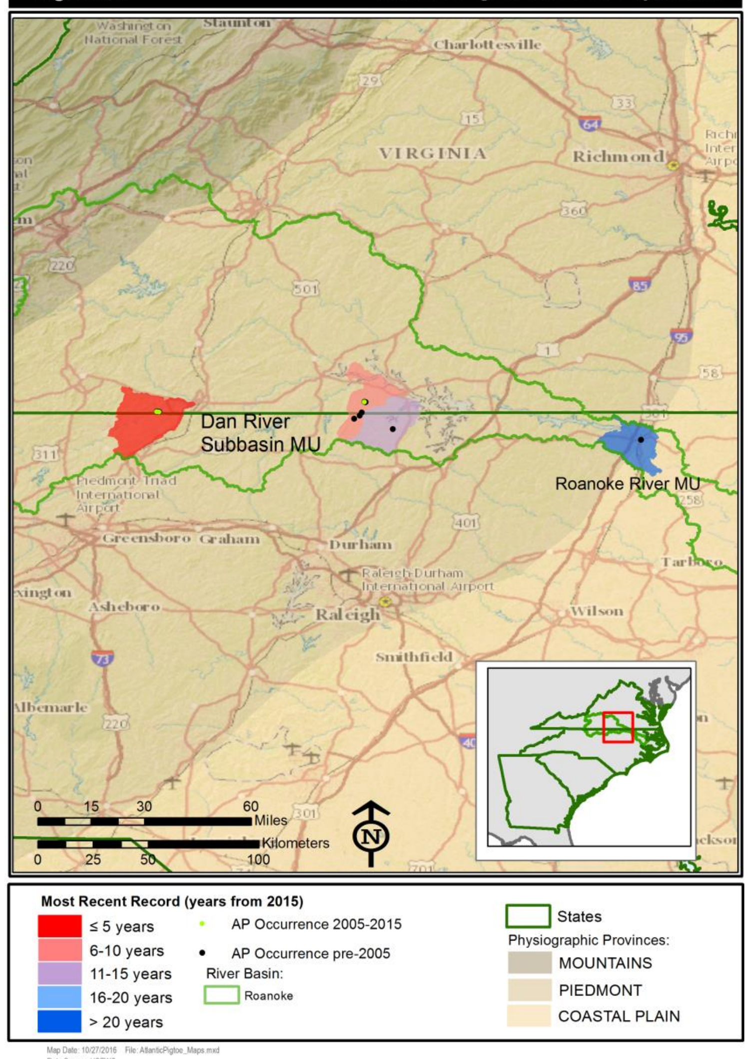


The Chowan River population consists of two MUs, herafter referred to as the Nottoway River Subbasin and the Meherrin River. Atlantic Pigtoe abundances were once recorded as “common” in the Nottoway Subbasin and “rare” in the Meherrin, however abundances have declined and the species has not been seen since 2015 in Sturgeon Creek of the Nottoway Subbasin, a former stronghold for the species (Alderman and Alderman 2014, p.21)

3.2.3 Roanoke River Population

Basin Overview: The Roanoke River Basin has a drainage area of approximately 3,493mi^2 with over 2,200 miles of rivers and streams (NCDENR 2013d, p.1). The headwaters of the Roanoke River originate in the Blue Ridge Mountains of southwestern Virginia and the river (and one of its major tributaries, the Dan River) flows southeast into North Carolina through the Piedmont and Coastal Plain until it reaches the Albemarle Sound. Frequent and serious flooding in the first half of the 20th century prompted the construction of a string of dams creating multiple reservoirs (Kerr Lake, Lake Gaston, Roanoke Rapids Lake) that have submerged over 82 miles of the Roanoke River (NCDENR 2013d, p.3). Interbasin transfers for water supplies to urban centers like Virginia Beach, VA and Raleigh, NC divert many million gallons of water from the basin daily. Pollution levels for dioxin, selenium, mercury and uranium are at such high levels that fish consumption advisories are numerous (NCDENR 2013d, p.5). The invasive plant Hydrilla has been a serious problem in the Roanoke River Basin since the 1990s (NCDENR 2013d, p.4). Based on the 2011 National Land Cover Data, the Roanoke River Basin has approximately 7% developed area, 21% agriculture, 5% wetlands, 11% grassland, and 54% forest. Development and population growth are centered around Roanoke and Danville in Virginia, and Eden, Roanoke Rapids, and Williamston in North Carolina.

Figure 3-5 *Atlantic Pigtoe Roanoke Population*

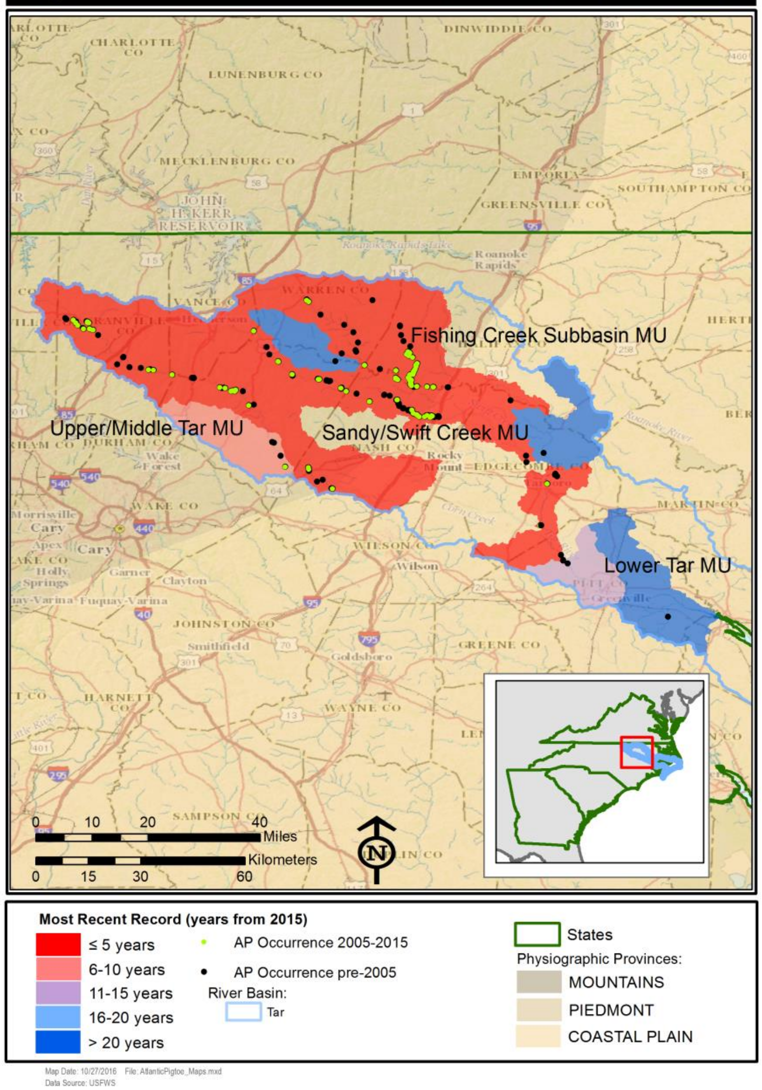


The Roanoke River population consists of two MUs, hereafter referred to as Dan River Subbasin and Roanoke River. The Roanoke River only has historical records, and all surveys from the Dan River Subbasin document the Atlantic Pigtoe as “rare”; the species was most recently seen in the Dan River in 2017, and in Little Grassy Creek in 2018.

3.2.4 Tar River Population

Basin Overview: The Tar-Pamlico River Basin is contained completely within the state of North Carolina and has a drainage area of approximately 6,148mi^2 with over 2,500 miles of rivers and streams (NCDENR 2013e, p.1). The headwaters of the Tar River originate in the Piedmont of central North Carolina in Person, Granville and Vance counties, and the river flows southeast through the Coastal Plain until it reaches tidal waters near Washington where it becomes the Pamlico River and empties into the Pamlico Sound. The entire basin is classified as Nutrient Sensitive Waters (NSW), meaning excessive amounts of nitrogen and phosphorus run off the land or are discharged into the waters, thus the basin has a special nutrient management plan to help reduce nutrients that cause excessive growth of microscopic or macroscopic vegetation and lead to extremely low levels of dissolved oxygen in the water (NCDENR 2013e, p.3). Based on the 2011 National Land Cover Data, the Tar-Pamlico River Basin has approximately 7% developed area, 29% agriculture, 23% wetlands, 12% grassland, and 27% forest. Development and population growth are centered around the municipalities of Greenville, Rocky Mount, and Washington and in rural areas within commuting distance to Raleigh.

Figure 3-6 Atlantic Pigtoe Tar Population

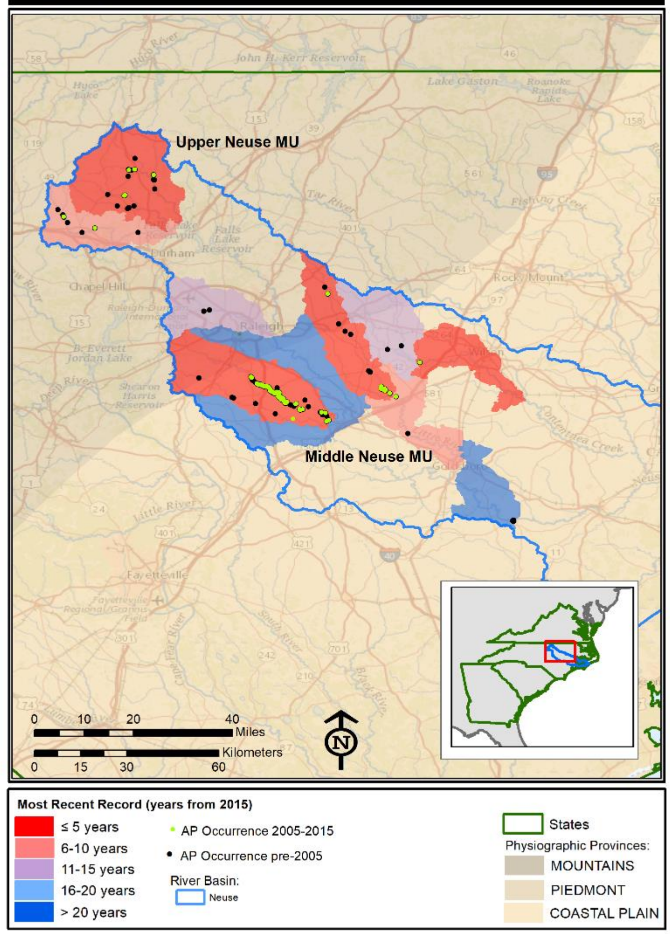


The Tar River population consists of four MUs, hereafter referred to as Upper/Middle Tar River, Lower Tar River, Fishing Creek Subbasin, and Sandy-Swift Creek (see Appendix A for more details). Many survey efforts have documented the presence of Atlantic Pigtoe over the years; the species was first seen in 1974 in the Tar River and it has been documented as recently as 2016 in Swift Creek. Most survey efforts document under 10 individuals, although as many as 38 live individuals have been seen in one survey (Little Fishing Creek in 2014). Evidence of recruitment is often observed in the Fishing Creek Subbasin and Sandy/Swift MUs.

3.2.5 Neuse River Population

Basin Overview: The Neuse River Basin is contained completely within the state of North Carolina and has a drainage area of approximately 6,062mi^2 with over 3,400 miles of rivers and streams (NCDENR 2013c, p.1). The headwaters of the Neuse River originate in the piedmont of central North Carolina in Person and Orange counties, and the river flows southeast through the Coastal Plain until it reaches tidal waters near New Bern where it empties into the Pamlico Sound. Major tributaries include Crabtree, Swift, and Contentnea Creek and the Eno, Little, and Trent rivers. Like the Tar River Basin, the Neuse River Basin is classified as NSW due to large quantities of nutrients (especially nitrogen) contributed by fertilizers and animal waste washed from lawns, urban developed areas, farm fields, and animal operations (NCDENR 2013c, p.3). In addition, more than 400 permitted point source sites discharge wastewater into streams and rivers in the basin (NCDENR 2013c, p.4). Based on the 2011 National Land Cover Data, the Neuse River Basin has approximately 13% developed area, 28% agriculture, 21% wetlands, 12% grassland, and 25% forest. Development and population growth are centered around the Triangle (primarily Durham and Raleigh) and the municipalities of Smithfield and Kinston. The Neuse River Basin contains one-sixth of the entire state's population (NCDENR 2013c, p.1), and increased development pressure has increased stormwater runoff, contributing to the basin's pollution and flow issues.

Figure 3-7 ***Atlantic Pigtoe Neuse Population***

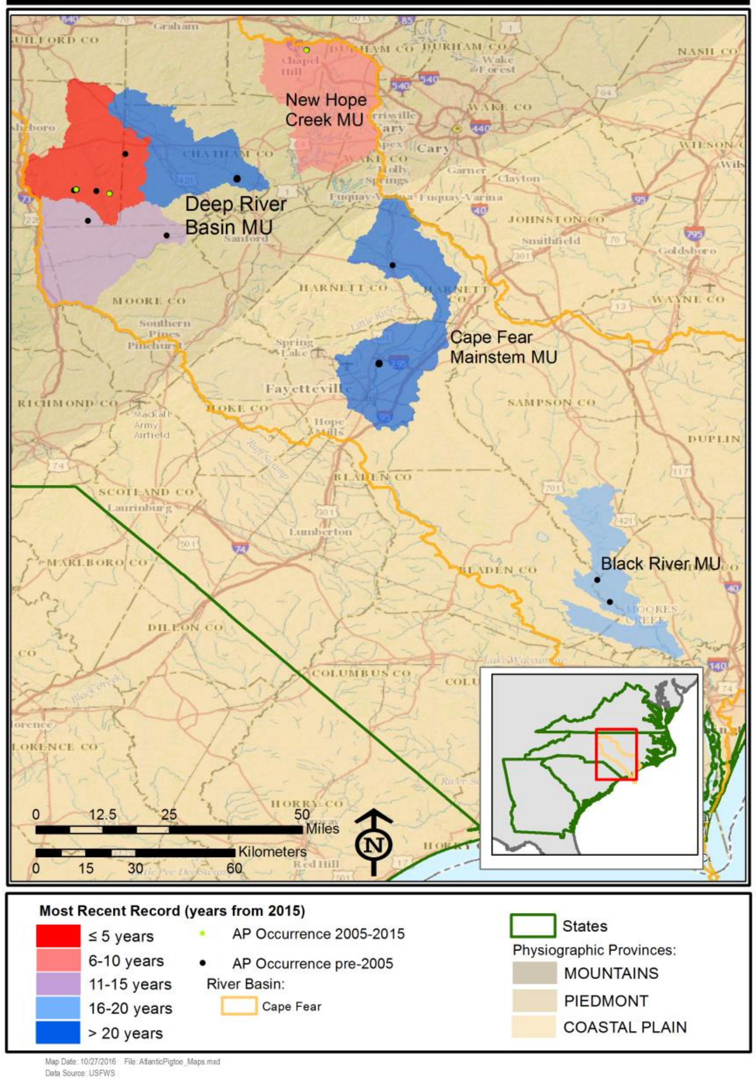


The Neuse River population consists of two MUs, hereafter referred to as the Upper Neuse River Basin and the Middle Neuse River Basin. The Atlantic Pigtoe was first seen in the Middle Neuse MU in 1983, and most recently was documented in 2016. Most surveys in the Middle Neuse MU report very low numbers observed (usually less than five live individuals or just shell material), although the species has been documented in higher numbers in the Upper Neuse MU, with 22 seen in one survey effort in the Eno River (1995) and 28 observed in the South Flat River (2001). There have been recent (2014-2016) intensive surveys in the Swift Creek watershed, and 62 live Atlantic Pigtoes have been observed.

3.2.6 Cape Fear River Population

Basin Overview: The Cape Fear River Basin is contained completely within the state of North Carolina and has a drainage area of approximately 9,164mi^2 with over 6,500 miles of rivers and streams (NCDENR 2013a, p.1). The headwaters of the Cape Fear River originate in the Piedmont of central North Carolina in Guilford, Rockingham, Caswell, and Alamance counties, and the river flows southeast through the Coastal Plain until it reaches the Atlantic Ocean near Wilmington. Major tributaries include the Deep, Haw, Black, and Northeast Cape Fear rivers. The basin has 33 reservoirs, many of them supplying water to some of the most populated areas in the state, including the Triad (Greensboro & High Point), Chapel Hill, Fayetteville, and Wilmington. The Cape Fear River Basin contains one-fifth of the entire state's population (NCDENR 2013a, p.1). The Cape Fear River Basin is the most industrialized basin in NC, and it also is home to the most large-scale livestock operations in the state (NCDENR 2013a, p.4). Based on the 2011 National Land Cover Data, the Cape Fear River Basin has approximately 12% developed area, 21% agriculture, 18% wetlands, 16% grassland, and 33% forest.

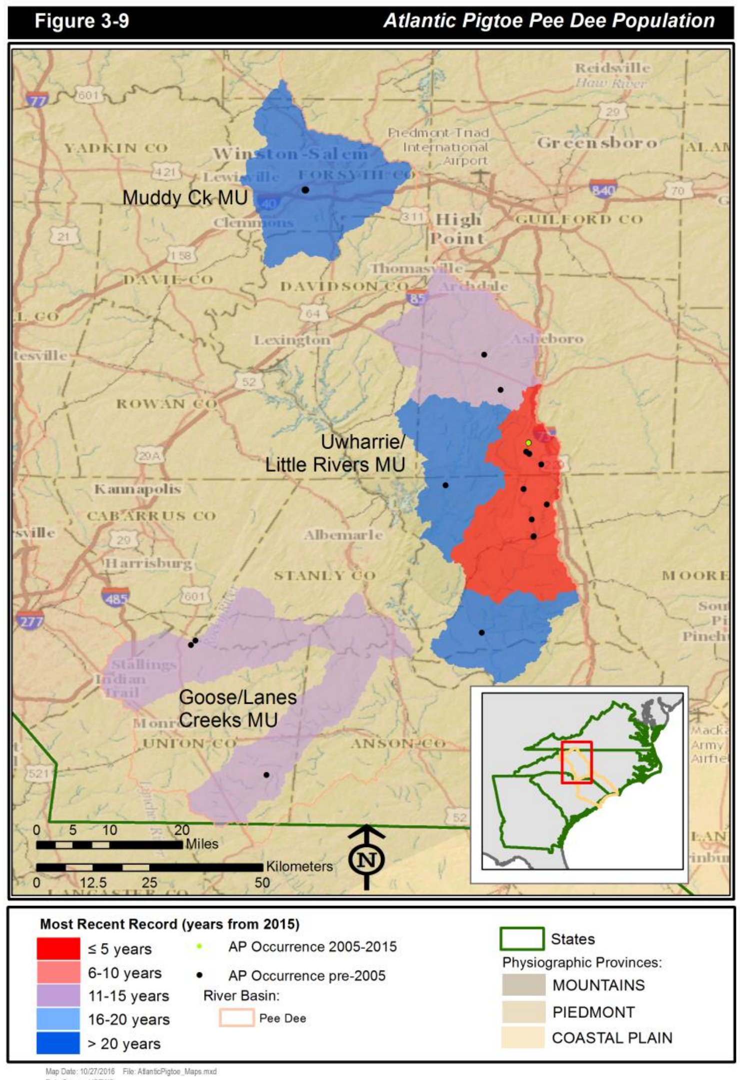
Figure 3-8 Atlantic Pigtoe Cape Fear Population



The Cape Fear River population consists of four MUs, hereafter referred to as New Hope Creek, Deep River Subbasin, mainstem Cape Fear, and Black River. Atlantic Pigtoes have only recently been observed in the Deep River Subbasin and the New Hope Creek MUs. A mark-recatpture study in New Hope Creek in 2001-2006 found 9 individuals over 14 intensive surveys of a 15x9m study area.

3.2.7 Pee Dee River Population

Basin Overview: The Yadkin-Pee Dee River Basin has a drainage area of approximately 9500mi^2 with approximately 8,000 miles of rivers and streams . The headwaters originate in the Blue Ridge Mountains near Blowing Rock, where the Yadkin River flows 203 miles east and then south across the Piedmont and Sandhills of North Carolina where it becomes the Pee Dee River below Lake Tillery and then flows 230 miles through South Carolina's Coastal Plain to the Winyah Bay east of Georgetown, SC where it meets the Atlantic Ocean (NCDENR 2013f, p.1). Major tributaries include the Yadkin, Uwharrie, Rocky, Lumber, Waccamaw, Little Pee Dee, and Lynches rivers. In North Carolina, there are seven man-made reservoirs on the mainstem – W. Kerr Scott, High Rock, Tuckertown, Badin, Falls, Tillery, and Blewett Falls - that were built in the first half of the 20th century to power aluminum smelters and electric utilities (NCDENR 2013f, p.2). Sedimentation from intensive agriculture and urban development is the top pollution problem in the basin. Based on the 2011 National Land Cover Data, the upper Yadkin-Pee Dee River Basin has approximately 13% developed area, 25% agriculture, 1% wetlands, 8% grassland, and 52% forest. The basin drains the urban landscapes of Winston-Salem, Statesville, Lexington, Salisbury, and part of Charlotte, NC, as well as Florence, Sumter, and Georgetown, SC.



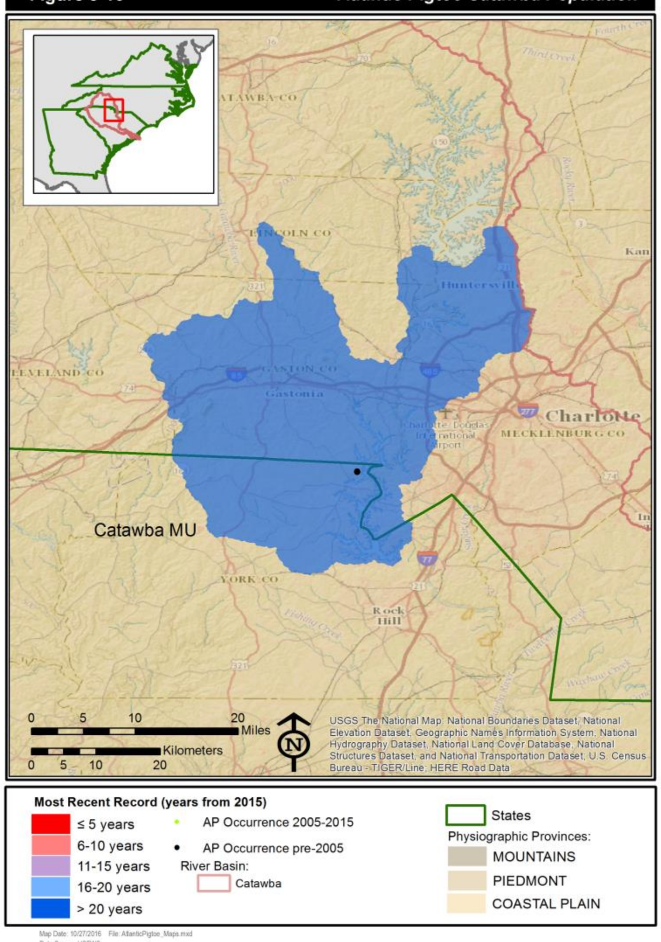
The Pee Dee population consists of three MUs, hereafter referred to as Muddy Creek, Uwharrie/Little rivers, and Goose/Lanes creeks. The species was first observed in the Uwharrie/Little rivers MU in 1987 and most recently in 2010. Most survey efforts document one or two individuals, with six being the most documented in one effort in the Little River (2010). Harvard Museum of Comparative Zoology has a specimen from the "Yadkin River" (MCZ376121).

3.2.8 Catawba River Population (*Presumed extirpated*)

Basin Overview: In North Carolina, the Catawba River has a drainage of approximately 3,285mi^2 with over 9,300 miles of rivers and streams. The headwaters begin in the Blue Ridge Mountains in McDowell County and then the river flows east, then south through the Piedmont into Lake Wylie on the North Carolina-South Carolina border. The river then flows south and becomes the Wateree River and eventually joins the Congaree River to form the Santee River in the Coastal Plain in South Carolina. Most of the river exists as a chain of seven man-made lakes, which provide electric power and water supply to expanding cities (NCDENR 2013b, p.1). Like many of the other river basins in North Carolina, the Catawba River Basin suffers from nutrient and contaminant pollution as well as explosive urban growth. Based on the 2011 National Land Cover Data, the Catawba River Basin has approximately 15% developed area, 14% agriculture, 7% wetlands, 10% grassland, and 51% forest. Development and population growth are centered around Hickory, Gastonia, and Charlotte in North Carolina.

Only one shell of an Atlantic Pigtoe has been observed in the Catawba River in the 1800s (Alderman and Alderman 2014, p.19), thus this population is presumed extirpated.

Figure 3-10 Atlantic Pigtoe Catawba Population



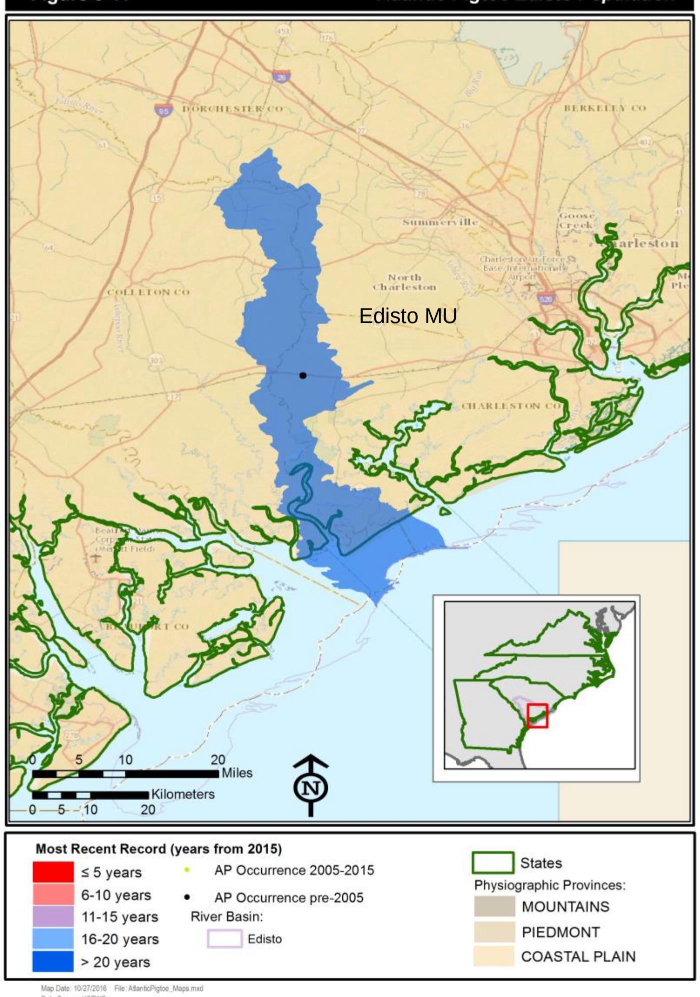
SOUTH CAROLINA

3.2.9 Edisto River Population (*Presumed extirpated*)

Basin Overview: The Edisto River has a drainage of approximately 3,151mi^2, with over 5,177 miles of rivers and streams extending across the Coastal Plain of South Carolina. The confluence of Chinquapin Creek and Lightwood Knot Creek form the North Fork Edisto River; the South Fork Edisto River drains Shaw Creek, Dean Swamp Creek, Goodland Creek, and Roberts Swamp before merging with the North Fork Edisto River to form the Edisto River. The Edisto River is one of the longest free-flowing blackwater rivers in North America, flowing over 250 miles completely within South Carolina. The Edisto River Basin has approximately 6% developed area, 34% agriculture, 21% wetlands, and 38% forest. The Edisto system flows through only one major city, Orangeburg.

Five shells of Atlantic Pigtoe from the Edisto River were discovered in a museum collection in Switzerland, dating back to the 1800s (A.Bogan (NCMS) email to S.McRae (USFWS) on 5/26/2016). This population is also presumed extirpated.

Figure 3-11 Atlantic Pigtoe Edisto Population

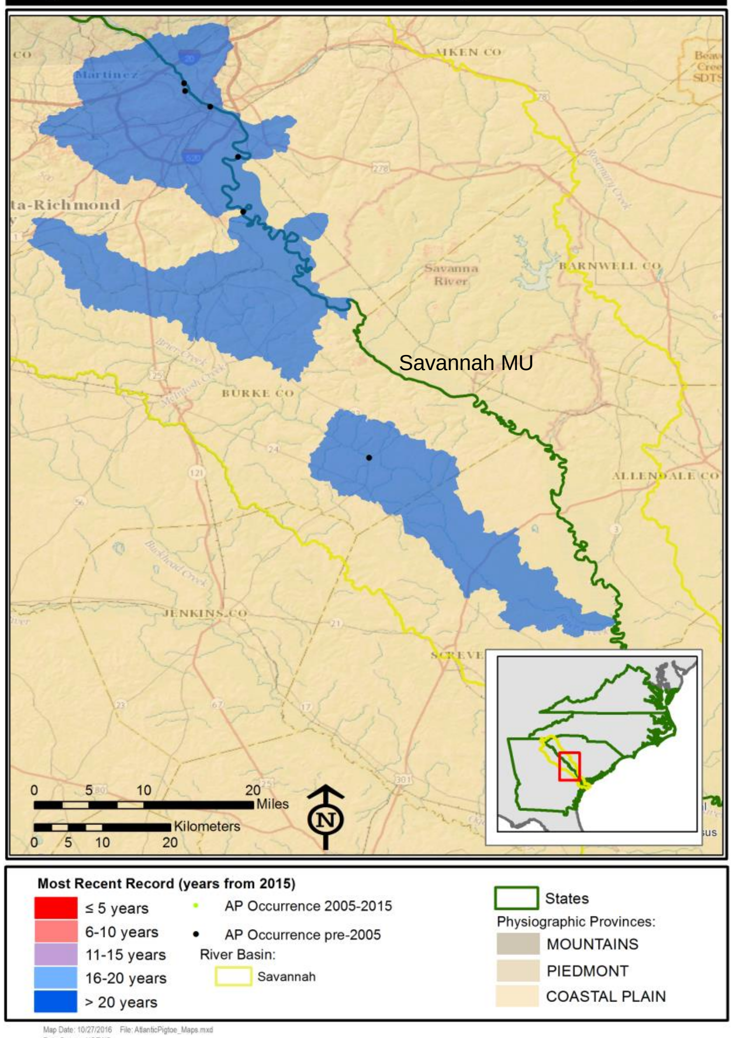


GEORGIA

3.2.10 Savannah River Population (*Presumed extirpated*)

Basin Overview: The Savannah River has a drainage of approximately 10,580mi^2, and it forms the state boundary between South Carolina and Georgia. The headwaters originate in the Blue Ridge Mountains of North Carolina, South Carolina, and Georgia near Ellicott Rock, the point where the three states meet. In the western part of the upper basin, the Chattooga and Tallulah rivers join in Lake Tugalo, South Carolina to form the Tugaloo River; in the eastern part of the upper basin, the confluence of Twelve Mile Creek and the Keowee River form the Seneca River. Near Hartwell, SC, the Tugaloo River joins with the Seneca River to form the Savannah River which flows southeast through the Georgia Coastal Plain to the Atlantic Ocean. The Savannah River provides drinking water to more than 1.5 million people in Augusta and Savannah, Georgia, and Hilton Head and Beaufort, South Carolina as well as many smaller municipalities in the basin. Based on the 2011 National Land Cover Data, the Savannah River Basin has approximately 10% developed area, 13% agriculture, 11% wetlands, 14% grassland, and 48% forest.

Figure 3-12 Atlantic Pigtoe Savannah Population

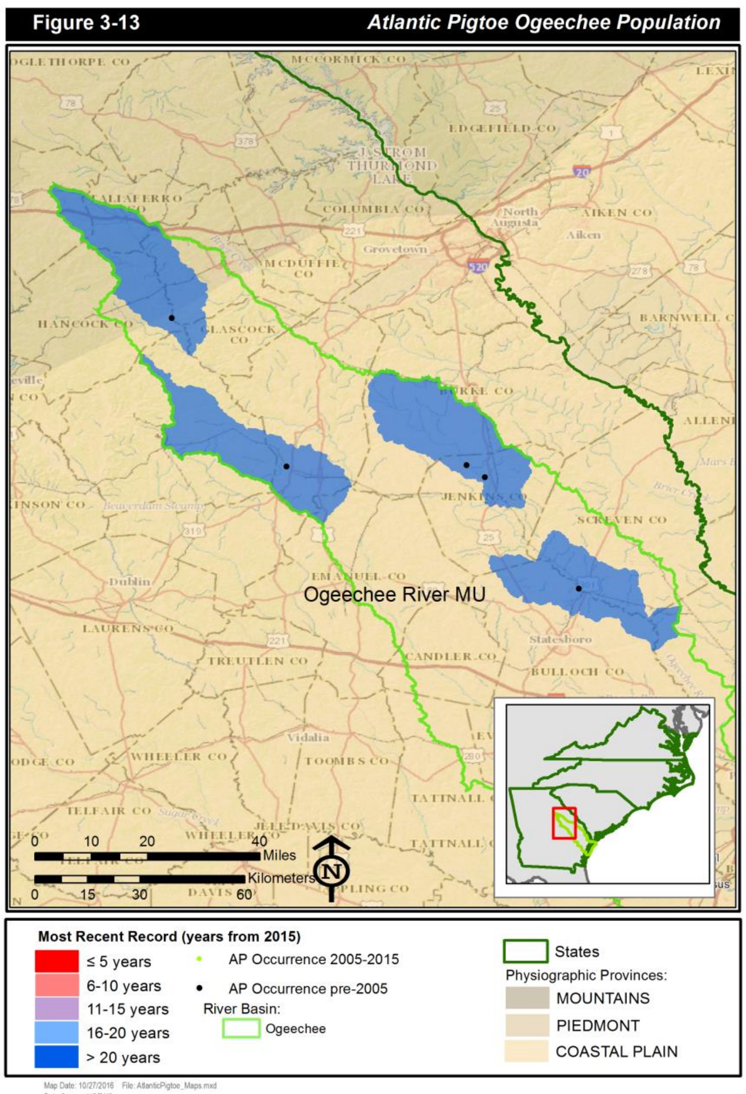


In 1834, the type specimen (i.e., the specimen from which the original species description was made) was collected from the Savannah River near Augusta, Georgia. Dive surveys in 2006 collected specimens of what were thought to be Atlantic Pigtoes (Wisniewski 2008, p.2), although further review of the specimens were confirmed to be *Ellipios,* not Atlantic Pigtoes (J.Alderman (AES) email to S.McRae (USFWS) on 9/24/2016; J.Wisniewski (GADNR) email to B.Forbus (USFWS) on 12/7/2016). Recent surveys have not been able to document the species, thus this population is presumed extirpated (J.Wisniewski (GADNR) email to B.Forbus (USFWS) on 12/7/2016).

3.2.11 Ogeechee River Population (*Presumed extirpated*)

Basin Overview: The Ogeechee River has a drainage of approximately 5,540mi^2. The headwaters are the North and South Fork Ogeechee rivers which join in the Piedmont of Georgia to form the Ogeechee River which flows southeast through the Coastal Plain to the Ossabaw Sound and the Atlantic Ocean just south of Savannah, GA. The Ogeechee is a free-flowing stream, with no major impoudments or reservoirs, and its largest tributary is the Canoochee River. Forestry is the predominant industry in the Ogeechee River Basin. Based on the 2011 National Land Cover Data, the Ogeechee River Basin has approximately 7% developed area, 16% agriculture, 32% wetlands, 15% grassland, and 29% forest.

The Atlantic Pigtoe was first observed in the Ogeechee River Basin in the 1970s, and the most recent observation of a live individual was in the early 1990s (four live individuals were collected from Williamson Swamp Creek by Alderman and McGrath (Alderman (AES) email to S.McRae (USFWS) on 12/6/2016). Several surveys in the mid-2000s failed to document the species, thus the population is presumed extirpated.

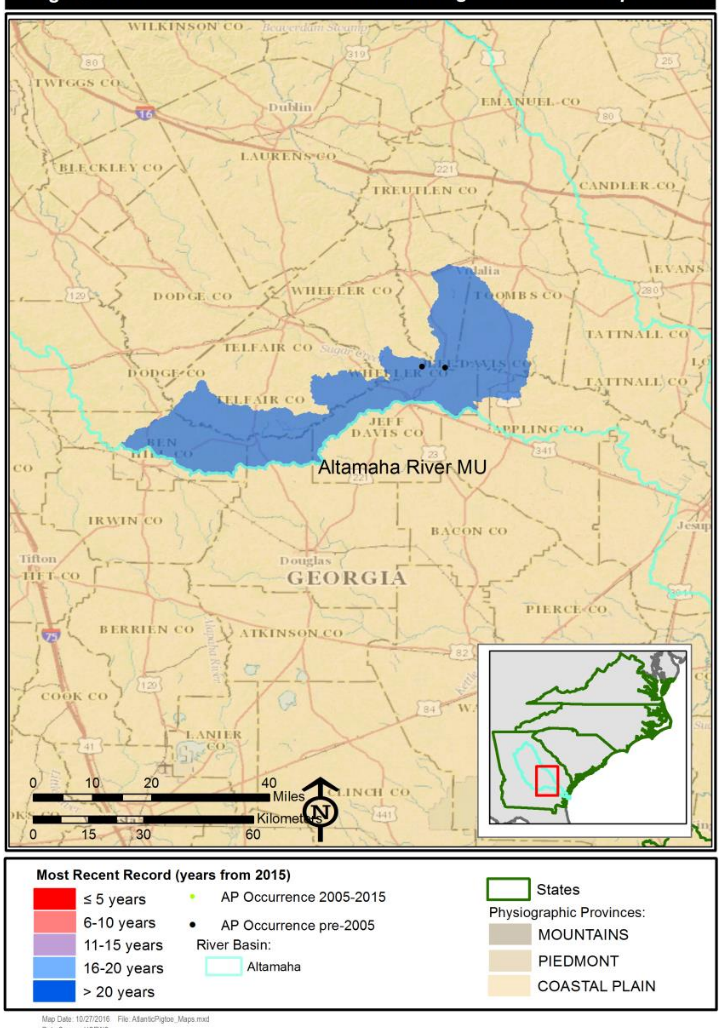


3.2.12 Altamaha River Population (*Presumed extirpated*)

Basin Overview: The Altamaha River has a drainage of approximately 14,000mi^2, draining nearly ¼ of the state of Georgia, and one of the larger river basins on the Atlantic Seaboard. The headwaters are the Oconee and Ocmulgee rivers which join to form the Altamaha River near Lumber City, Georgia and the river flows southeast through the Coastal Plain to join the Atlantic Ocean near Brunswick, GA. The Altamaha River is the largest free-flowing river on the East Coast. The river supports thermoelectric (coal and nuclear) power, livestock use, irrigation, municipal and industrial wastewater treatment, and hydroelectric power and agriculture dominates the landscape in the basin (GARN website 2016). Based on the 2011 National Land Cover Data, the Altamaha River Basin has approximately 11% developed area, 15% agriculture, 14% wetlands, 10% grassland, and 42% forest.

Two shells from the 1800s have documented the historical occurrence of the Atlantic Pigtoe in the Altamaha River Basin (Alderman and Alderman 2014, p.19).

Figure 3-14 ***Atlantic Pigtoe Altamaha Population***



3.3 Needs of the Atlantic Pigtoe

As discussed in Chapter 1, for the purpose of this assessment, we define viability as the ability of the species to sustain populations in the wild over time (in this case, 50 years). Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (the 3Rs, Figure 3-11). Using various time frames and the current and future characterization of the 3Rs, we thereby describe the species' level of viability over time.

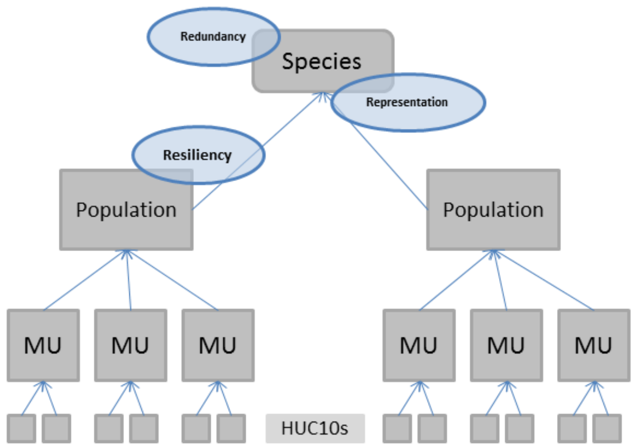


Figure 3-11 Resiliency is measured at the population level, representation is measured at the species and, possibly, population level, and redundancy is measured at the species level (after Fig 4, USFWS 2016a). MU=Management Unit; HUC10 = Hydrologic Unit

3.3.1 Atlantic Pigtoe MU Resiliency

As previously described, Atlantic Pigtoe populations were delineated at the river basin level, while MUs were defined at the finer geographic-level of HUC10 watersheds that encompass historically or currently documented occupied habitat. Note that MUs may be made up of one or more HUC10 watersheds, depending on the distribution of the species (see Section 2 and Appendix A). Because the river basin level was determined to be too coarse of a scale at which to estimate the condition of factors influencing resiliency, MUs were used to evaluate this metric. Given the hierarchical nature of the relationship between MUs, populations, and species (Figure 3-11), we first consider resiliency at the level of an MU, then scale up to populations, and, ultimately, make inferences at the species-level.

Resiliency (measured at the population level) is the foundational building block of the 3R SSA Framework; thus, for the Atlantic Pigtoe to be viable, some proportion of MUs must be resilient enough to withstand stochastic events. Stochastic events that have the potential to affect mussel populations include high flow events, droughts, pollutant discharge failures, and sediment pulses. Given the data available, the metrics that were used to assess resiliency were categorized as population factors (MU occupancy over time, approximate abundance, and recruitment) and habitat elements (water quality, water quantity, habitat connectivity, and instream substrate) (Appendix C). In the next section, we discuss the methods used to estimate resiliency metrics, and we explore potential causal relationships between resiliency and mussel habitat requisites (see Figure 3-13).

Population Factors that Influence Resiliency

Management Unit Occupancy - The known historical and current distribution of the species within HUC10 watersheds was used to document MU Occupancy. Atlantic Pigtoe presence was compiled from survey data made available by state agency databases. Those surveys involved tactile or visual (viewbucket, snorkel, or surface air-supply systems in deeper (>4ft) waters) methods to detect mussels. Most surveys involved timed searches where species were identified, counted, checked for gravidity, and, in some cases, the presence of juveniles was noted. Most mussels were returned to the river post-identification, although some were retained for propagation.

Approximate Abundance – During stream surveys, mussel abundance was recorded as either a qualitative approximation (e.g., "common" or "rare") or an actual count of the number of mussels observed in the survey location (e.g., density in a mussel bed). For most surveys, quantitative measures of density were not available and qualitative approximations were only sporadically documented. More often, surveyors recorded the number of live individuals or dead shells observed at a location. Thus, we used the cumulative record of the total number of live individuals and dead shells observed within a MU to provide an approximate estimate of abundance within MUs. We considered MUs with recent (≤ 10 years) documentation of high approximate abundance to be resilient. High approximate abundance was defined as cumulative counts of over 300 individuals observed over the period of record, or more than 100 live individuals observed over the past 10 years (Table 3-4). Pandolfo (2016, p.1671) approximated Atlantic Pigtoe detection probability to be 0.42 (95% CI, 0.36-.047), although this measure was derived by borrowing information from species associates and was the value for all species in the assemblage. Since our abundance estimates did not account for detection probability, the approximate abundances should be considered conservative. That is, Atlantic Pigtoes may have been present but not detected during some surveys, and we did not use an estimate of detection probability to account for these occasions.

Reproduction and Recruitment **-** While measures of population size reflect past influences on the mussel resiliency, reproduction and recruitment reflect where the population may be headed. For example, dense mussel beds containing only older, senescent (less-reproductive) individuals may be more susceptible to extirpation because they have few young individuals to sustain the population into the future. Conversely, less dense mussel beds containing many young and/or gravid individuals may be likely to grow more dense, thus sustaining the population into the future.

Detection of very young juvenile mussels during surveys happens extremely rarely due to sampling bias (Shea et al. 2013, p.383). Because mussel surveys involve underwater, tactile and visual searches, mussels less than 20mm are difficult to detect (Wisniewski et al. 2013, p.239; Alderman and Alderman 2014, p.31; USFWS 2016, p.22). While we do not have specific estimates of detection for juvenile Atlantic Pigtoes, detection probability for the species has been approximated to be 0.42 (Pandolfo 2014, p.46). To this end, sampling methods used to estimate reproduction involved repeatedly capturing small-sized individuals near the low end of the detectable size range (~20mm) and by capturing gravid females during the reproductively active time of year (generally, March – August). It should be noted that records of reproduction/recruitment were not consistently documented for all surveys; thus, they should be considered to represent the low end on a spectrum of uncertainty (i.e., it is possible that reproduction occurred but was not documented).

Habitat Elements that Influence Resiliency

Physical, biological, and chemical processes influence habitat types present within streams, which in turn determine the abundance and diversity of species present. In the case of the Atlantic Pigtoe, breeding, feeding, and sheltering needs such as successful host fish infestation and dispersal, adequate food delivery, and suitable stable habitat are all needs influenced by water quality, water quantity, and suitable in-stream (substrate) habitat and habitat connectivity (Figure 3-13). See Chapter 4 for further discussion about the many factors that influence the conditions of these habitat elements.

<u>Water Quality</u> - As sessile, benthic filter-feeders, mussels are particularly sensitive to poor water quality (Haag 2012, p. 355). Suitable habitat for mussels includes streams that have un-altered thermal regimes, average pH, low salinity, and negligible chemical pollution. As required by section 303(d) of the Clean Water Act, all waters that do not meet standards for the designated use of a particular waterbody (e.g., to support/protect aquatic life) are placed on the Impaired Streams List. Water quality metrics that reflect aquatic impairment include (but are not limited to): low bioassessment scores, low dissolved oxygen (DO) levels, low/high pH values, high nutrient inputs, and high levels of fecal coliform bacteria. For this assessment, the number and mileage of impaired stream reaches (as designated by state Water Quality programs), as well as the number of National Pollutant Discharge Elimination System (NPDES) point discharges were used to characterize water quality within a given MU. Since every stream is not assessed for impairment, the mileage of impaired stream reaches should be considered a conservative estimate of impairment for each MU.

<u>Water Quantity</u> - Optimal habitats for Atlantic Pigtoes are perennial streams with continuous, year-round flow. While mussels can survive low flows and (random) periodic drying events, intermittent stream habitats cannot support mussel populations.

Because a lotic environment is a critical need for the Atlantic Pigtoe, perturbations that disrupt natural discharge regimes have a potential negative influence on Atlantic Pigtoe resilience metrics. Atlantic Pigtoe habitat must have adequate flow to deliver oxygen, enable passive reproduction, and deliver food to filter-feeding mussels (see Table 2-1). Further, flow removes contaminants and fine sediments from interstitial spaces preventing mussel suffocation. Stream velocity is not static over time, and variations may be attributed to seasonal changes (with higher flows in winter/spring and lower flows in summer/fall), extreme weather events (e.g., drought or floods), and/or anthropogenic influence (e.g., flow regulation via impoundments).

While mussels have evolved in habitats that experience seasonal fluctuations in discharge, global weather patterns can have an impact on the normal regimes (e.g., El Niño or La Niña). Even during naturally occurring low flow events, mussels can become stressed either because they exert significant energy to move to deeper waters or they may succumb to desiccation. Because low flows in late summer and early fall are stress-inducing, droughts during this time of year may result in stress and, potentially, an increased rate of mortality. Recent information (Sound Rivers Inc. (SRI) public comment letter for Yellow Lance proposed listing to USFWS, 6/5/2017) surmised the median minimum monthly flows for three time periods starting in 1940 have been declining during most months of the year. The declines are slight starting in February, accelerate during May through August, and reach a maximum decline in median minimum flows in October when comparing data from the period 1940 – 1962 with data from 1986 – 2008 (SRI letter to USFWS, 6/5/2017). The flow declines can be related back to growth that leads to increased water use, diversion, and loss of groundwater that recharges the river system; such declining minimum flows can negatively affect stream temperatures, dissolved oxygen levels, nutrient processing, substrate composition, and numerous other parameters, which in turn affect species richness and abundances (SRI letter to USFWS, 6/5/2017).

To understand whether Atlantic Pigtoe populations were subject to droughts during low flow times of the year (late summer, early fall), we compiled a series of US Drought Monitor graphics. These were used to assess flow conditions during the first week of September during years 2000 to 2015 to identify times that mussels were exposed to consecutive droughts (see Figure 3-12 below).

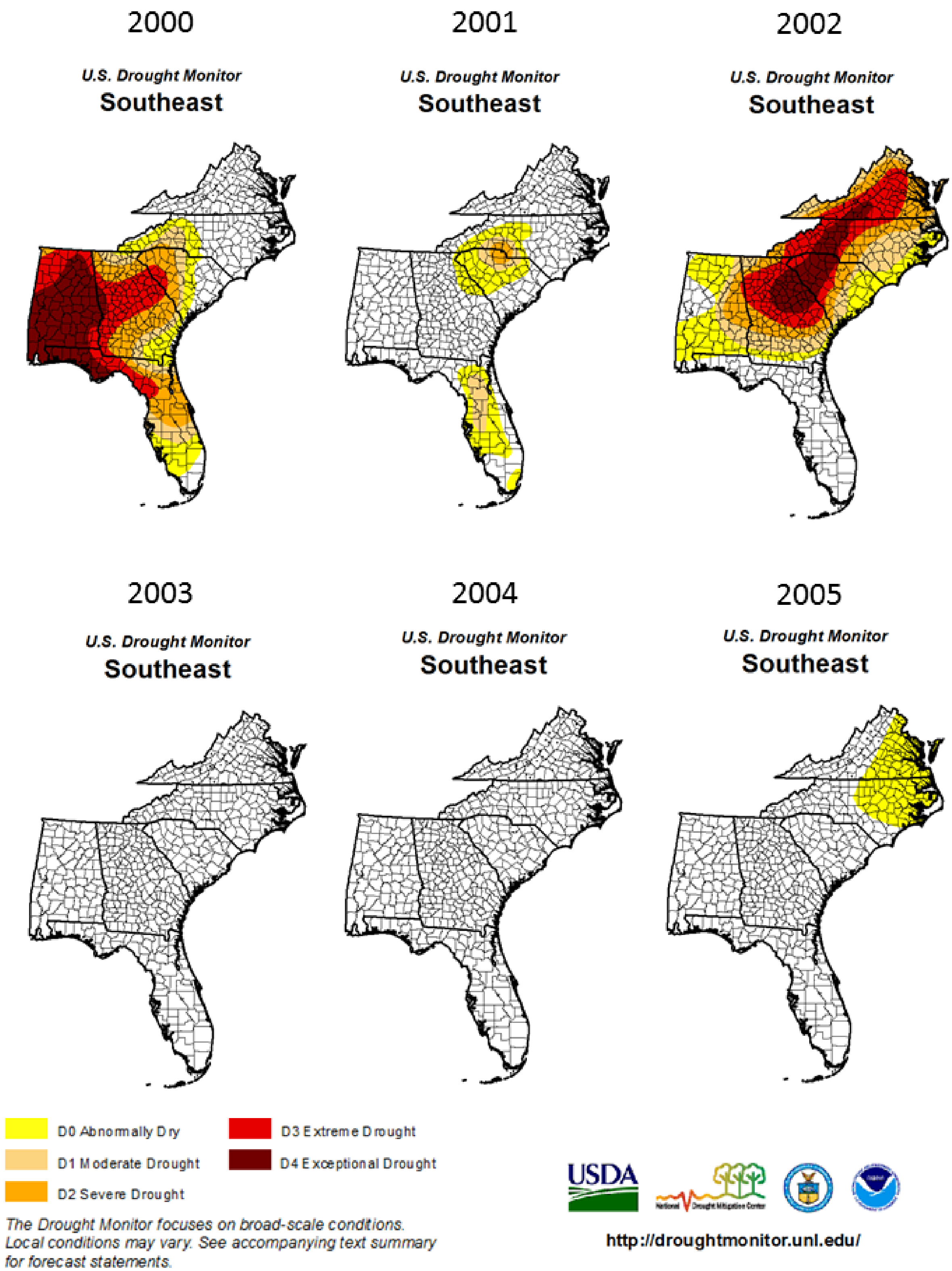


Figure 3-12 Southeast Drought Monitor annual images for 1st week in September

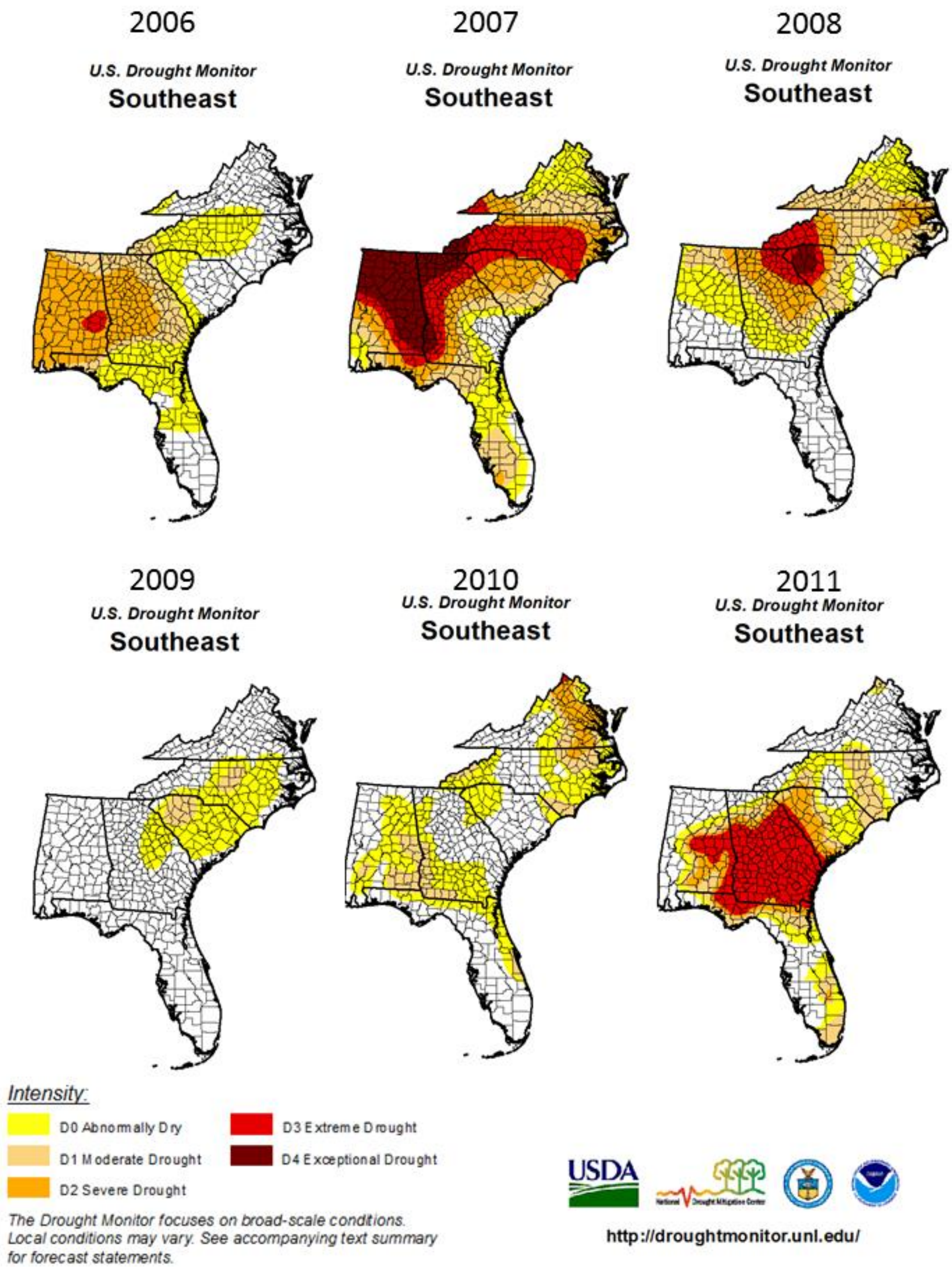


Figure 3-12 (cont) Southeast Drought Monitor annual images for 1st week in September

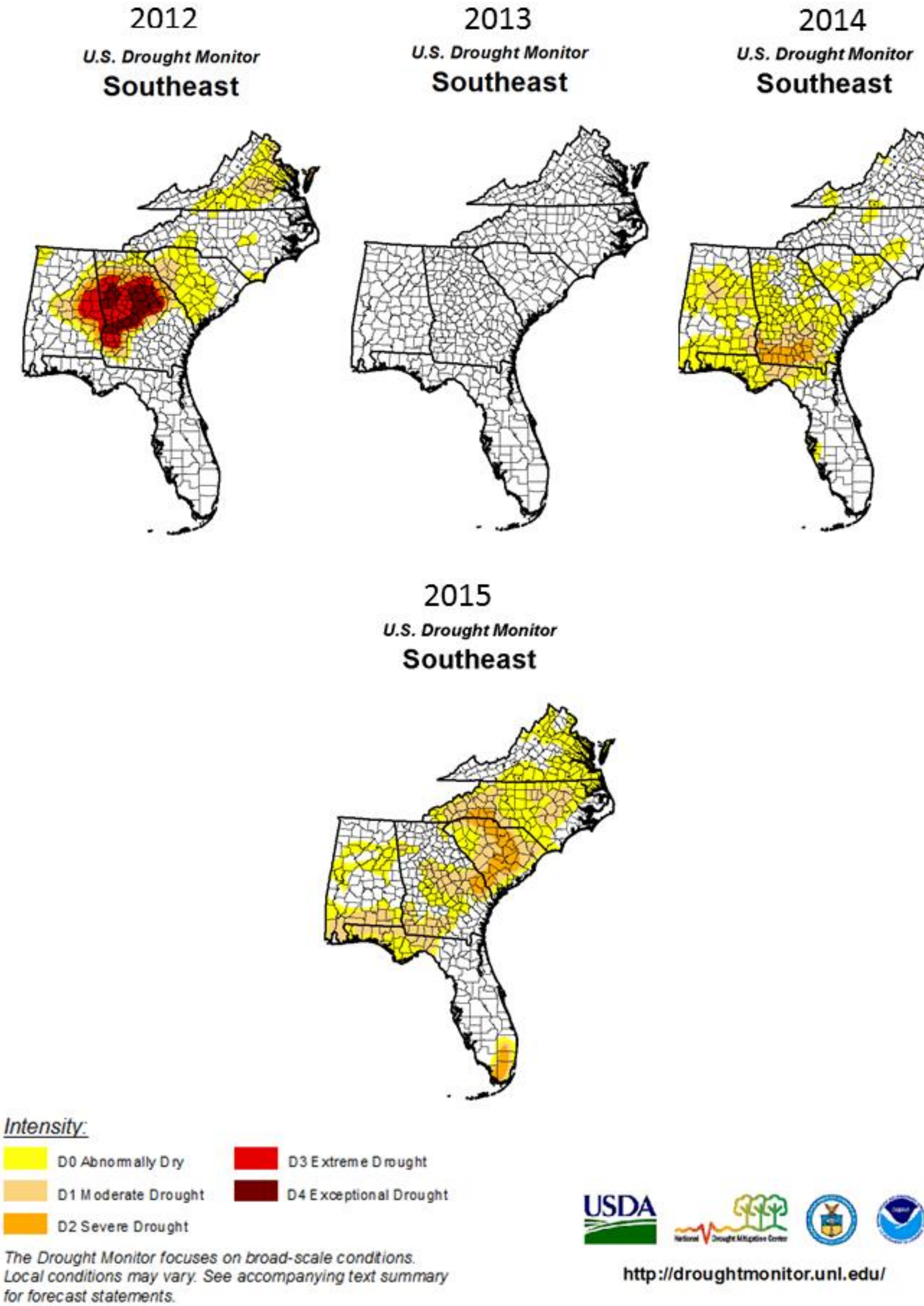


Figure 3-12 (cont) Southeast Drought Monitor annual images for 1st week in September

Substrate - Optimal substrate for the Atlantic Pigtoe is predominantly silt-free, stable sand, gravel, and cobble benthic habitat. Riparian condition strongly influences the composition and stability of substrates that mussels inhabit (Allan et al. 1997, p.149). Streams with urbanized or agriculturally dominated riparian corridors are subject to increased sediment-loading from unstable banks and/or impervious surface run-off, resulting in less suitable in-stream habitat for mussels as compared to habitat with forested corridors (Allan et al. 1997, p.156). For this assessment, we considered the stream-side riparian condition (as delineated by the Active River Area (ARA; Smith et al. 2008, entire) as an indicator of in-stream habitat condition. Rather than a fixed-width riparian buffer, the spatial extent of an ARA is defined by physical and ecological processes in areas of dynamic connection and interaction between the water and land through which it flows (Smith et al. 2008, p.1).

Habitat Connectivity - The fragmentation of river habitat by dams and other aquatic barriers (like perched or undersized culverts) is one of the primary threats to aquatic species in the U.S. (Martin and Apse 2014, p.7). Dams (whether man-made or nature-made (e.g., from beavers or windthrow)) have a profound impact on in-stream habitat as they can change lotic systems to lentic systems. Moreover, fragmentation by dams or culverts generally involves loss of access to quality habitat for one or more life stages of freshwater species. In the case of mussels, fragmentation can result in barriers to host fish movement which, in turn, may impact mussel distributions. Mussels that use smaller host fish (e.g., darters and minnows) are more susceptible to impacts from habitat fragmentation due to increasing distance between suitable habitat patches and low likelihood of host fish swimming over that distance (C.Eads (NCSU) email to S.McRae (USFWS) on 10/28/2016). Barriers to movement can cause isolated or patchy distributions of mussels which may limit both genetic exchange and recolonization (e.g., after a high flow, scouring event). To assess the influence of factors affecting habitat connectivity in Atlantic Pigtoe watersheds, we considered the number of dams from the US Army Corps of Engineers' (US ACE) National Inventory of Dams (NID) as well as the number of road crossings affecting Atlantic Pigtoe habitat at the HUC10 scale (see Section 4.1 below).

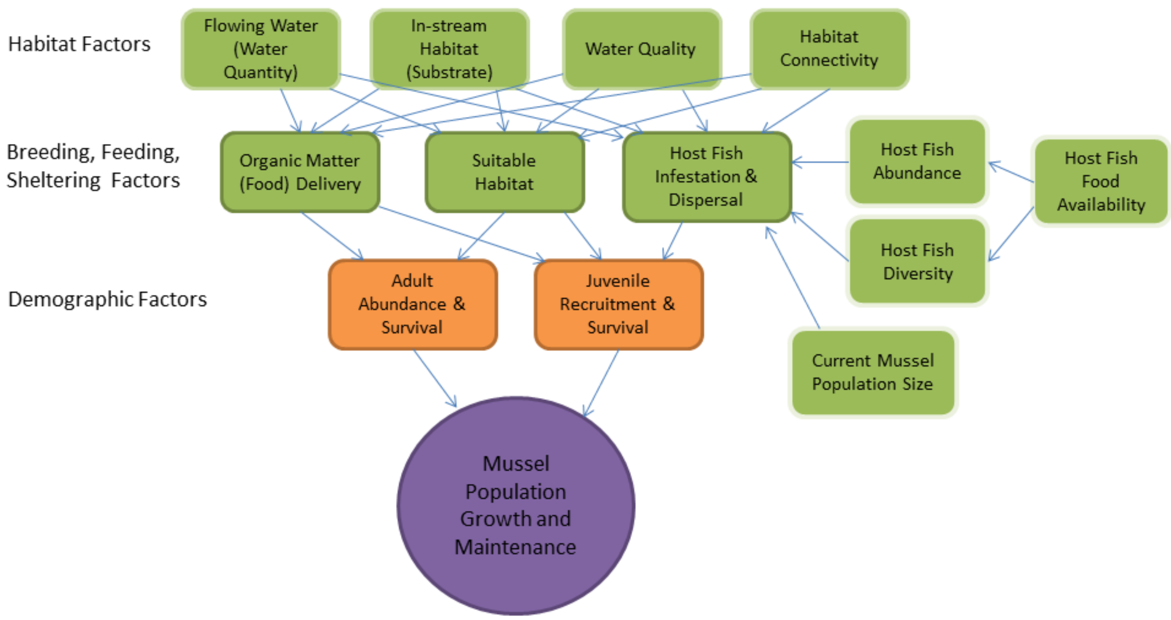


Figure 3-13 Atlantic Pigtoe Ecology: Influence diagram illustrating how habitat factors influence breeding, feeding, and sheltering factors, which in turn affect demographic factors that ultimately drive mussel population growth and maintenance. Diagram was developed by a group of freshwater mussel experts and substantiated from literature.

3.3.2 Species Representation

Identifying and evaluating representative units that contribute to a species' adaptive potential are important components of assessing overall species' viability (Shaffer and Stein 2000, entire; USFWS 2016b, p.23). This is because populations that are distributed throughout multiple representative units may buffer a species' response to environmental changes over time. Representation for the Atlantic Pigtoe can be described in terms of River Basin Variability, Physiographic Variability, and Latitudinal Variability. Below we examine these aspects of the historic and current distribution of the Atlantic Pigtoe and identify potential causal effects for changes in representation over time.

River Basin Variability – River Basin variability for the Atlantic Pigtoe has been reduced from 12 to seven river basins (Table 3-1); thus, the species has lost approximately 42% of River Basin Variability. However, it should be noted that this is a relatively conservative estimate of loss as variability for each population is largely represented by just one or two HUCs per MU (Table 3-2 below), and several of the populations have fewer than 60 individuals documented in the past 10 years (Table 3-1).

Table 3-1 Atlantic Pigtoe Basin Varibility:

Population (River Basin)	# of Historically Occupied MUs	# of Currently Occupied MUs	Total # of Live Individuals 2005-2015
James	6	2	173
Chowan	2	2	58
Roanoke	2	1	3
Tar	4	4	696
Neuse	2	2	265
Cape Fear	4	2	27
Pee Dee	3	1	10
Catawba	1	0	0
Edisto	1	0	0
Savannah	1	0	0
Ogeechee	1	0	0
Altamaha	1	0	0

Physiographic Variability - The Atlantic Pigtoe is found in three physiographic provinces – the Mountains, Piedmont, and Coastal Plain, with the largest proportion of their range (historically) in the Piedmont > Coastal Plain > Mountains (Figure 3-14). Monitoring data indicate precipitous declines in occurrence in all three physiographic regions. A 76% decline in occurrence was estimated in the Coastal Plain Province, a 48% decline in the Piedmont, and a 67% decline in the Mountains (Figure 3-14). The species has declined from its once much larger presence in the Coastal Plain, and has been reduced by nearly half in the Piedmont. Finally, the only remaining occurrence of Atlantic Pigtoe in the Mountain physiographic region is in Craig Creek, part of the James River Basin in Virginia.

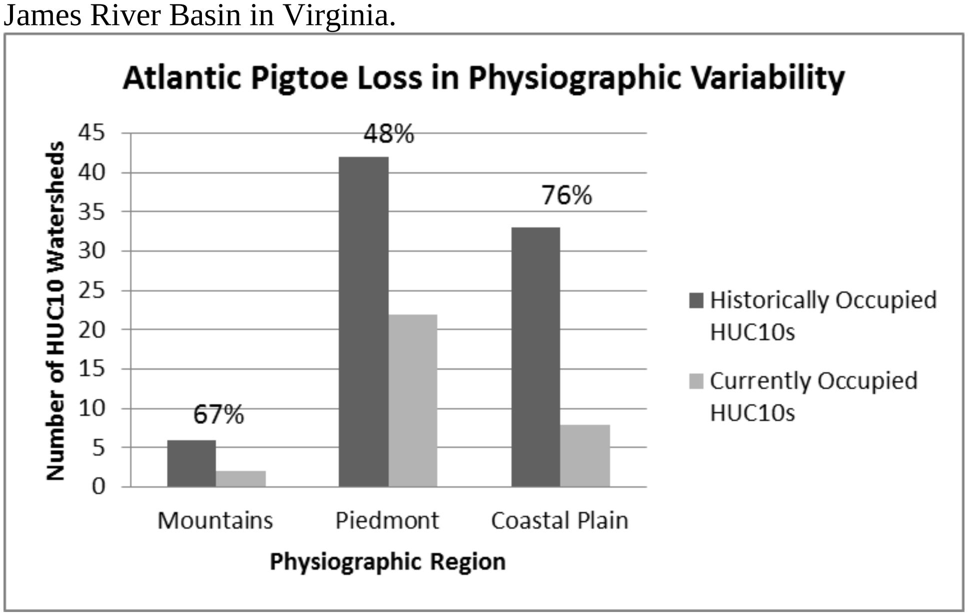


Figure 3-14 Change in physiographic variability for Atlantic Pigtoe. Percentages are the proportion lost from historically occupied HUC10s to currently occupied HUC10s.

Latitudinal Variability - Historically, the Atlantic Pigtoe occurred contiguously in perennial streams from Virginia to Georgia. Based on recent data, occurrences have become patchy in distribution and it appears as though the range of the Atlatnic Pigtoe has been contracted to the central basins within its former range, being extirpated from the southern portion of its range and nearly extirpated from the northern watersheds (Figure 3-15).

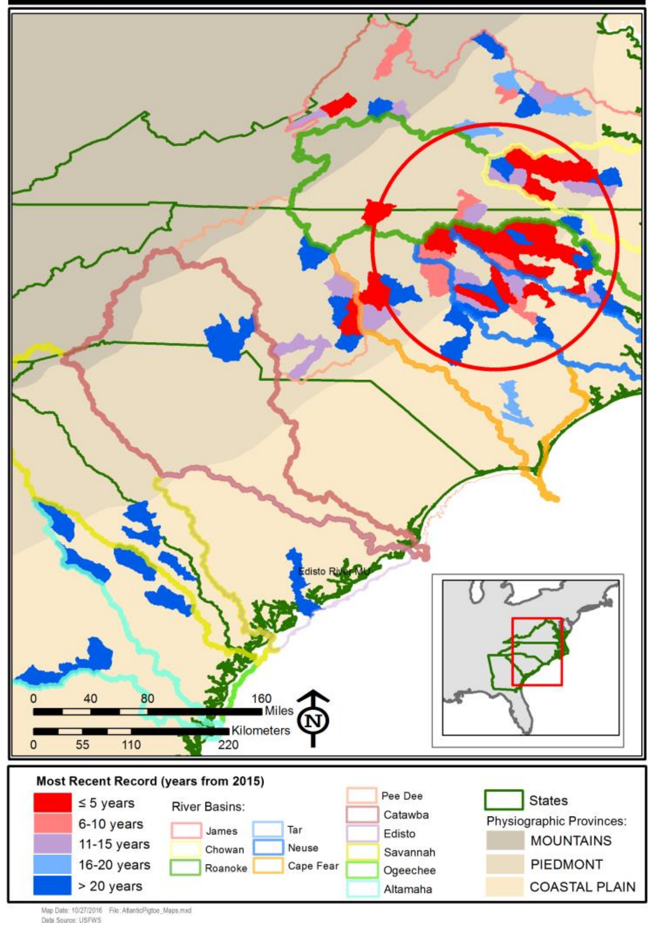


Figure 3-15 Atlantic Pigtoe Contraction of Range

Summary

As evaluated through the lens of river basin, physiographic province, and latitudinal variability, the contemporary distribution of Atlantic Pigtoe reflects a considerable loss in historic representation. Because representation is an indirect measure of a species' adaptive potential, this trend is concerning in terms of the ability of the species to respond to a changing environment. Later, we discuss the implications of a potential continued loss in representation.

3.3.3 Species Redundancy

Redundancy reduces the risk that a large portion of the species' range will be negatively affected by a natural or anthropogenic catastrophic event at a given point in time. Species that have resilient populations spread throughout their historical range are less susceptible to extinction (Carroll *et al.* 2010, entire; Redford *et al.* 2011, entire). Thus, high redundancy for Atlantic Pigtoe is defined as multiple resilient populations (inclusive of multiple, resilient MUs) distributed throughout the species' historical range. That is, highly resilient populations, coupled with a relatively broad distribution, have a positive relationship to species-level redundancy. Evidence indicates that Atlantic Pigtoe populations were once much more broadly distributed throughout their historical range (Figure 3-1). However, several factors, including impoundments and unsuitable water quality have resulted in population fragmentation (see Chapter 4), making repopulation of extirpated locations unlikely without human intervention.

We assessed Atlantic Pigtoe redundancy by first evaluating occupancy within each of the hydrologic units (i.e., HUC10s) that constitute MUs, and then we evaluated occupancy at the MU and ultimately the population levels. This assessment revealed that of the 81 HUC10s historically occupied by Atlantic Pigtoe, only 32 (40%) are currently occupied (Table 3-2). Note that current occupancy was defined as the observation of at least one Atlantic Pigtoe during surveys conducted from 2005 to 2015. Of those 32 HUC10s that were counted as occupied, only 19 had more than one observation during that 10-year sample period (Table 3-2). At the level of MUs, 13 are likely extirpated, 10 have experienced between an estimated 29-75% decline, and only five have experienced no decline. As a result, six populations (James, Chowan, Roanoke, Tar, Neuse, and Cape Fear) retain redundancy in the form of more than one HUC10 occupied, however, only two populations (Tar and Neuse) have multiple moderate or highly resilient MUs (Table 3-5), thus limiting overall redundancy for the species.

Table 3-2 Atlantic Pigtoe occupancy changes over time. Historical occupancy represents detections that occurred from 1966 to 2005, while current occupancy represents a sample period from 2005 to 2015. Note: MUs can be made up of one or more HUC10 watersheds, depending on the distribution of the species (see Section 3.3.1).

Population/ Management Unit	# Historically Occupied HUC10s	# Currently Occupied HUC10s	% Decline	Total # of Live Individuals 2005-2015
James	**12**	**2**	**83**	
Craig Ck Subbasin[+]	2	1	50	172
Mill Ck	1	1	0	1
Rivanna	2	0	100	0
Upper James	2	0	100	0
Middle James	4	0	100	0*
Appomattox	1	0	100	0
Chowan	**11**	**6**	**45**	
Nottoway[+]	7	5	29	56
Meherrin[+]	4	1	75	2
Roanoke	**4**	**2**	**50**	
Dan R Subbasin[+]	3	2	33	3
Roanoke	1	0	100	0
Tar	**15**	**11**	**27**	
Upper/Middle Tar[+]	5	5	0	82
Lower Tar	3	1	66	3
Fishing Ck Subbasin[+]	5	3	40	532
Sandy Swift Ck[+]	2	2	0	79

Population/ Management Unit	# Historically Occupied HUC10s	# Currently Occupied HUC10s	% Decline	Total # of Live Individuals 2005-2015
Neuse	**13**	**7**	**46**	
Upper Neuse[+]	3	3	0	24
Middle Neuse[+]	10	4	60	241
Cape Fear	**7**	**2**	**71**	
New Hope[+]	1	1	0	24
Deep R Subbasin	3	1	66	3
Cape Fear Mainstem	2	0	100	0
Black	1	0	100	0
Pee Dee	**7**	**1**	**86**	
Muddy Ck	1	0	100	0
Uwharrie/Little	4	1	75	10
Goose/Lanes	2	0	100	0
Catawba	3	0	**100**	0
Edisto	1	0	**100**	**0**
Savannah	2	0	**100**	0
Ogeechee	4	0	**100**	0
Altamaha	2	0	**100**	0

*shell observed; see p.A107

+ Management Units containing HUCs with more than one observation in past 10 years

3.4 Current Conditions

The results of surveys conducted from 2005 to 2015 suggest that the currently occupied range of the Atlantic Pigtoe includes 14 MUs from seven populations in Virginia and North Carolina, however only three populations (Nottoway, Tar, and Neuse) have multiple documented occurrences within the past 10 years. The species is presumed extirpated from the southern portion of its range, including the Catawba, Edisto, Savannah, Ogeechee, and Altamaha River basins. For context, Table 3-3 shows the current species status as tracked by national and state entities who track conservation status of species:

Table 3-3 Current species status/ranks by other entities who track conservation status of Atlantic Pigtoe

Entity	Status/Rank	Notes	Reference
NatureServe	G2N2 (Imperiled)	Moderate geographic range but not highly reduced in umber of known extant occurrences	NatureServe 2015
IUCN	Endangered	Very high risk of extinction in the wild	IUCN 2001
American Fisheries Society (AFS)	Endangered		Williams et al., in press
Virginia	Threatened/S2 (Imperiled)		VADCR-NHP 2016
North Carolina	Endangered/S1 (Critically Imperiled)		NCNHP 2014
South Carolina	SH (Historical)		NatureServe 2015
Georgia	Endangered/S1 (Critically Imperiled)		GADNR 2016b

3.4.1 Current MU/Population Resiliency

Methodology

To summarize the overall current conditions of Atlantic Pigtoe MUs, we sorted them into five categories (high, moderate, low, very low, and extirpated (ø)) based on the population factors and habitat elements discussed in Section 3.3.1 above (Table 3-4). MUs assessed include those areas where the species is presumed to be extirpated to portray the difference between the historical and current condition of the species. The current condition category is a qualitative estimate based on the analysis of the three population factors (MU Occupancy, Approximate Abundance, and Recruitment) and four habitat elements (Water Quality, Water Quantity/Flow, Instream Substrate, and Habitat Connectivity). Overall population condition rankings and habitat condition rankings were determined by combining the three population factors and four habitat elements, respectively.

For example, for the Nottoway MU, given the categorical scale of: High – Moderate – Low – Very Low – ø (see Table 3-4), the overall Current Condition is estimated to be *Moderate*; the *High* MU Occupancy Condition combined with the *Low* Reproduction Condition is *Moderate* and when that is combined with the Moderate Approximate Abundance condition, the overall ranking becomes *Moderate*:

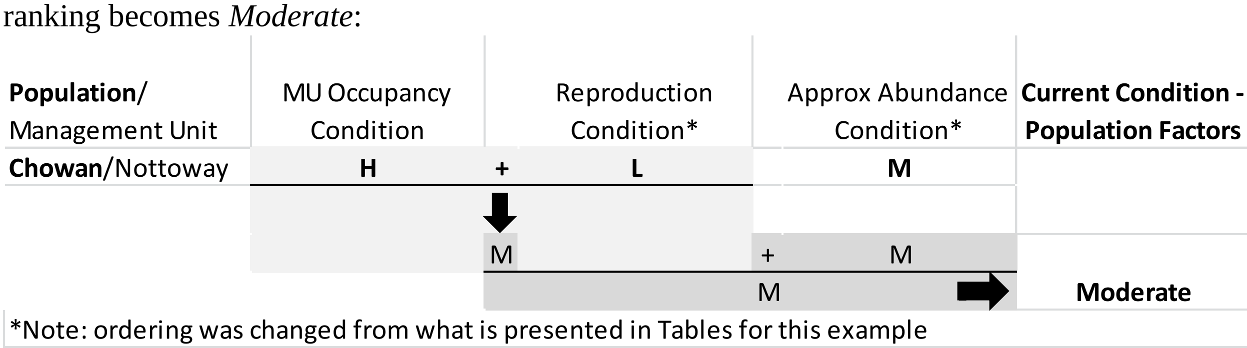


Figure 3-16 Current Population Condition calculation is determined by combining the three population factors (MU Occupancy Condition, Approximate Abundance Condition, and Reproduction Condition).

Note: When MU Occupancy Condition was estimated to be ø, this extirpated condition superseded all other category rankings and was assigned as the Population Condition.

For the Habitat Elements, the scale included the following categories: High – Moderate – Low – Very Low. For example, for the Meherrin MU, the overall Current Habitat Condition was determined by first combining the *Low* Water Quantity Condition with the *High* Connectivity

Condition to get *Moderate*; when this *Moderate* was then combined with the *Moderate* Water Quality Condition and *High* Instream Habitat Condition, the two *Moderate* ranks outweighed the *High* rank to get an overall Current Habitat Condition of *Moderate*:

Population/ Management Unit	Overall Water Quality Condition	Overall Water Quantity Condition		Overall Connectivity Condition		Overall Instream Habitat (Substrate) Condition	**Current Habitat Condition**
Chowan/Meherrin	**M**	**L**	**+**	**H**		**H**	
	M	+	M		+	H	
		M					**Moderate**

Figure 3-17 Current Habitat Condition calculation is determined by combining the four habitat elements (Water Quality Condition, Water Quantity Condition, Connectivity Condition, and Instream Habitat Condition)

Because population factors are direct indicators of Atlantic Pigtoe condition (Table 3-5), we weighed population factors (direct measures) two times higher than habitat elements (indirect measures) when estimating the summary Current Condition.

Table 3-4 Population and habitat characteristics used to create condition categories in Table 3-5.

Condition Category	POPULATION FACTORS: MU Occupancy Decline	POPULATION FACTORS: Approximate Abundance	POPULATION FACTORS: Reproduction	HABITAT ELEMENTS: Water Quality	HABITAT ELEMENTS: Water Quantity/Flow	HABITAT ELEMENTS: In-stream substrate	HABITAT ELEMENTS: Habitat Connectivity
High	<30% decline	Cumulative numbers at high end of known range (over 300 individuals observed over time); 100+ live individuals observed in past 10 years	More than 50% of sites with recent (past 10 years) documentation of reproduction (gravidity) or presence of small individuals	Very few (if any) known impairment or contaminant problems (<5 miles impaired streams; no major discharges, <10 non-major discharges)	Optimal flowing water conditions to remove fine sediments, allow for food delivery, and maximize reproduction; no known flow issues; isolated low flow/drought periods; not flashy flow regime	Predominantly natural (>70% forested) ARA; <6% impervious surfaces in HUC10 watershed	Very little (if any) known habitat fragmentation issues (<10 dams per MU; avg # of Road Crossings <300 per MU)
Moderate	31-50% decline	Moderate numbers (101 to 300) of individuals observed over time; 51-100 live individuals observed in past 10 years	25-50% of sites with recent documentation of reproduction or presence of small individuals	Impairment or contaminants known to be an issue, but not at a level to put population at risk of being eliminated (5-50 miles impaired streams; 1-3 major discharges; 10-25 non-major discharges)	Water flow not sufficent to consistently remove fine sediments, drying conditions which could impact both food delivery and successful reproduction; moderate flow issues, including 3 to 4 years of consecutive drought or moderately flashy flows	20-70% forested ARA; 6-15% impervious surfaces in HUC10 watershed	Some habitat fragmentation issues (10-30 dams per MU; Avg # of Road Crossings 300-500 per MU)
Low	51-70% decline	Low numbers (11-100) of individuals observed over time; 11-50 live individuals observed in past 10 years	Fewer than 25% of sites with documentation of recent reproduction or presence of small individuals	Impairment or contaminants at levels high enough to put the population at risk of being eliminated (>50 miles impaired streams; >4 major discharges; 25+ non-major discharges)	Water not flowing - either inundated or dry; severe flow issues; more than 4 consecutive years of drought; flashy flow regime	<20% forested ARA; >15% impervious surfaces in HUC10 watershed	Habitat severely fragmented (30+ dams in MU; 500+ Avg Road Crossings per MU)
Very Low	>70% decline	Very few (less than 10) individuals observed over time; 10 or fewer live individuals observed in past 10 years	Reproduction data are older than 10 years	Impairment or contaminant at levels that cannot support species survival	Flow conditions do not support species survival	Instream habitat unable to support species survival	Habitat extremely fragmented and unable to support species survival
Ø	Total Loss	Only shells observed over time (no live)	Population is extirpated or no data	N/A	N/A	N/A	N/A

Table 3-5 Resiliency of Atlantic Pigtoe populations. See Table 3-4 for condition categories.

	Population Factors				Habitat Elements					
Population/ Management Unit	**MU Occupancy**	**Approx Abundance**	**Reproduction**	**Combined Population Factors**	**Water Quality**	**Water Quantity**	**Connectivity**	**Instream Habitat (Substrate)**	**Combined Habitat Elements**	**Overall**
James				**Low**					**Moderate**	**Low**
Craig Ck Subbasin	Moderate	Moderate	Low	Moderate	Moderate	High	High	High	High	Moderate
Mill Ck	Ø	Very Low	Ø	Ø	High	Moderate	Moderate	High	Moderate	Ø
Rivanna	Ø	Very Low	Ø	Ø	Moderate	Low	Low	Moderate	Low	Ø
Upper James	Ø	Ø	Ø	Ø	High	Moderate	Moderate	High	Moderate	Ø
Middle James	Ø	Ø	Ø	Ø	Low	Low	Low	Moderate	Low	Ø
Appomattox	Ø	Low	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	Ø
Chowan				**Low**					**Moderate**	**Low**
Nottoway	High	Moderate	Low	Moderate	Low	Low	Low	Moderate	Low	Moderate
Meherrin	Very Low	Low	Low	Low	Moderate	Low	High	High	Moderate	Low
Roanoke				**Low**					**Moderate**	**Low**
Dan R Subbasin	High	Low	Low	Low	Low	Moderate	Low	Moderate	Moderate	Low
Roanoke	Ø	Ø	Ø	Ø	Moderate	Low	High	Moderate	Moderate	Ø
Tar				**High**					**Moderate**	**High**
Upper/Middle Tar	High	Moderate	High	High	Low	Low	Moderate	Moderate	Moderate	High
Lower Tar	Low	Low	Moderate	Low	Moderate	Moderate	Moderate	Low	Moderate	Low
Fishing Ck Subbasin	Moderate	High	High	High	Moderate	Moderate	High	Moderate	Moderate	High
Sandy Swift Ck	High	High	Moderate	High	High	Low	Moderate	Moderate	Moderate	High
Neuse				**Moderate**					**Low**	**Moderate**
Upper Neuse	High	Moderate	Moderate	Moderate	Low	Low	Low	Moderate	Low	Moderate
Middle Neuse	Low	High	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate
Cape Fear				**Low**					**Low**	**Low**
New Hope	High	Low	Low	Moderate	Low	Moderate	Low	Low	Low	Moderate
Deep R Subbasin	Low	Low	Low	Low	Low	Moderate	Low	Moderate	Low	Low
Cape Fear Mainstem	Ø	Very Low	Ø	Ø	Low	Moderate	Low	Moderate	Low	Ø
Black	Ø	Very Low	Ø	Ø	High	High	High	Low	High	Ø
Pee Dee				**Low**					**Low**	**Low**
Muddy Ck	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Uwharrie/Little	Very Low	Low	Low	Low	Moderate	Moderate	Low	High	Moderate	Low
Goose/Lanes	Ø	Very Low	Ø	Ø	Low	Low	Low	Moderate	Low	Ø
Catawba	**Ø**	**Ø**	**Ø**	**Ø**	**Low**	**Low**	**Low**	**Low**	**Low**	**Ø**
Edisto	**Ø**	**Ø**	**Ø**	**Ø**	**High**	**Moderate**	**High**	**Moderate**	**Moderate**	**Ø**
Savannah	**Ø**	**Very Low**	**Ø**	**Ø**	**Low**	**Low**	**Low**	**Low**	**Low**	**Ø**
Ogeechee	**Ø**	**Very Low**	**Ø**	**Ø**	**Moderate**	**Moderate**	**Low**	**Moderate**	**Moderate**	**Ø**
Altamaha	**Ø**	**Ø**	**Ø**	**Ø**	**Moderate**	**Moderate**	**Low**	**Moderate**	**Moderate**	**Ø**

Combined habitat elements, representing overall habitat condition, were high in two MUs, moderate in 14 MUs, and low in 12 MUs (Table 3-5). Combined population factors, representing a combination of occupancy, approximate abundance, and reproduction, was estimated to be high for three MUs, moderate for five MUs, low for six MUs, and extirpated for 14 MUs (Table 3-5). As noted in Section 3.3.1, both approximate abundances and recruitment should be considered conservative estimates.

At the population level, the overall current condition (= resiliency) was estimated to be high for the Tar Population, moderate for the Neuse Population, low for the James, Chowan, Roanoke, Cape Fear, and Pee Dee populations, and extirpated for the Catawba, Edisto, Savannah, Ogeechee, and Altamaha populations.

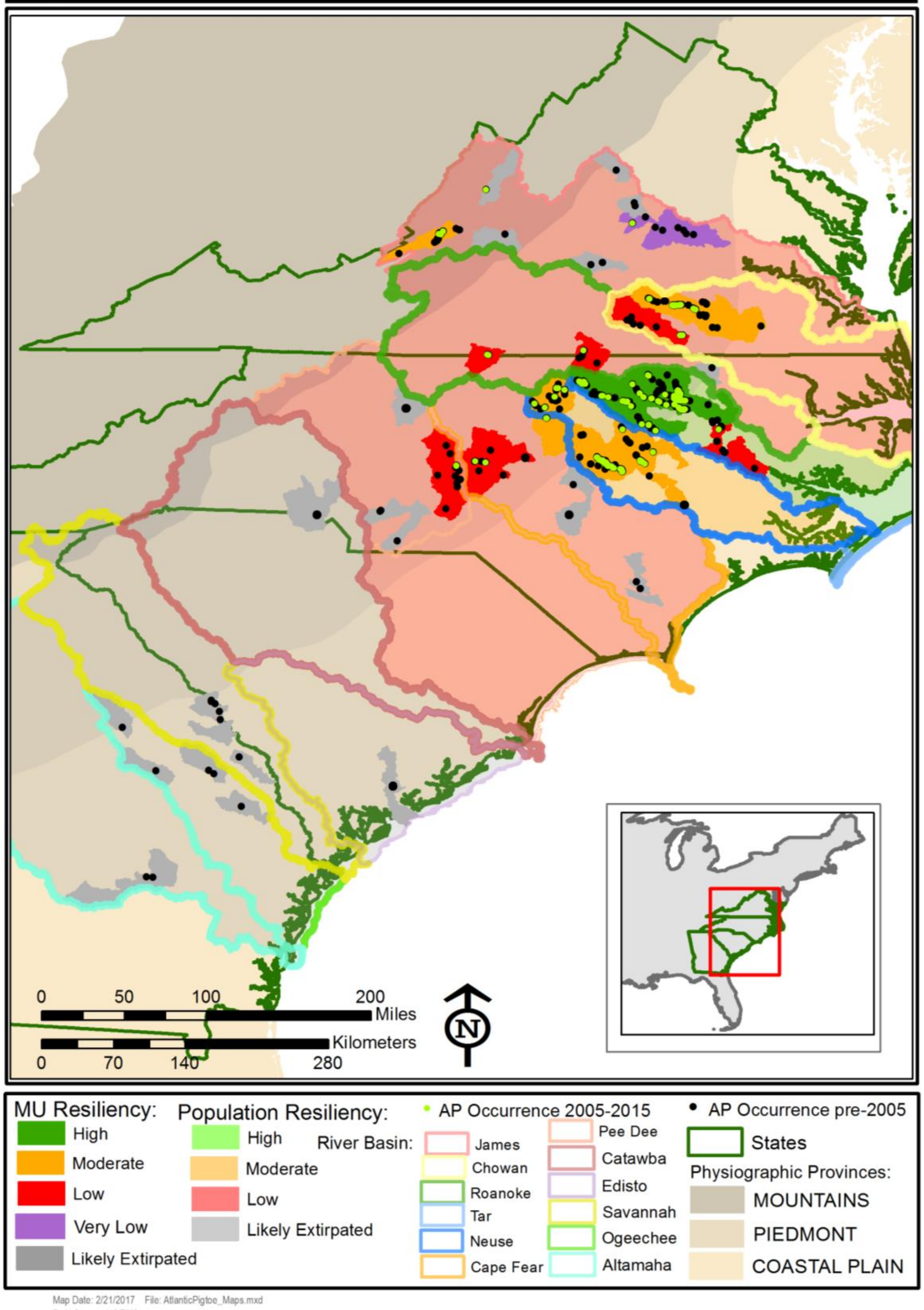
3.4.2 Current Species Representation

We estimated that the Atlantic Pigtoe currently has low adaptive potential due to limited representation in seven river basins and three physiographic regions (Figure 3-18). While the species retains 58% of its known River Basin variability, its distribution has been greatly reduced in the James, Chowan, Roanoke, Cape Fear and Pee Dee populations. In addition, compared to historical distribution, the species retains limited physiographic variability in the Coastal Plain (24%) and in the Mountains (33%), and moderate variability in the Piedmont (52%). Latitudinal variability is also reduced, as much of the species current distribution has contracted and is largely limited to the central portions of its historical range, primarily in the Tar and Neuse basins.

3.4.3 Current Species Redundancy

The range of the Atlantic Pigtoe has been reduced significantly, formerly known from Virginia to Georgia, and now limited to a small portion of Virginia and North Carolina, with currently resilient populations in the Tar and Neuse River drainages. Redundancy was estimated as the number of historically occupied MUs that remain currently occupied (Table 3-2). The species retains limited redundancy in low condition within the James, Chowan, Roanoke, and Cape Fear River populations, and only two populations (Tar and Neuse) have multiple moderate or highly resilient MUs (Table 3-5), thus limiting overall redundancy for the species. Overall, the species has decreased redundancy across its range due to an estimated 60% reduction in occupancy compared to historical levels.

Figure 3-18 ***Atlantic Pigtoe Current Condition***



CHAPTER 4 - FACTORS INFLUENCING VIABILITY

In this chapter, we evaluate the past, current, and future factors that are affecting what the Atlantic Pigtoe needs for long term viability. Aquatic systems face a multitude of natural and anthropogenic threats and stressors (Neves et al. 1997, p.44). State Wildlife Action Plans have identified several factors that have impacts on habitats (see blue boxes in Figure 4.1 below). Generally, these factors can be categorized as either environmental stressors (e.g., development, agriculture practices, forest management, or regulatory frameworks) or systematic changes (e.g., climate change, invasive species, barriers, or conservation management practices). Current and potential future effects, along with current expected distribution and abundance, determine present viability and, therefore, vulnerability to extinction. Those factors that are not known to have effects on Atlantic Pigtoe populations, such as overutilization for commercial and scientific purposes and disease, are not discussed in this SSA report.

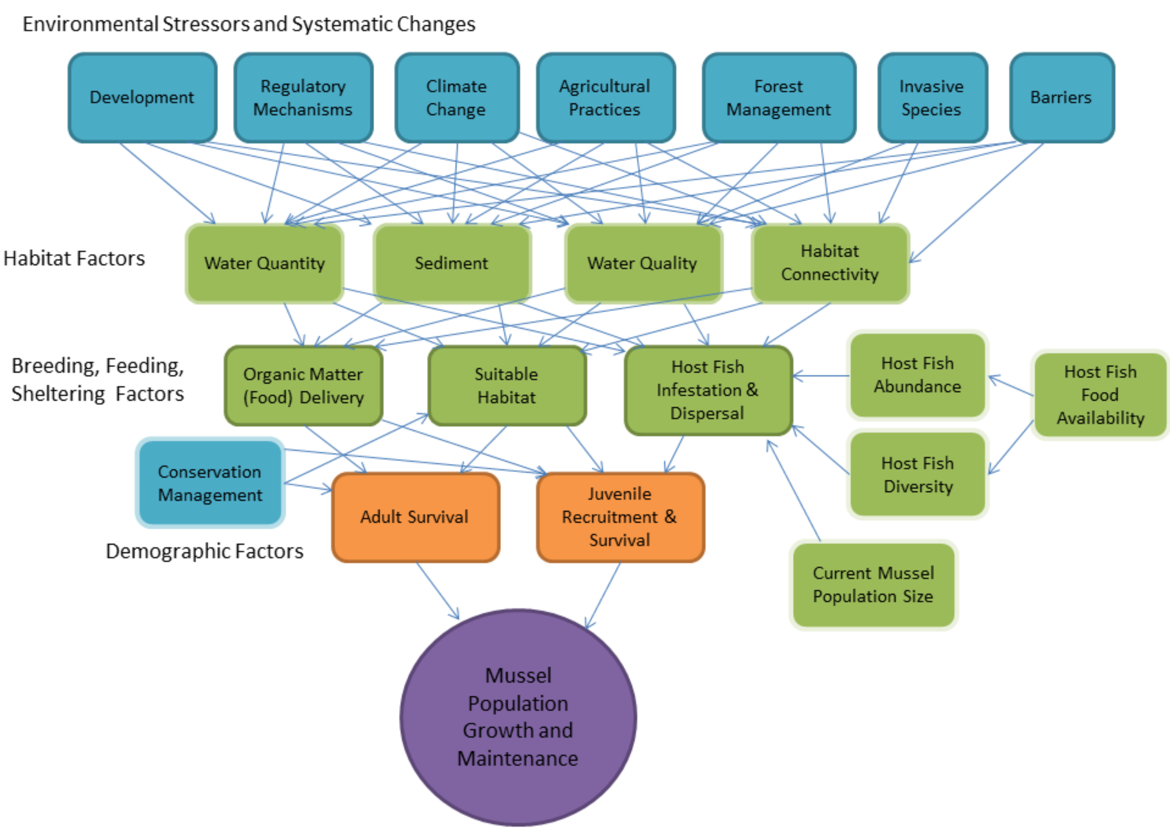


Figure 4-1 Influence diagram illustrating how environmental stressors and systematic changes influence habitat factors which in turn influence breeding, feeding, and sheltering needs of the species; in turn, these affect demographic factors which ultimately influence mussel population growth and maintenance.

4.1 Development

We use the term “development” to refer to urbanization of the landscape, including (but not necessarily limited to) land conversion for urban and commercial use, infrastructure (roads, bridges, utilities), and urban water uses (water supply reservoirs, wastewater treatment, etc.). The effects of urbanization may include alterations to water quality, water quantity, and habitat (both in-stream and stream-side) (Ren et al. 2003, p.649; Wilson 2015, p.424).

“Impervious surface” refers to all hard surfaces like paved roads, parking lots, roofs, and even highly compacted soils like sports fields. Impervious surfaces prevent the natural soaking of rainwater into the ground and slowly seeping into streams (Brabec et al. 2002, p.499; NHEP 2007, p.2). Instead, the rain water accumulates and flows rapidly into storm drains (Figure 4-2).

Figure 4-2 Flooding over impervious surface on Little Fishing Creek, NC (Credit: NCWRC)

This results in effects on streams in three important ways (USGS 2014, p.2-5):

1. Water Quantity: Storm drains deliver large volumes of water to streams much faster than would occur naturally, resulting in flooding and bank erosion. Species living in the streams become stressed, displaced, or killed by the fast moving water and the debris and sediment carried in it.
2. Water Quality: Pollutants (gasoline or oil drips, fertilizers, etc) accumulate on impervious surfaces and are washed directly into the streams.
3. Water Temperature: During warm weather, rain that falls on impervious surfaces becomes superheated and when it enters streams, can stress or kill species living in the stream.

Concentrations of contaminants, including nitrogen, phosphorus, chloride, insecticides, polycyclic aromatic hydrocarbons, and personal care products, increase with urban development (Giddings et al. 2009, p.2; Bringolf et al. 2010, p.1311). Water infrastructure development, including water supply, reclamation, and wastewater treatment, results in several pollution point discharges to streams. Urbanization increases the amount of impervious surfaces (CWP 2003, p.1). The resulting stormwater runoff affects water quality parameters such as temperature, pH, dissolved oxygen, and salinity, which in turn alters the water chemistry potentially making it inhospitable for aquatic biota (Figure 4-3).

Urban development can lead to increased variability in streamflow, typically increasing the amount of water entering a stream after a storm and decreasing the time it takes for the water to travel over the land before entering the stream (Giddings et al. 2009, p.1). In urban areas, flooding is often reduced by draining water quickly from roads and parking lots which results in increased amounts of water reaching a stream within a short period of time, leading to stream flashiness and altered stream channels (Giddings et al. 2009, p.1; Figure 4-2). The rapid runoff also reduces the amount of infiltration into the soil to recharge aquifers, resulting in lower sustained streamflows, especially during summer (Giddings et al. 2009, p.1). Ultimately, when the hydrology of the stream is altered and water quantities vary widely, the physical habitat of a stream often becomes degraded from channel erosion or lower summer flows that reduce feeding, spawning, and living spaces of the Atlantic Pigtoe and other aquatic biota (Giddings et al. 2009, p.1).

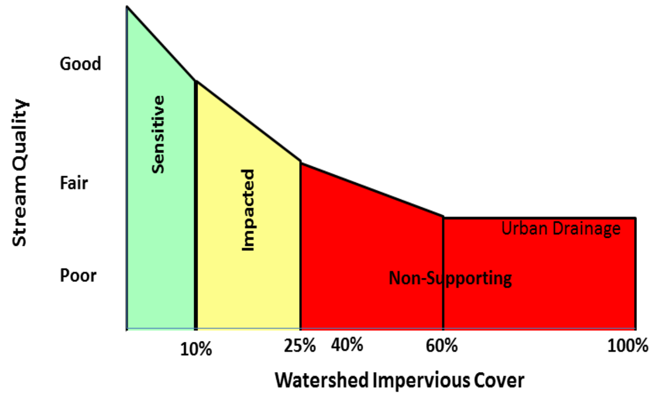


Figure 4-3. Stream Quality is adversely impacted by increased impervious surfaces (from CWP 2003, p.2)

Many of the known host fish of the Atlantic Pigtoe can tolerate short periods of turbidity associated with rain events, however the cyprinid host fish typically do not persist in streams with consistently high sedimentation resulting in turbidity that can reduce feeding efficiency and eliminate spawning habitat due to lack of clean gravel substrate (Jenkins and Burkhead 1993). As noted by Wolf (2012, p.33), excessive turbidity and sedimentation in habitats where Atlantic Pigtoe exist may reduce the interaction between mussels and host fish, and increased turbidity during the limited spawning window (between mid-May and early July) when they are releasing conglutinates could have a significant impact on reproductive success (C. Eads (NCSU) email to S.McRae (USFWS) on 1/13/2016).

Figure 4-4 Sedimentation from unstable banks, cleared riparian area (credit: Ann Hamblin)

Urban development can alter stream habitat either directly via channelization or clearing of riparian areas, or indirectly via high streamflows that reshape the channel and cause sediment erosion (Giddings et al. 2009, p.2; Figures 4-4 and 4-5).

Figure 4-5 Sedimentation from construction flows (credit: Nancy Pierce)

A major aspect of urbanization is the resultant road development. By its nature, road development increases impervious surfaces as well as land clearing and habitat fragmentation. Roads are generally associated with negative effects on the biotic integrity of aquatic ecosystems, including changes in surface water temperatures and patterns of runoff, sedimentation, adding heavy metals (especially lead), salts, organics, ozone, and nutrients to stream systems (Trombulak and Frissell 2000, p.18). In addition, a major impact of road development is improperly constructed culverts at stream crossings. These culverts act as barriers, either as flow through the culvert varies significantly from the rest of the stream, or if the culvert ends up being perched, and aquatic organisms, specifically host fish for the Atlantic Pigtoe, cannot pass through them (Figure 4-6).

Figure 4-6 Perched culvert (credit: Raleigh News and Observer)

Utility crossings and rights-of-way (ROW) maintenance are additional aspects of development that impact stream habitats. For example, the proposed Atlantic Coast Pipeline planned to deliver natural gas from supply areas in West Virginia to markets in Virginia and North Carolina, will include the construction, operation, and maintenance of approximately 595 miles of transmission pipeline, crossing hundreds of streams in WV, VA, and NC, including significant Atlantic Pigtoe habitats in the Tar, Neuse, and Cape Fear River basins. Direct impacts from utility crossings include direct exposure or crushing of individuals, sedimentation, and flow disturbance; the most significant cumulative impact involves the cleared ROW that allows for direct runoff and increased temperature at the crossing location, and potentially allows access of all-terrain/off-road vehicles from the ROW (which destroy banks and instream habitat).

4.2 Regulatory Mechanisms

State Endangered Species Laws

Each state within the range of the Atlantic Pigtoe has state-level legislation modeled after the federal Endangered Species Act: in Virginia it is both the Virginia Endangered Species Act and the Endangered Plant and Insect Species Act, in North Carolina it is the North Carolina Endangered Species Act, in South Carolina it is the Nongame and Endangered Species Conservation Act, and in Georgia it is the Endangered Wildlife Act. Animal species that are protected by the state laws are regulated by state wildlife agencies: the Virginia Department of Game and Inland Fisheries, the North Carolina Wildlife Resources Commission, the South Carolina Department of Natural Resources, and the Georgia Department of Natural Resources.

The state endangered species protection laws allow the state wildlife agencies to identify, document, and protect any animal species that is considered rare or in danger of extinction. In most of the states (VA, NC, SC, GA), illegal activities include take, transport, export, processing, selling, offering for sale, or shipping species, and the penalty for doing so is a misdemeanor crime, usually resulting in a fine of no more than $1,000 or imprisonment not to exceed a year (Pellerito 2002, entire). There are no mechanisms for recovery, consultation, or critical habitat designation other than in North Carolina where conservation plans must be developed for all state listed species (Pellerito 2002, Snape and George 2010, p.346). In addition, nothing in the North Carolina Endangered Species Act "shall be construed to limit the rights of a landholder in the management of his lands for agriculture, forestry, development, or any other lawful purpose" (NC GS 113-332).

State and Federal Stream Protections (Buffers & Permits)

A buffer is a strip of trees, plants, or grass along a stream or wetland that naturally filters out dirt and pollution from rain water runoff before it enters rivers, streams, wetlands, and marshes (SELC 2014, p.2). Several state laws require setbacks or buffers, and all allow variances/waivers for those restrictions. Virginia's Chesapeake Bay Preservation Act requires 100-foot buffers on all perennial streams in designated "Resource Protection Areas." North Carolina used to have buffer requirements in specific watersheds (e.g., Tar-Pamlico, Neuse, Catawba, Jordan Lake, and Goose Creek), however, as described below, the NC Legislature enacted a Regulatory Reform effort, including "Riparian Buffer Reform" that allowed for the amendment of the buffer rules to allow/exempt development (see Session Law 2012-200, Section 8 and Session Law 2015-246, Section 13.1, G.S. 143-214.23A (NCDEQ 2016, entire)). North Carolina also has guidance for 200 foot riparian buffer protections for streams draining to listed aquatic species habitats (NCWRC 2002, p.11). In South Carolina, 30-45ft buffer management zones are required for stormwater management (SCDHEC 2016, entire). In Georgia, all state waters are protected by a 25-foot vegetated buffer, and trout waters have a 50-foot vegetated buffer requirement.

Section 401 of the federal Clean Water Act (CWA) requires that an applicant for a federal license or permit provide a certification that any discharges from the facility will not degrade water quality or violate water-quality standards, including state-established water quality standard requirements. Section 404 of the CWA establishes a program to regulate the discharge of dredged and fill material into waters of the United States.

Permits to fill wetlands and fill, culvert, bridge or re-align streams or water features are issued by the U.S. Army Corps of Engineers under Nationwide, Regional General Permits or Individual Permits.

- Nationwide Permits are for "minor" impacts to streams and wetlands, and do not require an intense review process. These impacts usually include stream impacts under 150 feet, and wetland fill projects up to 0.50 acres. Mitigation is usually provided for the same type of wetland or stream impacted, and is usually at a 2:1 ratio to offset losses and make the "no net loss" closer to reality.
- Regional General Permits are for various specific types of impacts that are common to a particular region; these permits will vary based on location in a certain region/state.
- Individual permits are for the larger, higher impact and more complex projects. These require a complex permit process with multi-agency input and involvement. Impacts in these types of permits are reviewed individually and the compensatory mitigation chosen may vary depending on project and types of impacts.

State and Federal Water Quality Programs

Current State regulations regarding pollutants are designed to be protective of aquatic organisms; however, freshwater mollusks may be more susceptible to some pollutants than the test organisms commonly used in bioassays. Additionally, water quality criteria may not incorporate data available for freshwater mussels (March et al. 2007, pp. 2,066–2,067). A multitude of bioassays conducted on 16 mussel species (summarized by Augspurger et al. 2007, pp. 2025–2028) show that freshwater mollusks are more sensitive than previously known to some chemical pollutants, including chlorine, ammonia, copper, fungicides, and herbicide surfactants. Another study found that nickel and chlorine were toxic to a federally threatened mussel species at levels below the current criteria (Gibson 2015, pp. 90–91). The study also found mussels are sensitive to SDS (sodium dodecyl sulfate), a surfactant commonly used in household detergents, for which water quality criteria do not currently exist. Several studies have demonstrated that the criteria for ammonia developed by EPA in 1999 were not protective of freshwater mussels (Augspurger et al. 2003, p. 2,571; Newton et al. 2003, pp. 2,559–2,560; Mummert et al. 2003, pp. 2,548–2,552). However, in 2013 EPA revised its recommended criteria for ammonia. The new criteria are more stringent and reflect new toxicity data on sensitive freshwater mollusks (78 FR 52192, August 22, 2013; p. 2). All of the states in the range of the Atlantic Pigtoe have not yet adopted the new ammonia criteria. NPDES permits are valid for 5 years, so even after the new criteria are adopted, it could take several years before facilities must comply with the new limits.

TMDL, or Total Maximum Daily Load, is a regulatory term from the CWA describing a plan for restoring impaired waters that identify the maximum amount of a pollutant that a body of water can receive while still maintaining water quality standards. In North Carolina, despite management actions that started in the mid-1990s, long term monitoring and trend analyses have demonstrated that TMDL goals have not been met: "Despite the fact that the targeted point and nonpoint pollution sources have been able to meet their nutrient reductions, total nitrogen and total phosphorous concentrations do not show a downward trend and loads have not permanently fallen below 1991 baseline load goals" (as referenced (p.6) in SRI public comment letter on Yellow Lance Listing to USFWS, 6/5/2017).

Under the CWA, states are required to review their water quality standards and classifications every three years to make any modifications necessary to protect the waters of the state (NCDEQ 2016, entire). During this process, known as the Triennial Review, state water quality staff review current EPA guidelines, scientific data, and public comments and make recommendations for any changes of the water quality standards. In North Carolina, the most recent triennial review started in 2007 and was not completed until 2015 (NCDEQ 2016, entire). The state of North Carolina has not addressed water quality standards for several pollutants of concern for freshwater mussles, particularly ammonia, despite the EPA's 2013 recommended ambient water quality criteria for ammonia (as referenced (p.7) in SRI public comment letter on Yellow Lance Listing to USFWS, 6/5/2017).

In summary, despite existing authorities such as the Clean Water Act, pollutants continue to impair the water quality throughout the current range of the Atlantic Pigtoe. State and Federal regulatory mechanisms have helped reduce the negative effects of point source discharges since the 1970s, yet these regulations are difficult to implement and regulate. While new water quality criteria are being developed that take into account more sensitive aquatic species, most criteria currently do not. It is expected that several years will be needed to implement new water quality criteria throughout the range.

Regulatory Reform in North Carolina

North Carolina has undergone regulatory review and reform that is worthy of mention because of implications to stream habitat protections for aquatic species in the state, particularly areas that are the strongholds for species like the Atlantic Pigtoe. In the past six years (since 2010), there have been several changes to state regulations, dubbed as "Regulatory Reform" and in 2016, the changes are described in legislation titled as the "Regulatory Reduction Act." These changes in Session Laws, House and Senate Bills, and enacted Legislation have far reach and the most recent reforms have affected significant environmental programs and protections, including:

- disinvestment in data collection on rare and endangered species by significant funding reductions to the state's Natural Heritage Program (SL2015-241, Sections 14.4,14.30(a) and (r1) and (ggg) and (nnn1));
- revision of the State Environmental Policy Act review process (from NCDEQ's website):

  > "Session Law 2015-90…overhauled the criteria under which a SEPA review of a proposed project is evaluated. Prior to the passage of SL 2015-90, if a proposed project involved any amount of public funds, involved the use of public lands, or had significant environmental impacts as determined by the minimum criteria, then a SEPA review was necessary. With the passage of SL 2015-90, two key criteria must now be considered to determine if a proposed action may require a SEPA eview. The first is the funding source. If a proposed action involves more than $10,000,000 of

funds provided by the State of North Carolina for a single project or action or related group of projects or actions a SEPA review may be necessary. This is a change over the previous requirement which included any public funds (i.e. city, county, bonds, etc.). The second involves direct impacts resulting from the proposed project. If the proposed action will result in substantial, permanent changes to the natural cover or topography greater than or equal to ten acres of public lands a SEPA review may be required. This is a change over previous requirements that required a SEPA review for impacts to any type or amount of public lands" (NCDEQ 2016, entire);

- eliminating or limiting stormwater and stream buffer rules (and allowing unlimited development in a riparian buffer as long as the project complies with state stormwater requirements) in the Neuse River basin, the Tar-Pamlico River basin and the Jordan Lake watershed (SL2015-246, Section 13.1);
- change of state water quality rules to include a new stormwater standard which eliminates on-site stormwater controls, unless they are needed to meet specific state or federal laws (SL2014-90, Part II);
- reduction of 401 certification/404 permitting requirements by eliminating mitigation for projects impacting less than 300 feet of stream and reduced mitigation rations from 2:1 to 1:1 (SL2014-120, Section 54(b));
- limitation of state environmental agency authorities (G.S. 150B-19.3) and local government authorities.

As the title of the legislation states, these regulatory changes are intended to "improve and streamline the regulatory process in order to stimulate job creation, to eliminate unnecessary regulation, to make various other statutory changes, and to amend certain environmental and natural resource laws" (exact title of SL2013-413). The result of these regulatory changes could impact aquatic species such as the Atlantic Pigtoe, as well as the habitats that the species require for survival. For example, reduced resources to inventory, compile, and review data as well as changed criteria for project review, changed rules and standards, and reduced mitigation requirements could all result in project implementation without consideration of impacts to species, thus potentially directly or indirectly impacting the habitats the species depend on, resulting in degradation of stream quality and ultimately in species decline.

4.3 Climate Change

As mentioned in the Poff et al. 2002 (pp.ii-v) report on Aquatic Ecosystems and Global Climate Change, likely impacts of climate change on aquatic systems include:

- Increases in water temperatures that may alter fundamental ecological processes, thermal suitability of aquatic habitats for resident species, as well as the geographic distribution of species. Adaptation by migration to suitable habitat might be possible, however human alteration of dispersal corridors may limit the ability of species to relocate, thus increasing the likelihood of species extinction and loss of biodiversity.
- Changes and shifts in seasonal patterns of precipitation and runoff will alter the hydrology of stream systems, affecting species composition and ecosystem productivity. Aquatic organisms are sensitive to changes in frequency, duration, and timing of extreme precipitation events such as floods or droughts, potentially resulting in interference of

reproduction. Further, increased water temperatures and seasonally reduced streamflows will alter many ecosystem processes, including increases in nuisance algal blooms.

- Climate change is an additional stressor to sensitive freshwater systems, which are already adversely affected by a variety of other human impacts, such as altered flow regimes and deterioration of water quality.
- As mentioned by Poff et al. (2002, pp.ii-v), aquatic ecosystems have a limited ability to adapt to climate change. Reducing the likelihood of significant impacts will largely depend on human activities that reduce other sources of ecosystem stress to ultimately enhance adaptive capacity; these include maintaining riparian forests, reducing nutrient loading, restoring damaged ecosystems, minimizing groundwater (and stream) withdrawal, and strategically placing any new reservoirs to minimize adverse effects.
- Specific ecological responses to climate change cannot be easily predicted because new combinations of native and non-native species will interact in novel situations.
- Since sedentary freshwater mussels have limited refugia from disturbances such as droughts and floods, and since they are thermo-conformers whose physiological processes are constrained by water temperature within species-specific thermal preferences, climate-induced changes in water temperature can lead to shifts in mussel community structure (Galbraith et al. 2010, p.1176).

4.4 Agricultural Practices

Agricultural best management practices (BMPs) are changes in agricultural land management that can be focused on achieving multiple positive environmental outcomes. A wide variety of agricultural BMPs exist, including practices such as cover crops, conservation tillage, irrigation efficiency, contour farming, and agroforestry; these practices aim to reduce agrichemical pollution and erosion, manage nutrient and sediment runoff, and protect streams. The US Department of Agriculture's Natural Resource Conservation Service has prepared national technical guidance on conservation practices and activities that can be adapted at the local level, and incentives are available for local farmers to participate in programs to promote agricultural conservation practices (USDA 2018, entire).

Nutrient Pollution

Farming operations, including Concentrated Animal Feeding Operations (CAFOs), can contribute to nutrient pollution when not properly managed (USEPA 2016, entire). Fertilizers and animal manure, which are both rich in nitrogen and phosphorus, are the primary sources of nutrient pollution from agricultural sources. If fertilizers are not applied properly, at the right time of the year and with the right application method, water quality in the stream systems can be affected. Excess nutrients impact water quality when it rains or when water and soil containing nitrogen and phosphorus wash into nearby waters or leach into the water table/ground waters causing algal blooms (Figure 4-7).

Figure 4-7 Massive flooding in the wake of Hurricane Matthew (October 2016) isolated or swamped these and other hog farms and their waste lagoons in the Neuse and Tar River basins (credit: The Washington Post)

Fertilized soils and livestock can be significant sources of nitrogen-based compounds like ammonia and nitrogen oxides. Ammonia can be harmful to aquatic life if large amounts are deposited to surface waters (see information in "State Water Quality Programs" section above). The lack of stable stream bank slopes from agricultural clearing and/or the lack of stable cover crops between rotations on farmed lands can increase the amount of nutrients that make their way into the nearby streams by way of increased soil erosion (cover crops and other vegetation will use excess nutrients and increase soil stability). Livestock often use streams or created in-line ponds as a water source; this degrades water quality and stream bank stability and reduces water quantity available for downstream needs.

Pumping for Irrigation

Irrigation is the controlled application of water for agricultural purposes through manmade systems to supply water requirements not satisfied by rainfall. It is common practice to pump water for irrigation from adjacent streams or rivers into a reservoir pond, or sprayed directly onto crops. If the water withdrawal is excessive (usually over 10,000 gal/day) or done illegally (without permit if needed, or during dry time of year, or in areas where sensitive aquatic species occur without consultation), this may cause impacts to the amount of water available to downstream sensitive areas during low flow months, resulting in dewatering of channels and stranding of mussels.

Agriculture Exemptions from Permit Requirements

Normal farming, silviculture, and ranching activities are exempt from the 404 permitting process. This includes activities such as construction and maintenance of farm ponds, irrigation ditches, and farm roads. If the activity might impact rare aquatic species, the USACE does require farmers to ensure that any "discharge shall not take, or jeopardize the continued existence of, a threatened or endangered species, or adversely modify or destroy the critical habitat of such species," and to ensure that "adverse impacts to the aquatic environment are minimized," however the USACE does not require the farmer to consult with appropriate State or Federal Agencies regarding these sensitive species.

While there is an expectation for farmers to follow best management practices (BMPs), there are often cases where BMPs are not followed and go un-noticed as many farming activities are in rural locations and regulators are spread thin (Wells (USFWS) email to S.McRae (USFWS) on 5/12/2016).

4.5 Forest Conversion and Management

A forested landscape provides many ideal conditions for aquatic ecosystems. Depending on the structure and function of the forest, and particularly if native, natural mixed hardwood forests comprise the active river area (ARA), rain is allowed to slowly infiltrate and percolate (as opposed to rapid surface runoff), a variety of food resources enter the stream via leaf litter and woody debris, banks are stabilized by tree roots, habitat is created by occasional windthrow, and riparian trees shade the stream and maintain an ideal thermal climate (Edwards et al. 2015, p.60).

Forested ARAs, or riparian areas, perform many functions that are essential to maintaining water quality, aquatic species survival, and biological productivity (NCWRC 2002, p.6). Specifically, forested riparian areas serve a role as (USFWS 2006, p.6):

- mechanical barriers to runoff, increasing surface roughness to reduce flow velocity and promoting mechanical trapping of suspended solids;
- sediment traps and bank stabilizers, where the tree root structures retain erodible soils and stabilize streambanks;

Riparian Buffer Function	Range of reported effective widths (meters)	Average of reported effective widths (meters)	Number of studies included in analysis
Sediment retention	7-300	44	33
Nutrient retention	4-177	25	37
Nitrogen	7-33	18	15
Phosphorus	4-30	16	12
Bacteriological retention	9-58	31	6
Miscellaneous pollutant removal[1]	4-61	27	8
Sustain aquatic biota	23-100	35	13
Detritus input/structural complexity	7-80	37	18
Temperature moderation	8-173	34	17

Table 4-2 Range of buffer widths for specific riparian functional values (from USFWS 2006, p.22)

- cover refugia and nest sites, where woody debris from adjacent forested areas provides structural complexity of instream habitats;
- temperature regulation, as trees in the riparian area provide shading for temperature regulation/microclimate maintenance; and
- food resources, as adequate food input (detritus, allochthonous material) comes from the surrounding riparian zone (Stewart et al. 2000, p.210).

Wide, contiguous forested riparian buffers have greater and more flexible potential than other options to maintain biological integrity (Table 4-2; Horner et al. 1999, p.2) and could ameliorate many ecological issues related to land use and environmental quality (Naiman et al. 1993, p.209).

Silvicultural activities when performed according to strict Forest Practices Guidelines (FPGs) or Best Management Practices (BMPs) can retain adequate conditions for aquatic ecosystems, however, when FPGs/BMPs are not followed, these activities can also "cause measurable impacts" (NCASI 2015, p.1) and contribute to the myriad of stressors facing aquatic systems in the Southeast. Both small and large scale forestry activities have been shown to have a significant impact upon the physical, chemical, and biological characteristics of adjacent small streams (Allan 1995, pp. 324-327). Today, forests are harvested and converted for many reasons including, but not limited to: financial gain to the property owner by timber harvest, residential and commercial development, conversion for various agricultural practices, for the manufacturing of wood and paper products, and for fuel for electricity generation (Alig et al. 2010, pp.2-3; Maestas 2013, p.1; National Geographic 2016, entire). In many cases, natural mixed hardwood-conifer forests are clear-cut, then either left to naturally regenerate or replanted in rows of monoculture species such as pine, used for the growing need for timber building supplies and pulp products (Figure 4-8; Allen et al. 1996, p.4; Wear and Greis 2012, p.13; NCFA 2017, entire).

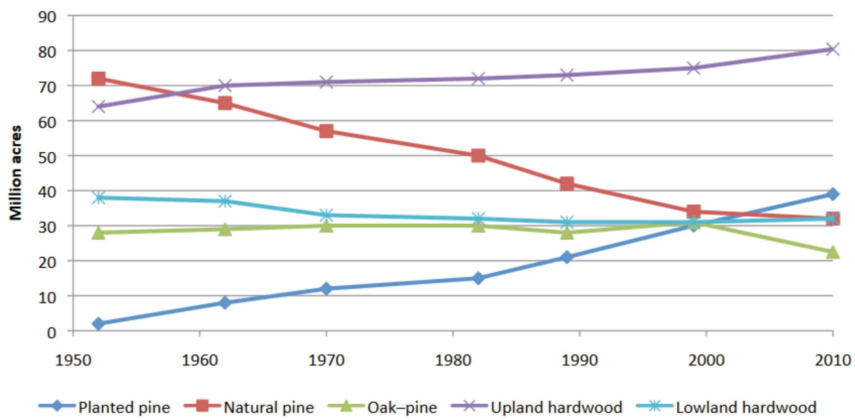


Figure 4-8 Historical trends in forest area by broad management type, showing an increase in planted pine over the past half-century (from Wear and Greis 2012, p.13)

These monoculture stands can impact overall water cycle dynamics (e.g., increased evapotranspiration and overall reduced stream flows)(Swank and Miner, 1968, entire; Swank and Douglass 1974, entire; Riggs et al. 2000, pp.118-119), as well as result in a reduction of biodiversity in the canopy, mid and understory vegetation as well as the fauna that uses this now monoculture area. Furthermore, the aquatic habitats of streams in these monoculture forested areas lose heterogeneity in food resources due to reduced variety in allochthonous (i.e., energy inputs derived from outside the stream system, or leaf matter that falls into stream) inputs, and this effect is mirrored among invertebrate and fish populations, including filter-feeding mussels and benthic insectivorous fish and amphibians (Webster et al. 1992, p.235; Allan 1995, p.129; Jones et al. 1999, p.1454).

The clearing of large areas of forested wetlands and riparian systems eliminates shade once provided by the canopies, exposing streams to more sunlight and increasing the in-stream water temperature (Wenger 1999, p.35). The increase in stream temperature and light after deforestation has been found to alter the macroinvertebrate and other aquatic species richness and abundance composition in streams to various degrees depending on each species tolerance to temperature change and increased light in the aquatic system (Swift and Messer 1971, p. 111; Hewlett and Forston 1982, p.983; GB Rishel 1982, p. 112; Lynch et al. 1984, p. 161; Allan 1995, p.325; Keim and Shoenholtz 1999, p.197; Carroll et al. 2004, p. 275; Kishi et al. 2004, p.283; Couceiro et al. 2007, p.272; B.D. Clinton 2011, p. 979; Caldwell et al. 2014, p.3).

Sediment runoff from cleared forested areas is a known stressor to aquatic systems (Webster et al. 1992, p.232; Jones et al. 1999, p.1455; Broadmeadow and Nisbet 2004, p.286; Aust et al. 2011, p.123). The physical characteristics of stream channels are affected when large quantities of sediment are added or removed (Watters 2000, p.263). Mussels and fish are potentially impacted by changes in suspended and bed material load, bed sediment composition associated with increased sediment production and runoff in the watershed, channel changes in form, position, and degree of stability; actively filling or scouring channels; and changes in channel position that may leave mussels or fish exposed (Brim Box and Mossa 1999, p.100; USFWS 2003, p.53). Interstitial spaces in mixed substrates may become clogged with sediment subsequently reducing habitat for the life history needs of aquatic species. In a series of studies, forest harvesting was implicated as a contributor to mussel decline, and both the quantity and quality of riparian zones were emphasized as important for mussel conservation. In these studies, sedimentation was negatively related to mussel recruitment (Osterling and Hogberg 2014, pp. 215–217), including instances of recruitment failure (Osterling et al. 2010, pp. 763–766); higher water temperature and turbidity contributed to reduced growth of gravid mussels (Osterling 2015, pp. 448–450); the juvenile life stage was identified as the likely bottleneck for recruitment failure (Osterling et al. 2008, pp. 1368–1369); and sedimentation also affected recruitment of host fish (Osterling 2019, pp. 446–448). “The results indicate a year round negative effect of sedimentation, having strong and combined direct and indirect effects on juvenile mussel recruitment” (Osterling 2019, p. 444). Similarly, the juvenile mussel life stage has been identified as a recruitment bottleneck, implicating sedimentation as a cause of mortality from water quality monitoring, including suspended solids (Reid et al. 2013, pp. 571, 577).

Stream crossings and inadequately buffered clearcut areas can be important sources of sediment entering streams (Taylor et al. 1999, p.13). Many forestry activities are not required to obtain a CWA 404 permit, as silviculture activities (such as harvesting for the production of fiber and forest products) are exempted (USACE 2016, entire: USEPA 2017, p.1). Because forestry activities often include the construction of logging roads through the riparian zone, this can directly degrade nearby stream environments (Aust et al. 2011, p.123). Logging roads constructed in wetlands adjacent to headwater drains and streams fall into this exemption category, but may impact the aquatic system for years as these roads do not always have to be removed immediately. Roads remain as long as the silviculture operation is ongoing, thus wetlands/streams/ditches draining into the more sensitive areas may be heavily impacted by adjacent fill and runoff if BMP’s fail or are not maintained, causing sedimentation to travel downstream into more sensitive in-stream habitats. Requirements maintain that flows are not to be restricted by logging roads, but culverts are only required per BMP’s and are not always adequately sized or spaced. Furthermore, stream crossings tend to have among the lowest implementation (Table 4-3), and this is particularly true in North Carolina (NCFS 2011, p.v; NCASI 2015, p.4).

Forestry practices that do not follow BMPs can impact natural flow regime, resulting in altered habitat connectivity. Logging staging areas, logging ruts, and not re-planting are all associated impacts that are a threat to downstream aquatic species. BMP's require foresters to ensure that "the discharge shall not take, or jeopardize the continued existence of, a threatened or endangered species, or adversely modify or destroy the critical habitat of such species," and to ensure that "adverse impacts to the aquatic environment are minimized," however, foresters are not required to consult with appropriate state or federal agencies regarding these sensitive species and ways to best reduce potential impacts prior to moving forward with management.

Around the turn of the 21st century, biologists, foresters, and managers alike recognized the need for wholesale implementation of BMPs to address many of the aforementioned issues related to forest conversion and silvicultural practices. Now, forestry BMP manuals suggest planning road systems and harvest operations to minimize the number of crossings. Proper construction and maintenance of crossings reduces soil erosion and sedimentation with the added benefit of increasing harvest operation efficiency (NCASI 2015, p.2). The non-point source programs for forestry in North Carolina is described as "quasi-regulatory" because it has defined the legal implications of non-compliance in a specific way (NCASI 2015, p. 1). FPGs (specific to North Carolina) are codified performance standards that govern forestry-related land-disturbing activities and BMPs are recommended actions/measures to minimize and control nonpoint pollution runoff from forestry operations. The NC Forest Service has noted that "improving BMP implementation of stream crossing BMPs will have the most positive influence on reducing the risk to water quality on active harvest sites, followed by BMPs for rehabilitation, debris entering streams, skid trails, and SMZs [streamside management zones]" (NCFS 2011, p.vi). In the South, the region-wide average for overall BMP implementation in 2011 was 92% (Table 4-3; NCASI 2015, pp.3-4).

Table 4-3. Forestry Best Management Practices Implementation Rates from the Most Recent Surveys for States in the Southeastern US (Sources: SGSF 2012; NASF 2015 (excerpted from NCASI 2015, p.4)

BMP Category	Range of Implementation Rates in SE States: SGSF (2012)[1]	NASF (2015)[2]	Average Implementation Rate (from SGSF 2012)
Overall BMP Implementation	85% to 99%	85% to 99%	92%
Harvesting	85% to 99%	88% to 99%	95%
Forest Roads	78% to 99%	84% to 99%	90%
Stream Crossings	72% to 98%	72% to 98%	89%
SMZs	85% to 99%	86% to 98%	93%
Site Preparation	74% to 99%	74% to 99%	92%
Firebreaks	33% to 100%	64% to 100%	82%
Chemical Application	94% to 100%	93% to 100%	98.5%

[1]SGSF (2012) includes implementation rates for Alabama, Arkansas, Florida, Georgia, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.
[2]NASF (2015) includes implementation rates for Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

While FPGs and BMPs are widely adhered to (Table 4-3), they were not always common practice, and even today there are instances (although rare) that do not rise to a level of threat minimization that is adequate for the sensitive species (e.g., freshwater mussels and fish) in the area. As an example, while NC's FPG .0201 indicates that "a SMZ shall be established and maintained along the margins of intermittent and perennial streams…[and] shall be of sufficient width to confine…visible sediment resulting from accelerated erosion", there is no information on the required width. Even if mandated 50 or 100 foot buffer zones (e.g., in the Neuse and Tar River basins) were enforced (see "Regulatory Reform" section above), data indicate that minimum native, forested buffer widths of 200-feet on perennial streams and 100-feet on intermittent streams, or the full extent of the 100-year floodplain, should be maintained in watersheds supporting federally endangered and threatened aquatic species (NCWRC 2002, pp.10-11; Broadmeadow and Nisbet 2004, p.286; NCNHP 2004, p. 4; USFWS 2006, p.17).

4.6 Invasive Species

The South Atlantic seaboard has many native species that are declining and nonnative nuisance species are one of the major causes. It is estimated that 42% of Federally Threatened or Endangered species are significantly impacted by nonnative nuisance species across the nation and nuisance species are significantly impeding recovery efforts for them in some way (NCANSMPC 2015, pp.8-9). There are many areas across the states of Maryland, Virginia, North Carolina, South Carolina, and Georgia where aquatic invasive species have invaded aquatic communities; are competing with native species for food, light, or breeding and nesting areas; and are impacting biodiversity.

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

Examples of invasive species that affect freshwater mussels like the Atlantic Pigtoe are the Asian Clam (*Corbicula fluminea*), the Flathead Catfish (*Pylodictis olivaris*), and Hydrilla (*Hydrilla verticillata*). The Asian Clam alters benthic substrates, competes with native species for limited resources, and causes ammonia spikes in surrounding water when they die off en masse (Scheller 1997, p.2). The Asian Clam is ubiquitous across the southeastern United States and is present in watersheds across the ranges of the Atlantic Pigtoe (Foster et al. 2017, p.1). A recent study demonstrated that native mussel growth was negatively associated with Asian clam abundance, indicating invasive clams may be a pervasive stressor to native species (Haag et al. 2021, pp. 451-454). The Flathead Catfish is an apex predator known to feed on almost anything, including other fish, crustaceans, and mollusks, and to impact host fish communities, reducing the amount of fish available as hosts for the mussels to complete their life cycle (VDGIF 2017, entire; NCANSMPC 2015, p.75). Hydrilla is an aquatic plant that alters stream habitat, decreases flows, and contributes to sediment buildup in streams (NCANSMPC 2015, p.57). High sedimentation can cause suffocation, reduce stream flow, and make it difficult for mussels' interactions with host fish necessary for development. Hydrilla occurs in several watersheds where the Atlantic Pigtoe occur, including recent documentation from the upper Neuse system, the Deep River, and the Tar River. The dense growth is altering the flow in these systems and causing sediment buildup, which can cause suffocation in filter-feeding mussels. While data are lacking on Hydrilla currently having population-level effects on the Atlantic Pigtoe, the spread of this invasive plant is expected to increase in the future.

4.7 Dams and Barriers

> *One of the greatest known extinction episodes in the first half of the twentieth century took place in the Southeast – the virtual disappearance of the Coosa River molluscan fauna. Dams on the Coosa River destroyed all the shoals on which the snails and mussels depended… Today, most of the remnants of this once diverse fauna teeter on the brink of extinction.* –G.W.Folkerts (1997, p.11)

Extinction/extirpation of North American freshwater mussels can be traced to impoundment and inundation of riffle habitats in all major river basins of the central and eastern United States (NCWRC 2015, p.109). Humans have constructed dams for a variety of reasons: flood prevention, water storage, electricity generation, irrigation, recreation, and navigation (Eissa and Zaki 2011, p.253). Manmade dams and natural dams (either created by beavers or by aggregations of woody debris) have a many impacts on stream ecosystems. Reductions in the diversity and abundance of mussels are primarily attributed to habitat shifts causes by impoundment (Neves et al. 1997, p.63):

- Upstream of dams – the change from flowing to impounded waters, increased depths, increased buildup of sediments, decreased dissolved oxygen, and the drastic alteration in resident fish populations inevitably can threaten the survival of mussels and their overall reproductive success.
- Downstream of dams – fluctuations in flow regimes, minimal releases and scouring flows, seasonal dissolved oxygen depletion, reduced or increased water temperatures, and changes in fish assemblages can also threaten the survival and reproduction of many mussel species.

Dams have also been identified as causing genetic isolation in river systems – resident fish can no longer move freely through different habitats and may become genetically isolated from other fish populations throughout the river; furthermore, as host fish, this can cause genetic segregation in the mussel populations as well.

Interestingly, recent studies have shown that some mussel populations may be more temporally persistent immediately downstream of small dams, more abundant and diverse, and attain larger sizes and grow faster than do conspecifics in populations further upstream or downstream (Gangloff 2013, p.476 and references therein). In today's rapidly changing landscape, it is possible that these small dams and their impoundments may perform some key ecological functions including filtration and detoxification of anthropogenically elevated nutrient loads, oxygenating low-gradient streams during low-water periods, and stabilizing portions of the stream beds that are needed for the persistence of fish and mollusk taxa (Gangloff 2013, pp.478-

479). Additional benefits of impoundments may include (Gangloff 2013, p.479 and references therein):

- retention of fine sediments and associated toxicants, as in the case of the Lake Benson Dam in the Swift Creek (Neuse) watershed,
- impediments to the spread of invasive species, as in the case of Bellamy's Mill Dam on Fishing Creek (Tar) that appears to prevent the upstream spread of flathead catfish, and
- attenuation of floods from urban or highly agrarian watersheds.

As mentioned above, improperly constructed culverts at stream crossings act as significant barriers, and have some similar effects as dams on stream systems. Fluctuating flows through the culvert can vary significantly from the rest of the stream, preventing fish passage and scouring downstream habitats. If a culvert ends up being perched above the stream bed, aquatic organisms cannot pass through them. These barriers not only fragment habitats along a stream course, they also contribute to genetic isolation of the aquatic species inhabiting the streams.

4.8 Conservation Management

Conservation management actions include *in situ* actions such as habitat protection and stream restoration as well as *ex situ* actions such as captive propagation, ultimately leading to species population restoration.

"It is…widely recognized that the future of rare aquatic species is best secured by protecting and restoring biological integrity of entire watersheds" (Shute et al. 1997, p.448 and references therein). While land acquisition is the most obvious means of affecting watershed protection, it is not feasible to acquire entire watersheds. Shute et al. (1997, p.448) offer up "Ecosystem Management" as the most effective method of protecting the greatest number of species, however, they warn that "the complex nature of aquatic ecosystems and the watershed scale necessary for aquatic ecosystem protection is problematic... [It] is expensive, time consuming, and requires considerable coordination with and commitment from various agencies, organizations, and private individuals."

The Service and State Wildlife Agencies are working with numerous partners to make Ecosystem Management a reality, primarily by providing technical guidance and offering development of conservation tools to meet both species and habitat needs in aquatic systems from Maryland to North Carolina. Land Trusts are targeting key parcels for acquisition, federal and state biologists are surveying and monitoring species occurrences, and recently there has been a concerted effort to ramp up captive propagation and species population restoration via augmentation, expansion, and reintroduction efforts.

In 2014, North Carolina Wildlife Resources Commission staff and partners began to propagate the Atlantic Pigtoe in hopes of augmenting existing populations in the Tar and Neuse River basins. In July 2015, ~50 Atlantic Pigtoes were stocked into Little Fishing Creek, a tributary of Fishing Creek the Tar River (NCWRC PAWS database). Annual monitoring to evaluate growth and survival is planned, and additional propagation and stocking efforts will continue in upcoming years.

4.9 Summary

Of the past, current, and future influences on what the Atlantic Pigtoe needs for long term viability, the largest threats to the future viability of the species relate to habitat degradation from stressors influencing water quality, water quantity, instream habitat, and habitat connectivity. All of these factors are influenced by climate change. We did not assess overutilization for scientific and commercial purposes or disease, because these risks do not appear to be occurring at a level that affects Atlantic Pigtoe populations. Impairment of water quality, declines in flows, riparian and instream habitat fragmentation and degradation, as well as management efforts, are carried forward in our assessment of the future conditions of Atlantic Pigtoe MUs and populations, and the viability of the species overall.

CHAPTER 5 – FUTURE CONDITIONS

Thus far, we have considered Atlantic Pigtoe life history characteristics and we have identified the habitat and demographic requisites needed for viability and we estimated the current condition of those needs through the lens of the 3Rs (Chapters 2 and 3). Next, we reviewed the factors that may be driving the historical, current, and future conditions of the species (Chapter 4). In this chapter, we predict the species' future conditions given a range of plausible future scenarios. As with estimates of current condition, future forecasts were made using the concepts of resiliency, redundancy, and representation to describe the future viability of the Atlantic Pigtoe.

5.1 Future Scenario Considerations

We identified the main drivers of change for the future scenario analyses to be human population growth and subsequent urbanization rates, both of which are predicted to result in patterns of increased urban sprawl across the landscape (Terando et al. 2014, p.1). According to the United States Census, the human population in the southeastern US has grown at an average annual rate of 36.7% since 2000 (US Census 2016, pp. 1-4), by far the most rapidly growing region in the country. This rapid growth has resulted in expanding urbanization, sometimes referred to as "urban sprawl." Urban sprawl increases the connectivity of urban habitats while simultaneously fragmenting non-urban habitats such as forests and grasslands (Terando et al. 2014, p.1). In turn, species and ecosystems are impacted by the increased sprawl, including impacts to water pollution, local climate conditions, and disturbance dynamics (Terando et al. 2014, p.1). One way to forecast how these changes will affect the Atlantic Pigtoe is to look at the spatial pattern and extent of urban sprawl across historically and currently occupied watersheds, and build a model predicting the effects of that sprawl to the habitat elements that influence Atlantic Pigtoe populations.

To forecast future urbanization, we developed future scenarios that incorporate the SLEUTH (Slope, Land use, Excluded area, Urban area, Transportation, Hillside area) model, which simulates patterns of urban expansion that are consistent with spatial observations of past urban growth and transportation networks, including the sprawling, fragmented, "leapfrog" development that has been the dominant form of development in the Southeast (Terando et al. 2014, p.2). Terando et al. (2014) projected urban sprawl changes for the next 50 years for the fast-growing Southeastern United States, using simulations that point to a future in which the extent of urbanization in the Southeast is projected to increase by 101% to 192%. This projection is based on the "business-as-usual" (BAU) scenario in which the net effect of growth is in line with that which has occurred in the past (Terando et al. 2014, p.1; Figure 5-1), and as mentioned above, is in line with the Southeast being the fastest growing region in the country. While more sophisticated models exist, the SLEUTH model provides scalability, uses commonly available datasets, and is adaptable to focus on patterns of suburban and exurban development (Terando et al. 2014, p.2). The BAU scenario simulations do not consider alternative policies that could promote different urbanization patterns, however, the broad patterns of growth used do reflect recent trends in terms of the speed at which urbanization has progressed in the Southeast and in the locations that are most affected by it (Terando et al. 2014, p.7).

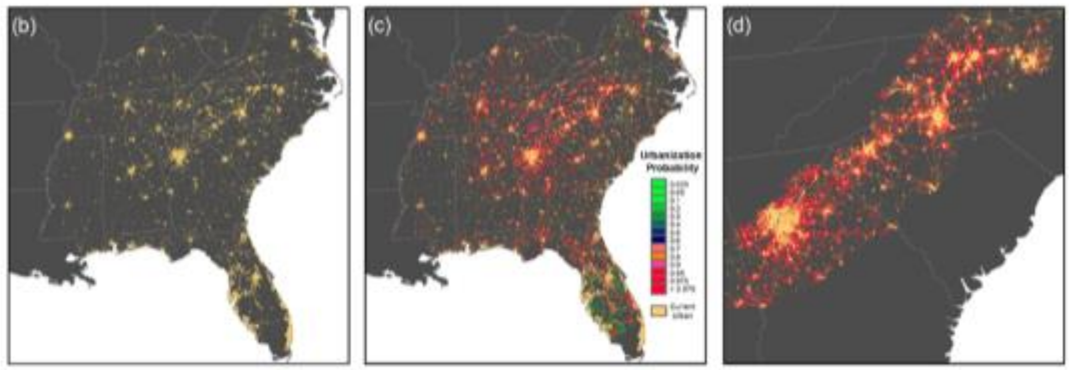


Figure 5-1 "Business-as-usual" urbanization scenario for the Southeast US from Terando et al. 2014, p.3. Red areas are the urban extent as classified by their methodology. (b) is the initial urban land cover in 2009; (c) is the projected urban land cover in 2060; and (d) is the projected urban land cover in the Piedmont ecoregion showing a connected urban landscape.

As discussed in section 4.1, the development promulgated from urban sprawl is expected to impact the habitat elements that were identified as essential for the survival of the Atlantic Pigtoe. Consequently, water quality and quantity will likely decline, habitat will become more fragmented, and instream substrate habitat may become less suitable for the species to survive. As such, this urban sprawl will, almost certainly, influence the ability of species to respond to climate change (Hannah 2011, p. 1141). Given all scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), greenhouse gas emissions are expected to continue at or above current rates which will lead to continued warming (Figure 5-2; IPCC 2013, p.7). Warming in the Southeast is expected to be greatest in the summer (NCCV 2016) which is predicted to increase drought frequency, while annual mean precipitation is expected to increase slightly, leading to increased flooding events (Figure 5-3; IPCC 2013, p.7; NCCV 2016).

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 IPCC's Fifth Assessment Report (AR5), published in 2014, presents findings based on a set of scenarios that use Representative Concentration Pathways (RCPs). The RCPs are representative of several different scenarios that have similar greenhouse gas emissions characteristics on a time-dependent trajectory to reach a certain projected outcome (Wayne 2013, p.1). 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 (RCP8.5); two intermediate stabilization pathways (RCP6.0 and RCP4.5); and one low trajectory pathway (RCP2.6 or RCP3PD)(Wayne 2013, p.11).

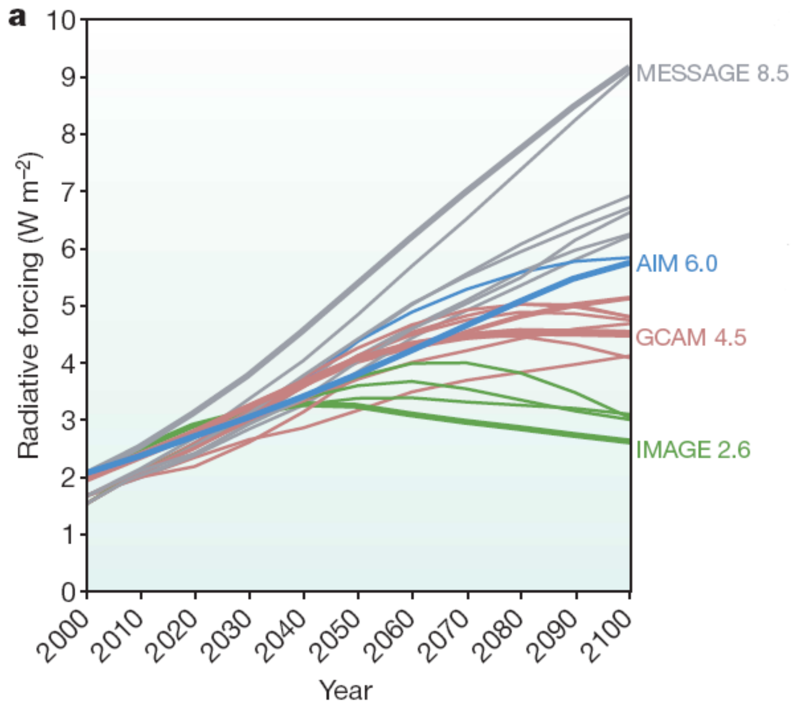


Figure 5-2 Changes in radiative forcing relative to pre-industrial conditions. Bold colored lines show the four RCPs; thin lines show individual scenarios from approximately 30 candidate RCP scenarios that provide information on all key factors affecting radiative forcing (from Moss et al. 2010).

RCP2.6 assumes that through drastic policy intervention, greenhouse gas emissions would be reduced almost immediately, leading to a slight reduction in today's levels by 2100; RCP8.5 assumes that emissions would be more or less unabated due to a lack of climate-change reversal policies (Wayne 2013, p.15). For RCP4.5 and RCP6.0, emissions are assumed to be relatively stable throughout the century, however RCP6.0 does not incorporate climate-reversal policies into forecasts, while RCP4.5 incorporates a number of climate policies into forecasts (Wayne 2013, p.15). As cited from DeWan et al. (2010, p.4), "it is difficult to predict the human choices that will shape our future emissions, and thus what the world might look like in 2100."

Changes in climate may affect ecosystem processes and communities by altering the abiotic conditions experienced by biotic assemblages resulting in potential effects on community composition and individual species interactions (DeWan et al. 2010, p.7). This is especially true for aquatic systems where climate change can trigger a cascade of ecological effects. For example, increases in air temperatures can lead to subsequent increases in water temperatures which, in turn, may lower water quality parameters (like dissolved oxygen), ultimately influencing overall habitat suitability for species like the Atlantic Pigtoe.

Despite the recognition of potential climate effects on ecosystem processes, there is uncertainty about what the exact climate future for the Southeastern US will be and how the ecosystems and species in this region will respond. In the "Threats" section of the North Carolina Wildlife Action Plan (NCWRC 2015, p.5-48), climate change is seen as a "low" threat to the Atlantic Pigtoe, with Small Scope (affecting 1-10% of the total population or occurrences) and Slight Severity (likely to only slightly degrade/reduce affected occurrences or habitat, or reduce the population by 1-10%). Furthermore, in an assessment of ecosystem response to climate change, factors associated with climate change ranked well below other factors that were deemed more imminent risks to Atlantic Pigtoe populations (e.g., development, pollution, water withdrawals, flood regime alteration, etc.; NCNHP 2010, entire). However, it should be recognized that the greatest threat from climate change may come from synergistic effects. That is, factors associated with a changing climate may act as risk multipliers by increasing the risk and severity of more imminent threats (Arabshahi and Raines 2012, p.8). As a result, impacts from rapid urbanization in the region might be exacerbated under even a mild to moderate climate future.

For future scenario predictions, we considered the "extreme" climate futures under RCPs 8.5 and 2.6 for the Pessimistic and Optimistic Scenarios respectively. Alternate climate scenarios were used to evaluate more moderate and/or stabilizing climate futures for the Status Quo and Opportunistic Scenarios (see Table 5-1 for details). Both of the "stabilizing" RCPs have a similar trajectory given our 50-year time frame (Figure 5-2); therefore, both RCP4.5 or RCP6.0 were used to help inform predictions related to a more moderate climate future. Regardless of a pessimistic, optimistic, opportunistic, or status quo climate future, the following systematic changes are expected to be realized to varying degrees in the Southeastern US (NCILT 2012, p.27; IPCC 2013, p.7):

- More frequent drought
- More extreme heat (resulting in increases in air and water temperatures, see Fig 5-3 below)
- Increased heavy precipitation events (e.g., flooding)
- More intense storms (e.g., frequency of major hurricanes increases)
- Rising sea level and accompanying storm surge

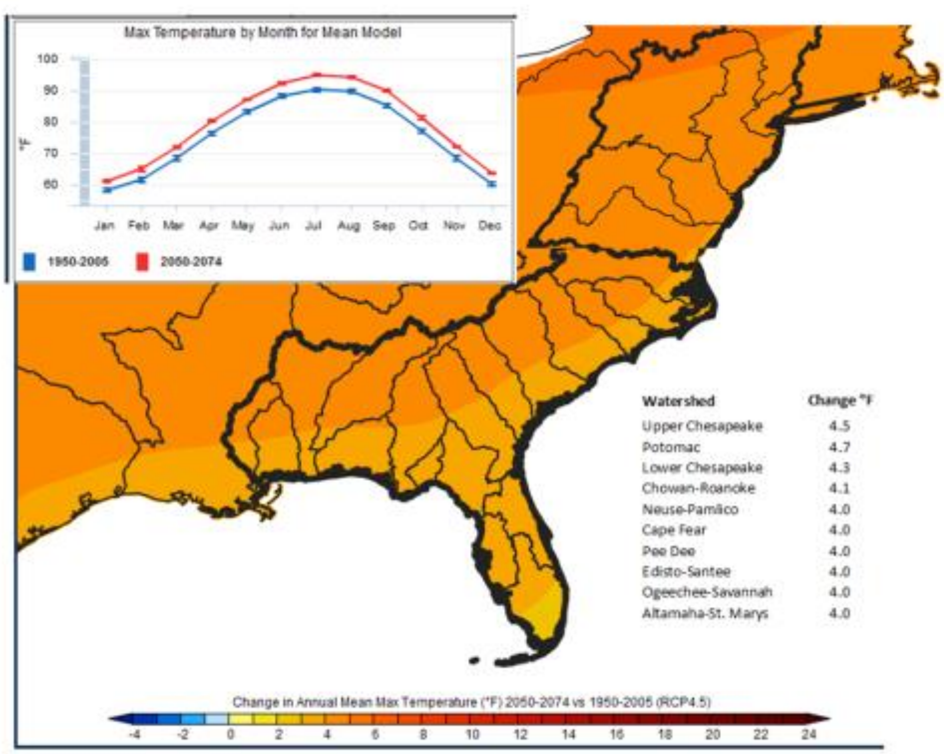


Figure 5-3 Predicted change in annual mean maximum air temperature under RCP4.5 (NCCV 2016)

5.1.1 The Scenarios

The Atlantic Pigtoe has declined precipitously in overall distribution and abundance. The species currently occupies approximately 40% of its historical range with most remaining populations being small and fragmented, occupying sporadic reaches compared to presumed historical populations, and several are isolated from one another. The prevailing hypothesis for this decline is habitat degradation, resulting from the cumulative impacts of land use change and subsequent watershed-level landscape changes that presumably impacted water quality, water quantity, habitat connectivity, and instream habitat suitability (see Chapter 4).

Populations in both large and small MUs face risks from both natural and anthropogenic sources. Climate change has already begun to affect the watersheds where Atlantic Pigtoe occurs, resulting in higher air temperatures and increased evaporation, and changing precipitation patterns such that water levels rangewide have already reached historic lows (NCILT 2012, p.6). These low water levels put the populations at elevated risk of habitat loss.

These risks, alone or in combination, could potentially result in the extirpation of additional populations, increasing population fragmentation, and, in turn, negative effects on species redundancy and representation. Given small and fragmented contemporary populations of Atlantic Pigtoe, maintaining future viability is largely reliant on preventing further declines in current populations and restoring/recovering population numbers and connectivity (where feasible). Because we have significant uncertainty regarding if and when flow loss, water quality impairment, or connectivity issues may occur, we have forecasted what the Atlantic Pigtoe may have in terms of the 3Rs under four plausible future scenarios.

Four scenarios, including a status quo scenario, were used to characterize the uncertainty regarding plausible futures for the Atlantic Pigtoe. Resiliency, representation, and redundancy were forecasted for each scenario using each of four possible climate futures coupled with variable levels of urbanization predicted by the SLEUTH BAU. Current levels of conservation management were assumed to be constant across all scenarios unless commitment of specific actions are currently, or will be imminently, in place. The expected future resiliency of each MU was forecasted based on events that were predicted to occur under each scenario. As with current condition estimates, estimates were made at the lowest hierarchical level (MUs) and were then scaled up to the population (i.e., river basin) level.

Predictions of Atlantic Pigtoe resiliency, redundancy, and representation were forecasted using a 50-year time horizon. This time horizon was chosen to correspond to the range of available urbanization and climate change model forecasts. Furthermore, 50-years represents a time frame during which the effects of management actions can be implemented and realized on the landscape, and it is a reasonable time frame (including approximately 4-5 generations) for the species to respond to potential changes on the landscape.

For these projections, high condition MUs were defined as those with high resiliency at the end of the predicted time horizon (50 years). MUs in high condition are expected to persist into the future, beyond 50 years, and have the ability to withstand stochastic events. MUs in moderate condition were defined as having lower resiliency than those in high condition but are still expected to persist to 50 years. Populations in moderate condition have lower abundances and reduced reproductive potential than those in high condition. Finally, those MUs in low condition were defined as having low resiliency and may not be able to withstand stochastic events. As a result, low condition MUs were predicted to be much less likely to persist 50 years into the future.

Table 5-1 Future Scenario Summary Table

			Future Condition Category Descriptions			
Scenario Name	**Climate Future**	**Urbanization**	**Species Condition**	**Water Quality Condition**	**Water Quantity Condition**	**Habitat Condition**
1) Status Quo Scenario	Current Climate effects continue on trend into the future, resulting in increased heat, drought, storms and flooding	Urbanization continues on trend with current levels	Current level of species response to impacts on landscape; current levels of propagation & augmentation and/or translocation capacity	Current level of regulation and oversight, including limited protective WQ[5] standards requirements and utilization of basic technologies for effluent treatment	Current level of regulation and oversight, including sustained IBTs[6] and irrigation withdrawals; current flow conditions	Current level of regulation, barrier improvement/removal projects, and riparian buffer protections
2) Pessimistic Scenario	Moderate to Worse Climate Future (RCP8.5[1])- exacerbated effects of climate change experienced related to heat, drought, storms and flooding	Urbanization rates at high end of BAU[4] model (~200%)	Species response to synergistic impacts on landscape result in significant declines coupled with limited propagation capacity and/or limited ability to augment/reintroduce propagules	Declining water quality resulting from increased impacts, limited regulation and restrictions, and overall reduced protections	Degraded flow conditions resulting from climate change effects, increased withdrawals and IBTs, limited regulation, and overall reduced protections	Degraded instream and riparian habitat conditions from increased impacts, limited regulation, fewer barrier improvement/removal projects, and overall reduced riparian buffer protections
3) Optimistic Scenario	Moderate to Improved Climate Future (trending towards RCP 2.6[2]) resulting in minimal effects of heat, drought, storms and flooding	Urbanization rates realized at lower levels than BAU model predicts (<100%)	Optimistic species response to impacts; targeted propagation and/or restoration efforts utilizing existing resources and capacity	Slightly increased impacts tempered by utilizing improved technologies and implementing protection strategies	Improved flow conditions through increased oversight and implementation of flow improvement strategies	Existing resources targeted to highest priority barrier removals; riparian buffer protections remain intact; targeted riparian connectivity projects; regulatory mechanisms remain the same
4) Opportunistic Scenario	Moderate Climate Future (RCP4.5/6[3]) - some climate change effects experienced; some areas impacted more than others by heat, drought, storms and flooding	Moderate BAU urbanization rates (~100%) realized	Selective improved species response to impacts as a result of targeted propagation and/or restoration efforts utilizing current resources and capacity	Moderate increase in WQ impacts resulting from continued levels of regulation, protection, and technology	Targeted strategies to improve flow conditions in priority areas	Targeted increase in riparian connectivity and protection of instream habitat in priority areas through targeted conservation efforts

[1]Representative concentration pathway 8.5
[2] Representative concentration pathway 2.6
[3] Representative concentration pathway 4.5/6
[4]Business as usual
[5]Water quality
[6]Interbasin transfer

5.2 Scenario 1 – Status Quo

Under the Status Quo scenario, factors that influence current populations of Atlantic Pigtoe were assumed to remain constant over the 50 year time horizon. Climate models predict that, if emissions continue at current rates, the Southeast Region will experience a rise in low flow (drought) events (IPCC 2013, p.7). Likewise, this scenario assumed the Business as Usual pattern of urban growth which predicted that urbanization would continue to increase rapidly (Terando et al. 2014, p.1). The Status Quo Scenario also assumed that current conservation efforts would remain in place but that no new actions would be taken. Below describe how factors affecting populations, including water quality, flow, and riparian cover, are expected to change given the Status Quo Scenario. Given predicted habitat conditions and current population factors (i.e., initial conditions) we then forecast Atlantic Pigtoe viability using the 3R framework.

- James – Due to the currently small population size in the the extreme headwaters MU (Craig Creek Subbasin) (B.Watson (VDGIF) email to S.McRae (USFWS) on 10/19/2016), this population will likely lose resiliency through a Status Quo Scenario, resulting in low population conditions despite continued moderate habitat conditions in Craig Creek into the future. The remaining five MUs are predicted to experience continued declining habitat conditions, resulting in the additional extirpation of the Atlantic Pigtoe from the Middle James (note: the species is currently extirpated from four of the other MUs) under the Status Quo Scenario.
- Chowan – Climate induced change, along with continued sedimentation from agricultural practices, is predicted to result in reduced flow in the Nottoway drainage as well as degraded instream habitats in both the Nottoway and Meherrin MUs (B.Watson (VDGIF) email to S.McRae (USFWS) on 10/19/2016; Table 3-2). The species is predicted to become extirpated in the both the Nottoway and Meherrin MUs under the Status Quo Scenario.
- Roanoke – On-trend degradation of habitat, specifically sedimentation issues stemming from agricultural practices (see Section 4.4), are predicted to result in reduced habitat conditions in the Dan River Subbasin such that the species will likely be extirpated from this MU under the Status Quo Scenario. The species is predicted to remain extirpated from the Roanoke MU.
- Tar – Continued climate induced changes that reduce flows (NCILT 2012, p.27), coupled with the continuation of water quality impacts are predicted to result in poor habitat conditions throughout the Upper/Middle Tar MU. Factors affecting water quality in the Upper/Middle Tar MU are wastewater treatment (e.g. basic effluent treatment technologies) and reduced riparian habitat protections (see Section 4.2; Table 5-2). Both the Fishing Creek and Sandy/Swift Creek MUs are predicted to maintain moderate habitat conditions in the Status Quo Scenario, thus perpetuating existing moderate population conditions into the future.
- Neuse – On-trend urbanization in both the Upper and Middle Neuse River basins is predicted to result in continued declines in water quality from stormwater runoff and wastewater effluent issues (see Section 4-1). Additionally this scenario predicts declines in water quantity as the area continues to withdraw water to support continued population growth, declines in habitat connectivity by maintaining existing dam infrastructure and

population-growth inducing more road crossings; all of these factors contribute to declining instream habitat for the species. These factors are likely to contribute to a precipitous overall decline in habitat for the species (Table 5-2), with predicted extirpation in the Middle Neuse MU.

- Cape Fear – On-trend urbanization is predicted to affect habitat quality via stormwater runoff (see Section 4-1) in the New Hope MU, reducing the species resiliency to low condition under the Status Quo Scenario. The Deep River MU is predicted to experience continued habitat declines via potential wastewater effluent issues and sedimentation from agricultural practices (see Section 4-4); the small, isolated occurrences are not predicted to persist under the status quo scenario. The other two MUs (Cape Fear mainstem and Black River) will remain extirpated.
- Pee Dee – The Status Quo scenario is predicted to see continued moderate habitat conditions in the Uwharrie/Little rivers MU, thus the Atlantic Pigtoe will continue to persist in low condition. The other two MUs for this population (Muddy Creek and Lanes/Goose creeks) are predicted to remain extirpated.
- Catawba – This population is predicted to remain extirpated under the Status Quo Scenario.
- Edisto – This population is predicted to remain extirpated under the Status Quo Scenario.
- Savannah – This population is predicted to remain extirpated under the Status Quo Scenario.
- Ogeechee – This population is predicted to remain extirpated under the Status Quo Scenario.
- Altamaha – This population is predicted to remain extirpated under the Status Quo Scenario.

5.2.1 Resiliency

Given the Status Quo Scenario, extant populations were predicted to persist in MUs where habitat conditions (described above and in Table 5-2) are expected to remain sufficient for Atlantic Pigtoe reproduction and survival. Only the Sandy/Swift MU and Fishing Creek MU were predicted to remain moderately resilient, while the Craig Creek MU, Upper/Middle Tar MU, Lower Tar MU, Upper Neuse MU, New Hope Creek MU, and Uwharrie/Little rivers MU were predicted to have low resiliency at the end of the predictive time horizon (Table 5-2). All other MUs were predicted to become extirpated.

Scaling up to the population level, only one population (Tar) is expected to have moderate resiliency, and four populations (James, Neuse, Cape Fear, and Pee Dee) are expected to retain low resiliency under the Status Quo Scenario. All other populations of Atlantic Pigtoe are predicted to become or remain extirpated in 50 years under the Status Quo scenario.

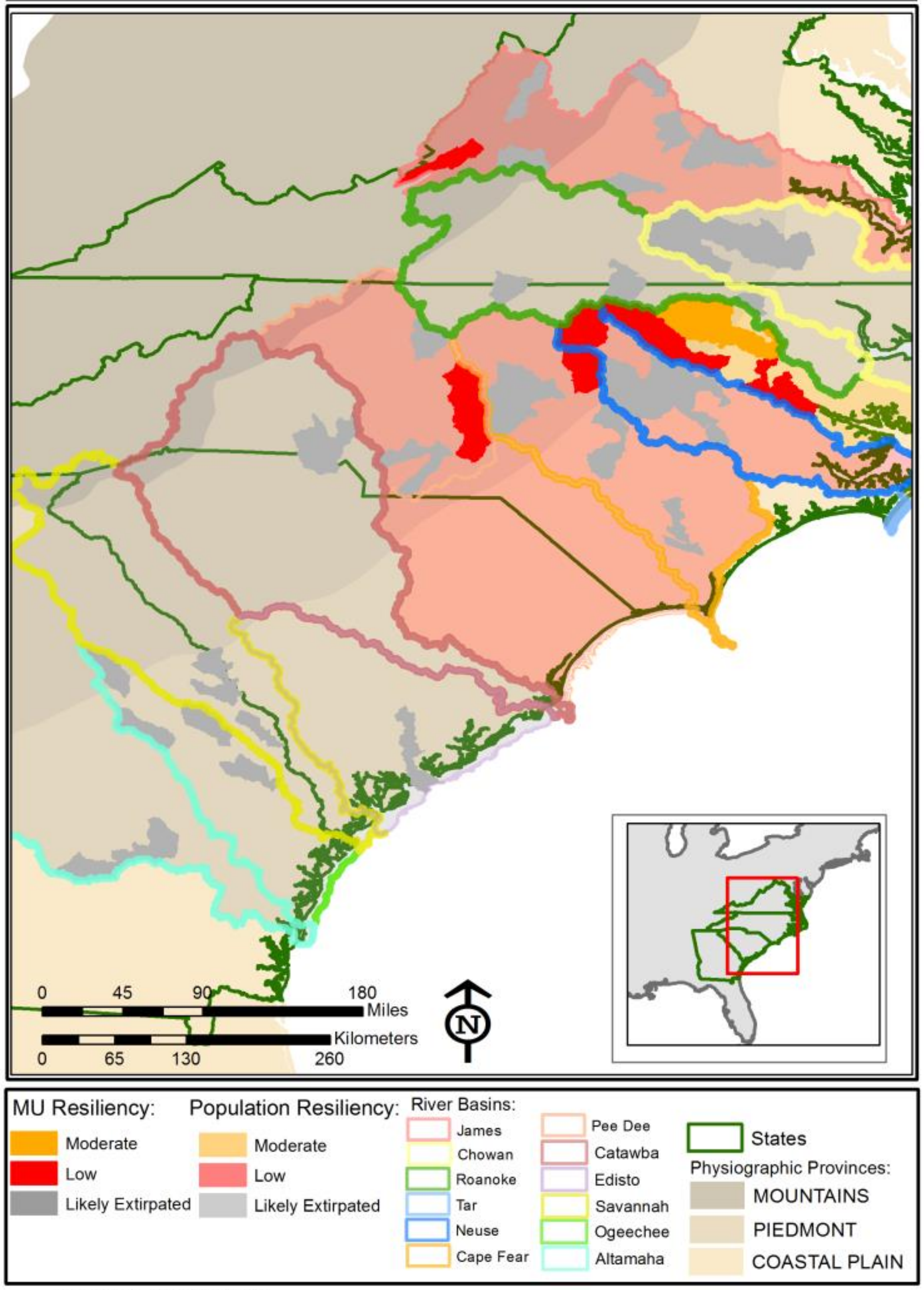
Table 5-2 Atlantic Pigtoe Resiliency under Scenario 1 - Status Quo

	Population Factors				Habitat Elements					
Population/ Management Unit	**MU Occupancy**	**Abundance**	**Reproduction**	**Combined Population Factors**	**Water Quality**	**Water Quantity**	**Connectivity**	**Instream Habitat (Substrate)**	**Combined Habitat Elements**	**Overall**
James										**Low**
Craig Creek Subbasin	Moderate	Low	Low	Low	Moderate	High	High	High	High	Low
Mill Creek	Ø	Ø	Ø	Ø	High	Moderate	High	High	High	Ø
Rivanna	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Upper James	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	Ø
Middle James	Ø	Ø	Ø	Ø	Very Low	Low	Low	Low	Low	Ø
Appomattox	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Low	Moderate	Ø
Chowan										**Ø**
Nottoway	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Meherrin	Ø	Ø	Ø	Ø	Low	Low	High	Moderate	Moderate	Ø
Roanoke										**Ø**
Dan R Subbasin	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Roanoke	Ø	Ø	Ø	Ø	Low	Low	Moderate	Low	Low	Ø
Tar										**Moderate**
Upper/Middle Tar	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Lower Tar	Low	Low	Low	Low	Low	Moderate	Moderate	Low	Low	Low
Fishing Ck Subbasin	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Moderate
Sandy Swift Ck	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Neuse										**Low**
Upper Neuse	Moderate	Low	Low	Low	Low	Low	Low	Low	Low	Low
Middle Neuse	Ø	Ø	Ø	Ø	Very Low	Very Low	Low	Low	Very Low	Ø
Cape Fear										**Low**
New Hope	Low	Low	Low	Low	Very Low	Low	Very Low	Low	Low	Low
Deep R Subbasin	Ø	Ø	Ø	Ø	Very Low	Moderate	Low	Low	Low	Ø
Cape Fear Mainstem	Ø	Ø	Ø	Ø	Very Low	Moderate	Low	Low	Low	Ø
Black	Ø	Ø	Ø	Ø	Low	High	High	Low	Moderate	Ø
Pee Dee										**Low**
Muddy Ck	Ø	Ø	Ø	Ø	Very Low	Very Low	Very Low	Very Low	Very Low	Ø
Uwharrie/Little	Low	Low	Low	Low	Moderate	Moderate	Low	Moderate	Moderate	Low
Goose/Lanes	Ø	Ø	Ø	Ø	Very Low	Very Low	Very Low	Low	Very Low	Ø
Catawba	Ø	Ø	Ø	Ø	Very Low	Low	Very Low	Very Low	Very Low	Ø
Edisto	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	Ø
Savannah	Ø	Ø	Ø	Ø	Very Low	Low	Very Low	Very Low	Very Low	Ø
Ogeechee	Ø	Ø	Ø	Ø	Low	Moderate	Low	Low	Low	Ø
Altamaha	Ø	Ø	Ø	Ø	Low	Moderate	Low	Low	Low	Ø

5.2.2 Representation

Given our measures of representation, including Physiographic, Latitudinal and River Basin Variability, we predicted that the Atlantic Pigtoe will have limited representation at the end of the predictive time horizon. Under the Status Quo Scenario, the species is expected to lose 58% of its known River Basin Variability with populations remaining only in the James, Tar, Neuse, Cape Fear, and Pee Dee River Basins. Physiographic Variability is also expected to decline precipitously in the Mountains (83%), the Piedmont (69%), and the Coastal Plain (90%). As for Latitudinal Variability, the species' occurrences are expected to further contract to the central basins (primarily the Tar River Basin), thus further reducing the species distribution (Figure 5-4).

Figure 5-4 ***Atlantic Pigtoe Status Quo Representation***



Map Date: 10/27/2016 File: AtlanticPigtoe_Maps.mxd
Data Source: USFWS

5.2.3 Redundancy

Under the Status Quo scenario, we predicted that the number of resilient Atlantic Pigtoe populations will decline considerably with likely extirpation in 20 of the 28 MUs; only the Tar Population retains more than one moderately resilient MU (Table 5-2). This expected loss in both the number and distribution of resilient populations is likely to make the species vulnerable to stochastic disturbance events.

5.3 Scenario 2 – Pessimistic

Factors that negatively influence Atlantic Pigtoe populations (see Chapter 4) get worse under the Pessimistic Scenario (Table 5-1). Reflecting RCP8.5 (Wayne 2013, p.11), effects of climate change are expected to be magnified beyond what is experienced in the Status Quo Scenario. Effects are predicted to result in extreme heat (Figure 5-5), more storms and flooding, and exacerbated drought conditions (IPCC 2013, p.7).

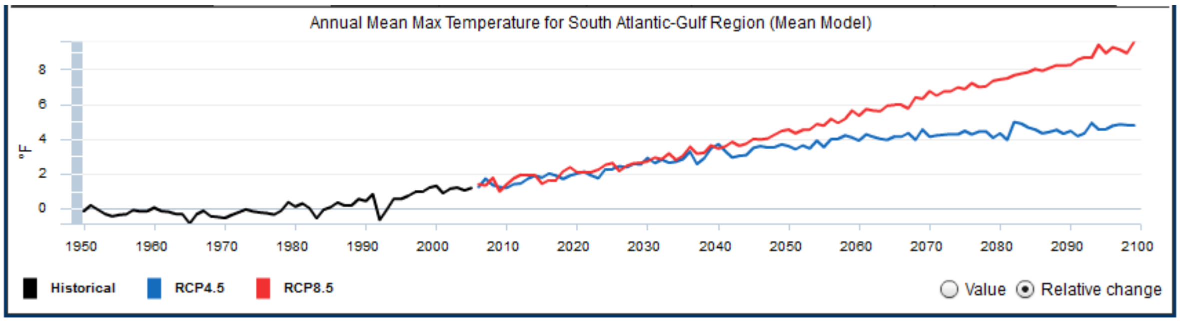


Figure 5-5 Time Series of Annual Mean Maximum Temperature under RCP8.5 (shown in red) (NCCV 2016)

Based on the results of the SLEUTH BAU model (Terando et al. 2014, entire), urbanization in Atlantic Pigtoe watersheds could expand to triple the amount of developed area resulting in large increases of impervious surface cover and, potentially, consumptive water use. Increased urbanization and climate change impacts are likely to result in increased impacts to water quality, flow, and habitat connectivity, and we predict that there is limited capacity for species restoration under this scenario.

- James – Habitat conditions in the Craig Creek Subbasin MU are predicted to decline under a Pessimistic Scenario, due primarily to climate-induced changes. The reduced habitat conditions will not sustain the small occurrence of Atlantic Pigtoes into the future. The remaining MUs are predicted to remain extirpated.
- Chowan – Under the Pessimistic Scenario, the species is predicted to not respond well to reduced habitat conditions, primarily from climate-induced impacts. Thus, Atlantic Pigtoes are expected to become extirpated from both the Nottoway and Meherrin MUs.
- Roanoke – Given the low numbers of individuals in the Roanoke Basin MUs, the species response to synergistic climate and urbanization impacts to the habitat result in the extirpation of this population under the Pessimistic Scenario.
- Tar – Under a Pessimistic Scenario, the extreme climate change future resulting in increased drought impacts coupled with basic effluent treatment in the upper Tar Basin is expected to cause reduced resiliency in the Upper/Middle Tar MU. Similarly, while the habitat conditions in the Fishing Creek and Sandy/Swift MUs are predicted to decline under a more extreme climate future and a high urbanization future, both MUs will likely retain the species albeit in low condition. The lower Tar MU is predicted to be extirpated because of synergistic climate and urbanization impacts affecting downstream portions of the basin.
- Neuse - High urbanization rates (up to 200% in 50-years, or double of what is currently occurring (Terando et al. 2014)) are predicted to further degrade habitat conditions, especially through water quality stressors and instream habitat unsuitability, thus the

species is not expected to persist in the Neuse River Basin under the Pessimistic Scenario.

- Cape Fear –High urbanization rates and declining habitat conditions, primarily water quality related impacts, are predicted to lead to the likely extirpation of this population of Atlantic Pigtoe under the Pessimistic Scenario.
- Pee Dee – Under the Pessimistic Scenario, the species is expected to remain extirpated from the Muddy Creek and Lanes/Goose creeks MUs. Sustained habitat conditions are predicted to enable the species to retain low resiliency in the Uwharrie/Little rivers MU.
- Catawba – This population is predicted to remain extirpated under the Pessimistic Scenario.
- Edisto – This population is predicted to remain extirpated under the Pessimistic Scenario.
- Savannah – This population is predicted to remain extirpated under the Pessimistic Scenario.
- Ogeechee – This population is predicted to remain extirpated under the Pessimistic Scenario.
- Altamaha – This population is predicted to remain extirpated under the Pessimistic Scenario.

5.3.1 Resiliency

The Pessimistic Scenario projects the condition of the Atlantic Pigtoe populations under a more extreme climate and urbanization future, with increased impacts and reduced species response. Under this scenario, there are only two remaining extant populations where habitat conditions support survival of the species, but at low levels (Table 5-3). There are no highly resilient populations nor are there any moderately resilient populations remaining under the Pessimistic Scenario; only the Upper/Middle Tar MU, Fishing Creek MU, Sandy/Swift MU, and Uwharrie/Little rivers MU are predicted to have low resiliency into the future. In this scenario, all the MUs in the James, Chowan, Roanoke, Neuse and Cape Fear basins are predicted to become extirpated.

At the population level, resiliency is severely reduced, and only two populations (Tar and Pee Dee) exist in low condition under the Pessimistic Scenario. Ten of the twelve populations of Atlantic Pigtoe are predicted to become extirpated in 50 years, however the reduced overall resiliency for the remaining populations under the Pessimistic scenario makes persistence of the species tenuous.

Table 5-3 Atlantic Pigtoe Resiliency under Scenario 2 - Pessimistic

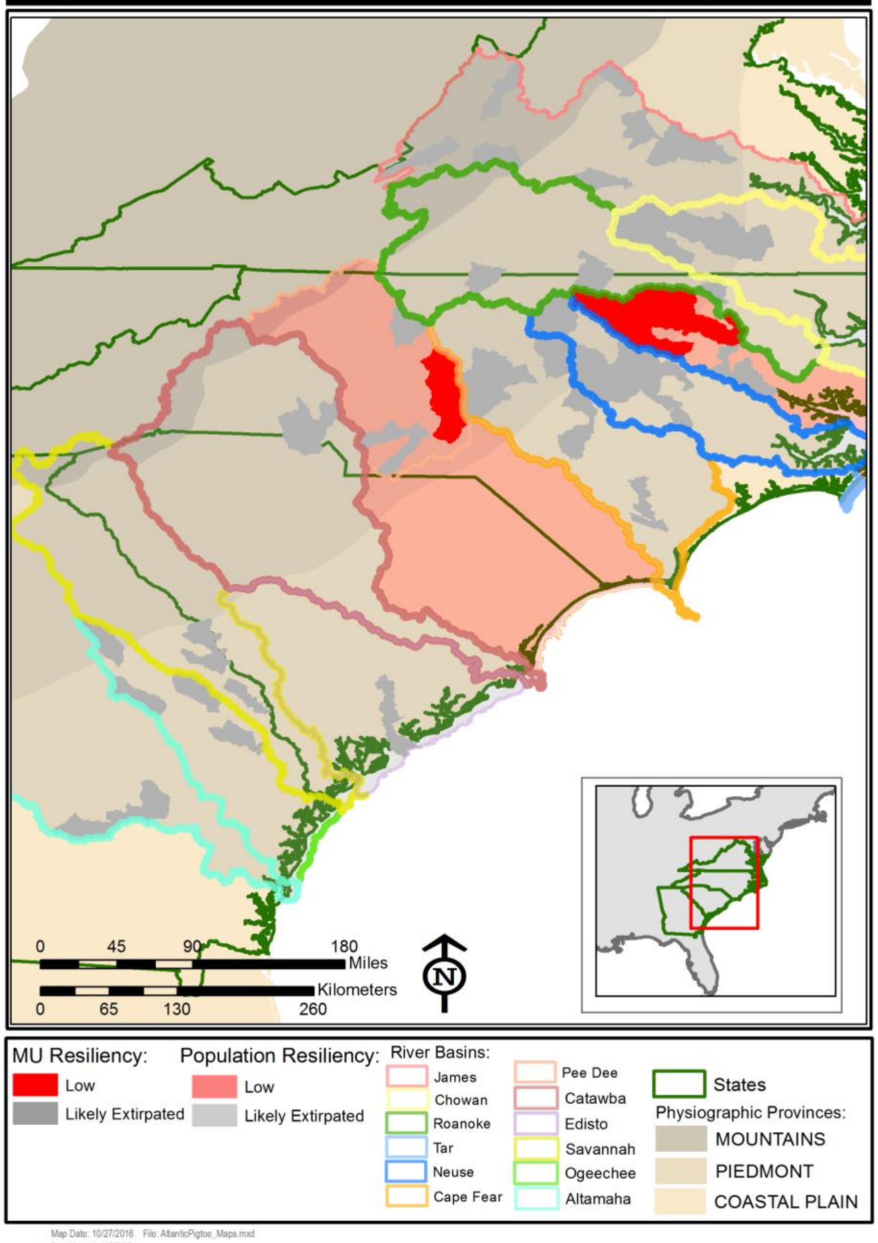
	Population Factors				Habitat Elements					
Population/ Management Unit	MU Occupancy	Abundance	Reproduction	Combined Population Factors	Water Quality	Water Quantity	Connectivity	Instream Habitat (Substrate)	Combined Habitat Elements	Overall
James										Ø
Craig Creek Subbasin	Ø	Ø	Ø	Ø	Low	Low	Moderate	Moderate	Moderate	Ø
Mill Creek	Ø	Ø	Ø	Ø	Low	Moderate	Low	Low	Low	Ø
Rivanna	Ø	Ø	Ø	Ø	Very Low	Low	Very Low	Very Low	Very Low	Ø
Upper James	Ø	Ø	Ø	Ø	Low	Moderate	Low	Moderate	Low	Ø
Middle James	Ø	Ø	Ø	Ø	Very Low	Low	Very Low	Very Low	Very Low	Ø
Appomattox	Ø	Ø	Ø	Ø	Low	Moderate	Low	Low	Low	Ø
Chowan										Ø
Nottoway	Ø	Ø	Ø	Ø	Low	Very Low	Low	Very Low	Low	Ø
Meherrin	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Roanoke										Ø
Dan R Subbasin	Ø	Ø	Ø	Ø	Very Low	Low	Low	Very Low	Low	Ø
Roanoke	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Tar										**Low**
Upper/Middle Tar	Low	Low	Low	Low	Very Low	Very Low	Low	Very Low	Very Low	Low
Lower Tar	Ø	Ø	Ø	Ø	Low	Moderate	Low	Low	Low	Ø
Fishing Ck Subbasin	Low	Moderate	Low	Low	Moderate	Low	Low	Low	Low	Low
Sandy Swift Ck	Moderate	Low	Low	Low	Low	Low	Moderate	Moderate	Low	Low
Neuse										Ø
Upper Neuse	Ø	Ø	Ø	Ø	Low	Low	Very Low	Low	Low	Ø
Middle Neuse	Ø	Ø	Ø	Ø	Very Low	Very Low	Low	Very Low	Very Low	Ø
Cape Fear										Ø
New Hope	Ø	Ø	Ø	Ø	Very Low	Low	Very Low	Very Low	Very Low	Ø
Deep R Subbasin	Ø	Ø	Ø	Ø	Very Low	Moderate	Low	Very Low	Low	Ø
Cape Fear Mainstem	Ø	Ø	Ø	Ø	Very Low	Low	Low	Low	Low	Ø
Black	Ø	Ø	Ø	Ø	Very Low	Moderate	Moderate	Low	Low	Ø
Pee Dee										**Low**
Muddy Ck	Ø	Ø	Ø	Ø	Very Low	Very Low	Very Low	Very Low	Very Low	Ø
Uwharrie/Little	Low	Low	Ø	Low	Low	Moderate	Low	Low	Low	Low
Goose/Lanes	Ø	Ø	Ø	Ø	Very Low	Very Low	Very Low	Low	Very Low	Ø
Catawba	Ø	Ø	Ø	Ø	Very Low	Low	Very Low	Very Low	Very Low	Ø
Edisto	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Low	Low	Ø
Savannah	Ø	Ø	Ø	Ø	Very Low	Low	Very Low	Very Low	Very Low	Ø
Ogeechee	Ø	Ø	Ø	Ø	Very Low	Low	Low	Low	Low	Ø
Altamaha	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø

5.3.2 Representation

Measures of representation – River Basin Variability, Physiographic Variability, and Latitudinal Variability – are expected to be reduced at the end of the predicted time horizon under the Pessimistic Scenario. The species is expected to lose 83% of its known River Basin Variability with populations remaining only in the Tar and Pee Dee river basins. Physiographic Variability is also expected to decline precipitously, with total loss in the Mountains (100%), and reductions in the Piedmont (77%) and Coastal Plain (92%). For Latitudinal Variability, the species' northernmost occurrence is expected to move south from the James (under current conditions) to the Tar (under predicted future conditions), and the species' southernmost occurrence is expected to stay in the Pee Dee, which is already a contraction from its once known southern-most occurrence in the Altamaha Basin (Figure 5-6).

At the population level, less than one sixth of the known populations maintain representation (Figure 5-6).

Figure 5-6 ***Atlantic Pigtoe Pessimistic Representation***



5.3.3 Redundancy

Under the Pessimistic scenario, we predicted that the Atlantic Pigtoe will lose considerable redundancy, with likely extirpation in 24 of the 28 MUs, and only one population (Tar) has redundancy with three MUs, although all are predicted to be in low condition. The expected loss in both the number and distribution of resilient populations will likely make the species extremely vulnerable to stochastic events.

5.4 Scenario 3 - Optimistic

Under the Optimistic Scenario, factors that influence the habitat conditions where Atlantic Pigtoe populations exist were predicted to slightly improve over the 50 year time horizon. Climate change effects are expected to be minimal, resulting in negligible heat, storm, and drought impacts (IPCC 2013, p.7). This scenario assumed urbanization to be slightly lower than what Business as Usual model predicts (Ternado et al. 2014, p.1). Water quality, flow, and habitat impacts are expected to be less severe as in other scenarios, thus the species is predicted to have an overall optimistic response. The capacity for species restoration under the Optimistic Scenario remains at current levels, however a stronger positive species response is predicted to occur relative to these targeted activities. There is also the possibility of the species turning up in new locations, as indicated below:

- James – Both habitat and population conditions remain resilient in the Craig Creek Subbasin under the Optimistic Scenario, and targeted species restoration (in conjunction with current associated-species restoration efforts) improves the Atlantic Pigtoe's adaptive capacity in the Craig Creek Subbasin MU. The condition of the remaining five MUs will not likely warrant targeted species restoration, therefore they are predicted to be likely extirpated in the future.
- Chowan – With minimal climate change effects and lower levels of urbanization, water quality, flow, and habitat conditions could remain in moderate condition under the optimistic future. Optimal species response is predicted to enable the species to persist, but since restoration efforts are not likely to be targeted in this watershed, the species is expected to only persist at low levels in the Nottoway MU. The species is expected to remain extirpated from the Meherrin MU.
- Roanoke – Improved habitat conditions through ongoing sedimentation-reduction efforts in the Dan River Subbasin, coupled with targeted species augmentations and optimal species' response, are predicted to enable the Atlantic Pigtoe to have moderate resiliency under the Optimistic Scenario. The Roanoke MU is expected to remain extirpated.
- Tar – Under the Optimistic Scenario, both urbanization and climate-induced impacts will be minimal in the Tar Basin. As such, habitat conditions, including water quality, flows, and instream and riparian habitat, are predicted to enable population persistence at moderate levels in the upper portions of the basin and at high levels in the Fishing Creek and Sandy/Swift MUs. Further, species restoration efforts will be continue to be targeted to the highest condition areas to improve overall Atlantic Pigtoe resiliency.
- Neuse – Targeted species restoration efforts in areas where future conservation efforts are predicted to be highest (i.e., the upper Neuse Basin, where water supply protections are expected) and in areas least affected by urbanization, coupled with optimal species response are expected to enable the persistence of the species into the future. The Upper Neuse MU is predicted to have moderate levels of resiliency, while the Middle Neuse, where urbanization impacts will likely be more prevalent, is predicted to have low levels of resiliency under the Optimistic Scenario.
- Cape Fear – Under the Optimistic Scenario, targeted species restoration efforts in the few areas least affected by urbanization (primarily the Rocky River watershed), coupled with optimal species response are predicted to enable the persistence of the species at

moderate levels in the Deep River Subbasin MU. It is possible that new locations will be discovered upon further future surveys in the Black River portion of the basin (B.Jones, pers.comm).

- Pee Dee – Optimal species response to minimal climate and urbanization futures are predicted to maintain habitat conditions, thus enabling the Atlantic Pigtoe to retain low resiliency in the Uwharrie/Little rivers MU under the Optimistic Scenario. The remaining MUs are predicted to remain extirpated.
- Catawba - This population is predicted to remain extirpated under the Optimistic Scenario.
- Edisto - This population is predicted to remain extirpated under the Optimistic Scenario.
- Savannah - This population is predicted to remain extirpated under the Optimistic Scenario.
- Ogeechee - This population is predicted to remain extirpated under the Optimistic Scenario.
- Altamaha - This population is predicted to remain extirpated under the Optimistic Scenario.

5.4.1 Resiliency

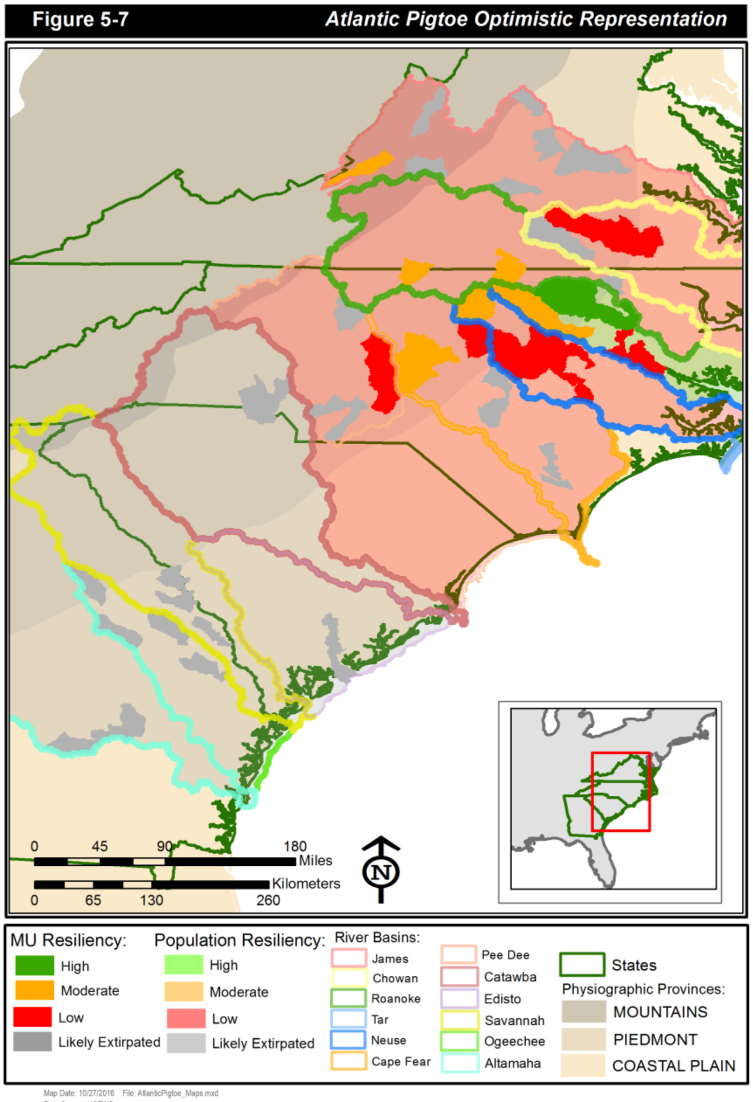
The Optimistic Scenario predicts the condition of the Atlantic Pigtoe populations if the current risks are on a slightly improved trend from what they are on now. Under this scenario, the remaining extant populations occur in areas where habitat conditions support continued reproduction and survival of the species, at varying levels. The Tar River population is predicted to be highly resilient under the Optimistic Scenario, with the Sandy/Swift and Fishing Creek MUs maintaining high condition. The remaining extant populations are expected to maintain low levels of resiliency. Overall, no additional population extirpations are predicted under the Optimistic Scenario, but the five southern-most populations remain extirpated (Figure 5-7).

Table 5-3 Atlantic Pigtoe Resiliency under Scenario 3 - Optimistic

	Population Factors				Habitat Elements					
Population/ Management Unit	MU Occupancy	Abundance	Reproduction	Combined Population Factors	Water Quality	Water Quantity	Connectivity	Instream Habitat (Substrate)	Combined Habitat Elements	Overall
James										**Low**
Craig Creek Subbasin	High	Moderate	Moderate	Moderate	Moderate	High	High	High	High	Moderate
Mill Creek	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	Ø
Rivanna	Ø	Ø	Ø	Ø	Moderate	Low	Low	Low	Low	Ø
Upper James	Ø	Ø	Ø	Ø	High	Moderate	Moderate	High	Moderate	Ø
Middle James	Ø	Ø	Ø	Ø	Moderate	Low	Moderate	Low	Low	Ø
Appomattox	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Low	Moderate	Ø
Chowan										**Low**
Nottoway	Low	Moderate	Low	Low	Low	Low	Low	Low	Low	Low
Meherrin	Ø	Ø	Ø	Ø	Moderate	Moderate	High	Moderate	Moderate	Ø
Roanoke										**Low**
Dan R Subbasin	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Roanoke	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	Ø
Tar										**High**
Upper/Middle Tar	High	Moderate	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate
Lower Tar	Low	Moderate	Low	Low	Low	Moderate	Moderate	Moderate	Moderate	Low
Fishing Ck Subbasin	High	High	Moderate	High	Moderate	Moderate	High	Moderate	Moderate	High
Sandy Swift Ck	High	High	Moderate	High	Moderate	Moderate	High	Moderate	Moderate	High
Neuse										**Low**
Upper Neuse	Moderate	Moderate	Low	Moderate	Low	Low	Low	Low	Low	Moderate
Middle Neuse	Low	Low	Low	Low	Low	Very Low	Low	Low	Low	Low
Cape Fear										**Low**
New Hope	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Deep R Subbasin	Moderate	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Low	Moderate	Moderate
Cape Fear Mainstem	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Low	Low	Ø
Black	Ø	Ø	Ø	Ø	Moderate	High	Moderate	Moderate	Moderate	Ø
Pee Dee										**Low**
Muddy Ck	Ø	Ø	Ø	Ø	Low	Very Low	Low	Very Low	Low	Ø
Uwharrie/Little	Low	Low	Low	Low	Moderate	Moderate	Low	Moderate	Moderate	Low
Goose/Lanes	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Catawba	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	**Ø**
Edisto	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	**Ø**
Savannah	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	**Ø**
Ogeechee	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	**Ø**
Altamaha	Ø	Ø	Ø	Ø	Low	Moderate	Low	Low	Low	**Ø**

5.4.2 Representation

Under the Optimistic Scenario, it is predicted that the Atlantic Pigtoe will retain current levels of representation, with 58% of its River Basin Variability. Under the Optimistic Scenario, the species is predicted to retain very limited Physiographic variability in the Coastal Plain (21%) and Mountains (17%), and moderate variability in the Piedmont (54%). At the population level, only one population (Tar) will have high condition representation 50 years into the future under the Optimistic Scenario, whereas six populations (James, Chowan, Roanoke, Neuse, Cape Fear and Pee Dee) will have low condition representation, and five populations will remain extirpated (Figure 5-7).



5.4.3 Redundancy

Under the Optimistic scenario, we predicted that the Atlantic Pigtoe will have redundancy in the Tar, Neuse, and Cape Fear River basins. Only the Tar River Population will have high resiliency with two MUs in high condition, one in moderate condition, and one in low condition. The five populations that are currently presumed extirpated are predicted to remain extirpated. Scaling up to the population level, this leaves the species with seven of the twelve (historically) populations under the Optimistic Scenario.

5.5 Scenario 4 – Opportunistic

Under the Opportunistic Scenario, landscape-level factors (e.g., development and climate change) that influence populations of Atlantic Pigtoes are predicted to get moderately worse (Table 5-1). Climate change effects are moderate, resulting in some increased impacts from heat, storms, and droughts (IPCC 2013, p.7). Urbanization is predicted to be at moderate BAU model levels (Terando et al. 2014), indicating approximately double the amount of developed area compared to what currently exists. The species is expected to respond poorly to the synergistic water quality, flow, and habitat connectivity impacts on the landscape, however, there is some continued capacity for species restoration which is targeted in areas that are less heavily impacted.

- James – Habitat conditions are expected to remain unchanged in the Craig Creek Subbasin (Table 5-4), and the population continues in moderate condition under the Opportunistic Scenario. The remaining MUs however, experience expected habitat degradation from climate and urbanization-induced impacts, and under the Opportunistic Scenario conditions the species is predicted to be extirpated from these MUs.
- Chowan – Under the Opportunistic Scenario, the moderate climate future will likely affect habitat conditions (see Section 4-3) in both the Nottoway and Meherrin MUs such that the species is expected to persist at low levels only in the Nottoway MU, and is predicted to be extirpated from the Meherrin MU.
- Roanoke – Under the Opportunistic Scenario, we predicted that future habitat conditions (Table 5-4) would not be sufficient to enable species persistence in the Dan River Basin. The Atlantic Pigoe is expected to remain extirpated in the Roanoke MU.
- Tar – Under the Opportunistic Scenario, the moderate climate-induced impacts are expected to result in continued drought issues in the Upper/Middle Tar MU, resulting in low resilience for this MU. Potential storm related windthrow issues in the Sandy/Swift MU are predicted to result in moderate resilience for this MU. Habitat in the lower Tar is expected to decline, thus preventing species persistence, and moderate habitat conditions in Fishing Creek plus existing targeted species restoration will likely sustain a moderately resilient population condition for the species in this MU into the future.
- Neuse – Impacts from urbanization, including declining water quality from stormwater runoff, wastewater effluent issues, and decreased flows from consumptive use, along with minimal development restrictions (Section 4-2) are predicted to lead to species extirpation in the Middle Neuse MU under the Opportunistic Scenario. The species is expected to continue to persist at low resiliency levels in the Upper Neuse MU because of potential water supply watershed protections, and possible targeted species restoration efforts.
- Cape Fear – Under the Opportunistic Scenario, habitat conditions in the rapidly urbanizing New Hope Creek MU are predicted to lead to species extirpation. Habitat restoration and conservation efforts in the Deep River Subbasin MU, coupled with possible species restoration efforts, will likely sustain the Atlantic Pigtoe at low levels of resilience. The Cape Fear mainstem and Black River MUs are predicted to remain extirpated.
- Pee Dee - The Opportunistic Scenario predicts continued moderate habitat conditions in the Uwharrie/Little rivers MU, thus the Atlantic Pigtoe is expected to continue to persist

in low condition. The other two MUs for this population (Muddy Creek and Lanes/Goose creeks) are expected to remain extirpated.

- Catawba - This population is expected to remain extirpated under the Opportunistic Scenario.
- Edisto - This population is expected to remain extirpated under the Opportunistic Scenario.
- Savannah - This population is expected to remain extirpated under the Opportunistic Scenario.
- Ogeechee - This population is expected to remain extirpated under the Opportunistic Scenario.
- Altamaha - This population is expected to remain extirpated under the Opportunistic Scenario.

5.5.1 Resiliency

The Opportunistic Scenario predicts the condition of the Atlantic Pigtoe populations if the risks continue at moderately increased levels compared to what they are now. Under this scenario, the remaining extant populations occur in areas where habitat conditions support continued reproduction and survival of the species, at varying levels. None of the MUs are expected to have high resiliency under this scenario. Only the Craig Creek Subbasin, Fishing Creek Subbasin, and Sandy-Swift Creek MU are expected to have moderate resiliency; whereas the remaining extant MUs (Nottoway, Upper/Middle Tar, Upper Neuse, Deep River Subbasin and Uwharrie/Little rivers) are predicted to retain low resiliency. At the population level, only one population (Tar) retains moderate resiliency. Under this scenario, it is predicted that six of the twelve populations of Atlantic Pigtoe will become/remain extirpated and the remaining six populations will have reduced resiliency in 50 years.

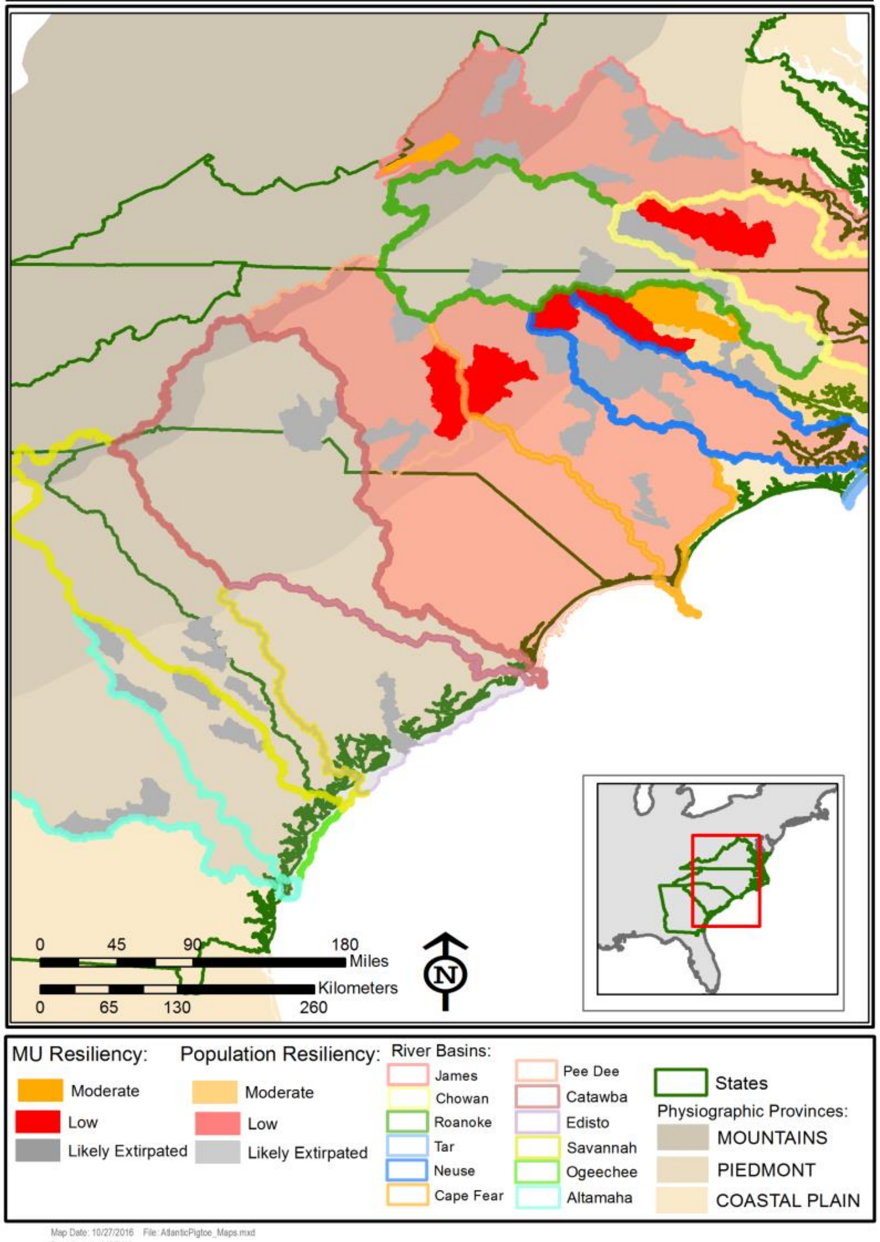
Table 5-4 Atlantic Pigtoe Resiliency under Scenario 3 - Opportunistic

	Population Factors				Habitat Elements					
Population/ Management Unit	MU Occupancy	Abundance	Reproduction	Combined Population Factors	Water Quality	Water Quantity	Connectivity	Instream Habitat (Substrate)	Combined Habitat Elements	Overall
James										Low
Craig Creek Subbasin	Moderate	Moderate	Low	Moderate	Moderate	High	High	High	High	Moderate
Mill Creek	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	Ø
Rivanna	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Upper James	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	Ø
Middle James	Ø	Ø	Ø	Ø	Very Low	Low	Low	Low	Low	Ø
Appomattox	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Low	Moderate	Ø
Chowan										Low
Nottoway	Low	Moderate	Low	Low	Moderate	Low	Low	Moderate	Moderate	Low
Meherrin	Ø	Ø	Ø	Ø	Low	Moderate	High	Moderate	Moderate	Ø
Roanoke										Ø
Dan R Subbasin	Ø	Ø	Ø	Ø	Low	Low	Moderate	Low	Low	Ø
Roanoke	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Low	Low	Ø
Tar										Moderate
Upper/Middle Tar	Moderate	Moderate	Low	Moderate	Low	Low	Moderate	Low	Low	Low
Lower Tar	Low	Low	Low	Low	Low	Moderate	Moderate	Low	Low	Ø
Fishing Ck Subbasin	Moderate	High	Moderate	High	Moderate	Moderate	High	Moderate	Moderate	Moderate
Sandy Swift Ck	Moderate	High	Moderate	Moderate	Moderate	Moderate	High	Moderate	High	Moderate
Neuse										Low
Upper Neuse	Low	Moderate	Low	Low	Low	Low	Low	Low	Low	Low
Middle Neuse	Ø	Ø	Ø	Ø	Very Low	Very Low	Low	Low	Very Low	Ø
Cape Fear										Low
New Hope	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Deep R Subbasin	Low	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Low
Cape Fear Mainstem	Ø	Ø	Ø	Ø	Very Low	Moderate	Moderate	Low	Low	Ø
Black	Ø	Ø	Ø	Ø	Low	High	Moderate	Low	Moderate	Ø
Pee Dee										Low
Muddy Ck	Ø	Ø	Ø	Ø	Very Low	Very Low	Very Low	Very Low	Very Low	Ø
Uwharrie/Little	Low	Low	Ø	Low	Moderate	Moderate	Low	Moderate	Moderate	Low
Goose/Lanes	Ø	Ø	Ø	Ø	Very Low	Very Low	Very Low	Low	Very Low	Ø
Catawba	Ø	Ø	Ø	Ø	Very Low	Low	Very Low	Very Low	Very Low	Ø
Edisto	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	Ø
Savannah	Ø	Ø	Ø	Ø	Very Low	Low	Very Low	Very Low	Very Low	Ø
Ogeechee	Ø	Ø	Ø	Ø	Moderate	Moderate	Low	Moderate	Moderate	Ø
Altamaha	Ø	Ø	Ø	Ø	Low	Moderate	Low	Low	Low	Ø

5.5.2 Representation

Given our measures of representation, including River Basin, Physiographic, and Latitudinal Variability, we predicted that Atlantic Pigtoe will have limited representation at the end of the predicted time horizon (Figure 5-8). Under the Opportunistic Scenario, the species is expected to lose 50% of its known River Basin Variability with populations remaining in the James, Chowan, Tar, Neuse, Cape Fear, and Pee Dee River basins. Physiographic Variability is expected to decline, with considerable losses in the Mountains (83%) and Coastal Plain (91%), in addition to losses in the Piedmont (57%). As for Latitudinal Variability, the species' occurrences are predicted to remain contracted, with continued extirpation in the southern portion of the range.

Figure 5-8 ***Atlantic Pigtoe Opportunistic Representation***



5.5.3 Redundancy

Under the Opportunistic Scenario, we predicted that the number of resilient Atlantic Pigtoe populations will decline considerably with likely extirpation in 20 of the 28 MUs, and only the Tar Population is predicted to have multiple moderately resilient MUs into the future. This expected loss in both the number and distribution of resilient populations is likely to make the species vulnerable to stochastic disturbance events.

5.6 Status Assessment Summary

Future Viability Summary

The goal of this assessment was to describe the viability of the Atlantic Pigtoe in terms of resiliency, representation, and redundancy by using the best science available at the time of the analysis. To capture the uncertainty associated with the degree and extent of potential future risks and their impacts on species' needs, each of the 3Rs were assessed using four plausible future scenarios (Status Quo, Pessimistic, Optimistic, and Opportunistic). These scenarios were based, in part, on the results of urbanization (Terando et. al. 2014) and climate models (IPCC 2013) that predict changes in habitat used by the Atlantic Pigtoe. The results of the predictive analysis describe a range of possible conditions in terms of the number and distribution of Atlantic Pigtoe populations (Table 5-6). It is important to note that not all scenarios have the same probability of occurrence at any one time step. To account for this, a discretized range of probabilities (Table 5-7) were used to describe the likelihood of scenario occurrence at a 50 year time-step based on professional judgment (Table 5-8). (Note: the range of likelihoods in Table 5-7 was based on IPCC guidance (Mastrandea et al. 2011) and has been accepted and is understood relatively well by and in the scientific community).

Table 5-6 Summary of future scenario outcomes

		Future Scenarios of Population Conditions			
POPULATIONS: Management Units	Current	#1 Status Quo	#2 Pessimistic	#3 Optimistic	#4 Opportunistic
James: Craig Creek Subbasin	Moderate	Low	Likely Extirpated	Moderate	Moderate
James: Mill Creek	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
James: Rivanna	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
James: Upper James	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
James: Middle James	Very Low	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
James: Appomattox	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Chowan: Nottoway	Moderate	Likely Extirpated	Likely Extirpated	Low	Low
Chowan: Meherrin	Low	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Roanoke: Dan River Subbasin	Low	Likely Extirpated	Likely Extirpated	Moderate	Likely Extirpated
Roanoke: Roanoke	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Tar: Upper/Middle Tar	High	Low	Low	Moderate	Low
Tar: Lower Tar	Low	Low	Likely Extirpated	Low	Likely Extirpated
Tar: Fishing Ck	High	Moderate	Low	High	Moderate
Tar: Sandy-Swift	High	Moderate	Low	High	Moderate
Neuse: Upper Neuse	Moderate	Low	Likely Extirpated	Moderate	Low
Neuse: Middle Neuse	Moderate	Likely Extirpated	Likely Extirpated	Low	Likely Extirpated
Cape Fear: New Hope	Moderate	Low	Likely Extirpated	Low	Likely Extirpated
Cape Fear: Deep River Subbasin	Low	Likely Extirpated	Likely Extirpated	Moderate	Low
Cape Fear: Mainstem	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Cape Fear: Black	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Pee Dee: Muddy	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Pee Dee: Uwharrie/Little	Low	Low	Low	Low	Low
Pee Dee: Goose/Lanes	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Catawba	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Edisto	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Savannah	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Ogeechee	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Altamaha	Presumed Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated

Table 5-7 Explanation of confidence terminologies used to estimate the likelihood of scenario (after IPCC guidance, Mastrandrea et al. 2011).

Confidence Terminology	Explanation
Very likely	We are **greater than 90% sure** that this scenario will occur.
Likely	We are **70-90% sure** that this scenario will occur.
As Likely As Not	We are **40-70% sure** that this scenario will occur.
Unlikely	We are **10-40% sure** that this scenario will occur.
Very unlikely	We are **less than 10% sure** that this scenario will occur.

Table 5-8 Likelihood of Scenario occurrence at 50 years

	#1 Status Quo	#2 Pessimistic	#3 Optimistic	#4 Opportunistic
Likelihood of Scenario Occurring at 50 Years	Very Likely	Likely	As Likely As Not	As Likely As Not

An important assumption of the predictive analysis was that future population resiliency is largely dependent on water quality, water flow, riparian, and instream habitat conditions. Our assessment predicted that at least seven (of 12) currently extant Atlantic Pigtoe populations would experience negative changes to these important habitat requisites. Predicted viability varied amongst scenarios and is summarized below and in Table ES-3.

Given Scenario 1, the "Status Quo" option, a substantial loss of resiliency, representation, and redundancy is expected. Under this scenario, we predicted that no MUs would remain in high condition, two in moderate condition, six in low condition, and the remaining MUs (20) would be likely extirpated. Redundancy would be reduced with likely extirpation of six out of 14 currently extant MUs; only the Tar Population retains more than one moderately resilient MU. Representation would be reduced, with only five (42%) of the former river basins occupied, and with extremely limited variability in the Mountains and Coastal Plain, and reduced variability in the Piedmont. This scenario is very likely at the 50 year time-step (Tables 5-7, 5-8).

Given Scenario 2, the "Pessimistic" option, we predicted a near complete loss of resiliency, representation, and redundancy. Redundancy would be reduced to two populations (i.e., likely extirpation of 10 populations), and the resiliency of those populations is expected to be low. The majority of MUs are predicted to be extirpated, and of the remaining four MUs, all would be in low condition. Representation is reduced with only 17% of the former river basins occupied, and all Mountain representation and nearly all Coastal Plain representation is lost. This scenario is likely at the 50 year time-step (Tables 5-7, 5-8).

Given Scenario 3, the "Optimistic" option, we predicted slightly higher levels of resiliency, representation, and redundancy in some areas than was estimated for the Status Quo Scenario. Two MUs are predicted to maintain high condition, five are predicted to be in moderate condition, five in low condition, and the remaining 16 MUs are predicted to be likely extirpated. Despite all current populations continuing to persist, only the Tar population would retain moderate levels of resiliency. Existing levels of representation are predicted to remain unchanged under this scenario. This scenario is as likely as not at the 50 year time-step (Tables 5-7, 5-8), primarily because it will take many years for effects of management actions to be realized on the landscape.

Given Scenario 4, the "Opportunistic" option, we predicted reduced levels of resiliency, representation, and redundancy. No MUs are predicted to be in high condition, three in moderate condition, five in low condition, and 20 are predicted to be likely extirpated. Redundancy would be reduced by losing 6 MUs compared to current condition. Representation is predicted to be reduced with only six (50%) of the former 12 populations occupied, and with reduced variability in the Mountains, Piedmont, and Coastal Plain. This scenario is likely at the 50 year time-step (Tables 5-7, 5-8).

Current Viability Summary

The historical range of the Atlantic Pigtoe included streams and rivers in the Atlantic Slope drainages from the James River Basin to the Altamaha River Basin with the documented historical distribution in 28 MUs within twelve former populations. The Atlantic Pigtoe is presumed extirpated from 50% (14) of the historically occupied MUs. Of the remaining 14 occupied MUs, only three (21%) are estimated to be highly resilient, five (36%) are moderately resilient, and six (43%) have low resiliency. Scaling up from the MU to the population level, one of twelve former populations (the Tar Population) was estimated to have high resiliency, one population (the Neuse Population) was estimated to have moderate resiliency, five populations (James, Chowan, Roanoke, Cape Fear, Pee Dee) had low estimated resiliency, and five of the former 12 populations are presumed extirpated, thus eliminating 42%, or the entire southern portion, of the species' range. 71% of streams that remain part of the current species' range aere estimated to be in low condition, potentially putting the Atlantic Pigtoe at risk of extirpation. Once known to occupy streams in three physiographic regions, the species has also lost substantial physiographic representation. An estimated 67% loss has occurred in the Mountain watersheds, 48% loss in the Piedmont, and 76% loss in the Coastal Plain watersheds.

Overall Summary

Estimates of current and future resiliency for Atlantic Pigtoe are low, as are estimates for representation and redundancy. The Atlantic Pigtoe faces a variety of threats from declines in water quality, loss of stream flow, riparian and instream fragmentation, and deterioration of instream habitats. These threats, which are expected to be exacerbated by urbanization and climate change, were important factors in our assessment of the future viability of the Atlantic Pigtoe. Given current and future decreases in resiliency, populations become more vulnerable to extirpation from stochastic events, in turn, resulting in concurrent losses in representation and redundancy. Predictions of Atlantic Pigtoe habitat conditions and population factors suggest possible extirpation in up to five of seven currently extant populations. The two populations predicted to remain extant at the end of the predictive time horizon are expected to be characterized by low occupancy and abundance.

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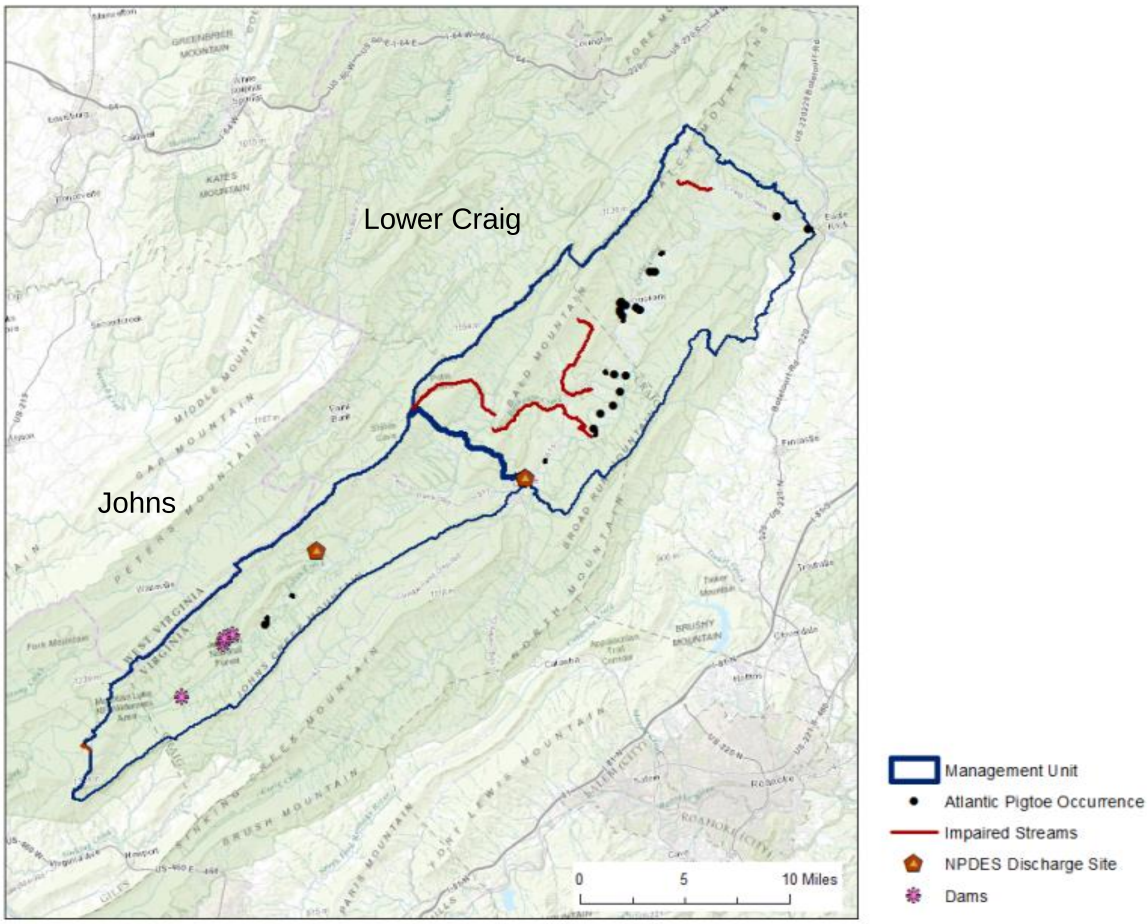
APPENDIX A – Atlantic Pigtoe Distribution Information

James River Population

Consists of six MUs: Craig Creek Subbasin, Mill Creek, Rivanna River, Upper James River, Middle James River, and Appamattox River.

Craig Creek Subbasin Management Unit

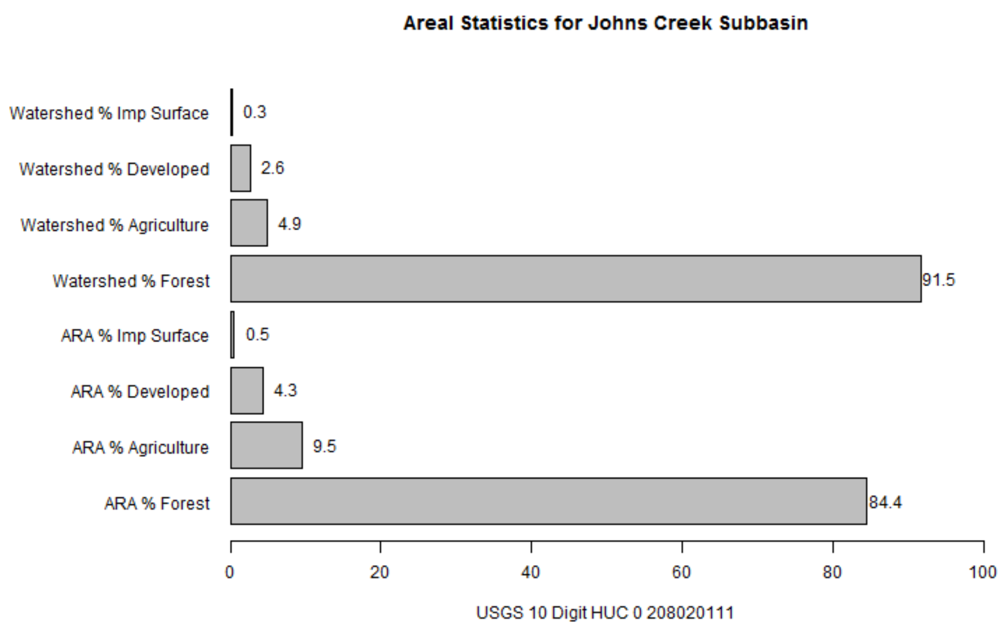


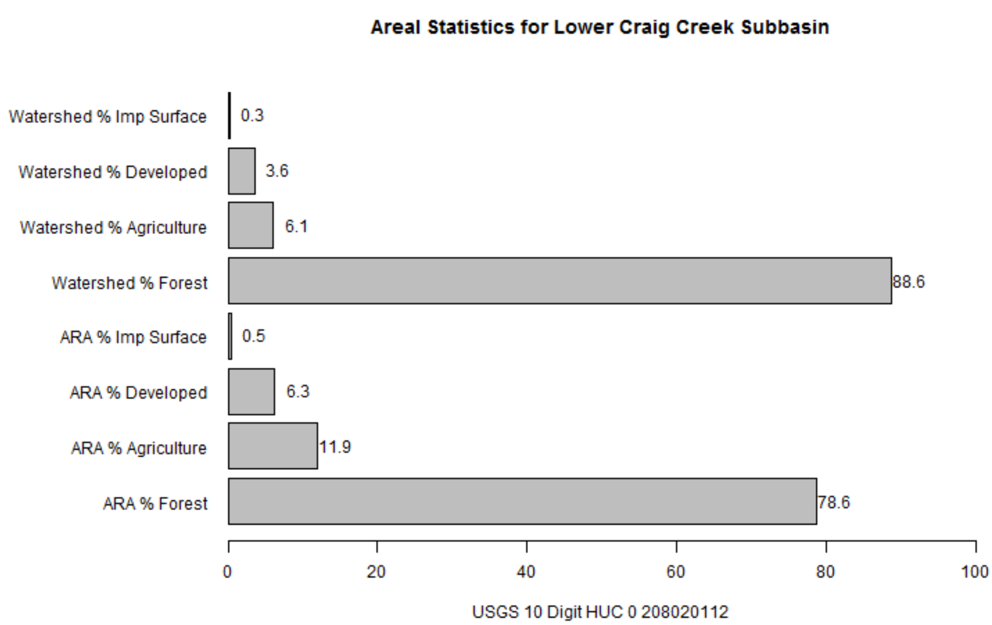
Survey Summary: There have been nearly 30 surveys at several locations throughout Johns and Craig Creek in this two 10-digit HUC MU. The species was first discovered in the Craig Creek Subbasin in the mid-1980s. The majority of surveys described the abundance of Atlantic Pigtoes as “rare”, with less than 10 individuals found at a site, however a few surveys in the mid-2000s had some “common” abundances with up to 50 individuals observed and documentation of reproduction (e.g., “juveniles present”) as recent as 2006. The last observation was in 2013. Over all known surveys, 204 live and 5 shells of Atlantic Pigtoe have been observed in this MU (Alderman and Alderman 2014, p.21).

Water Quality Summary: Based on 2012 data, there are five stream reaches, totaling ~21 miles that are impaired for aquatic life in the lower Craig Creek watershed. Impairment is indicated by low benthic-macroinvertebrate bioassessments, pH issues, high temperature, and fecal coliform.

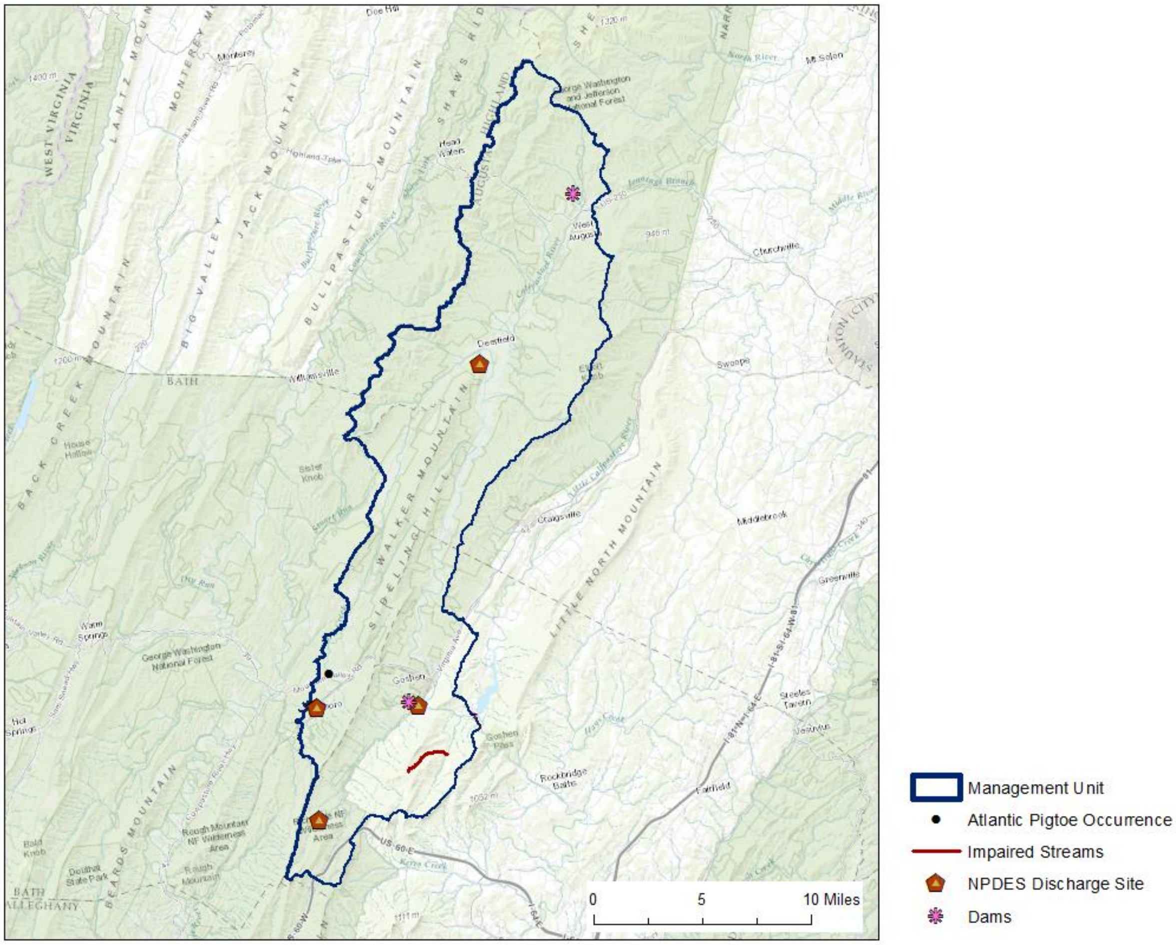
There are two non-major NPDES discharges in the MU, including the New Castle WWTP discharge into Craig Creek.

Land Use/Land Cover Summary:





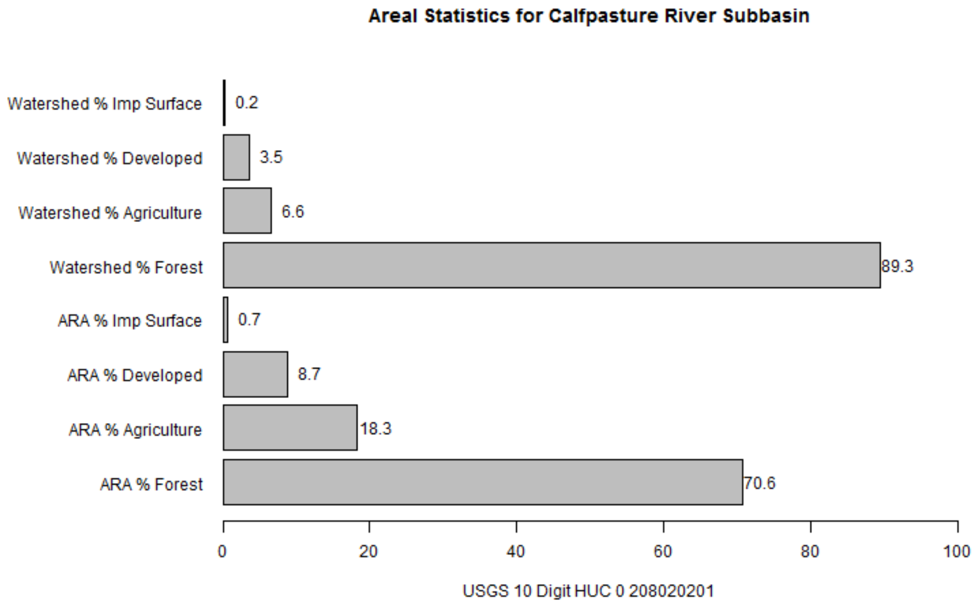
Mill Creek Management Unit



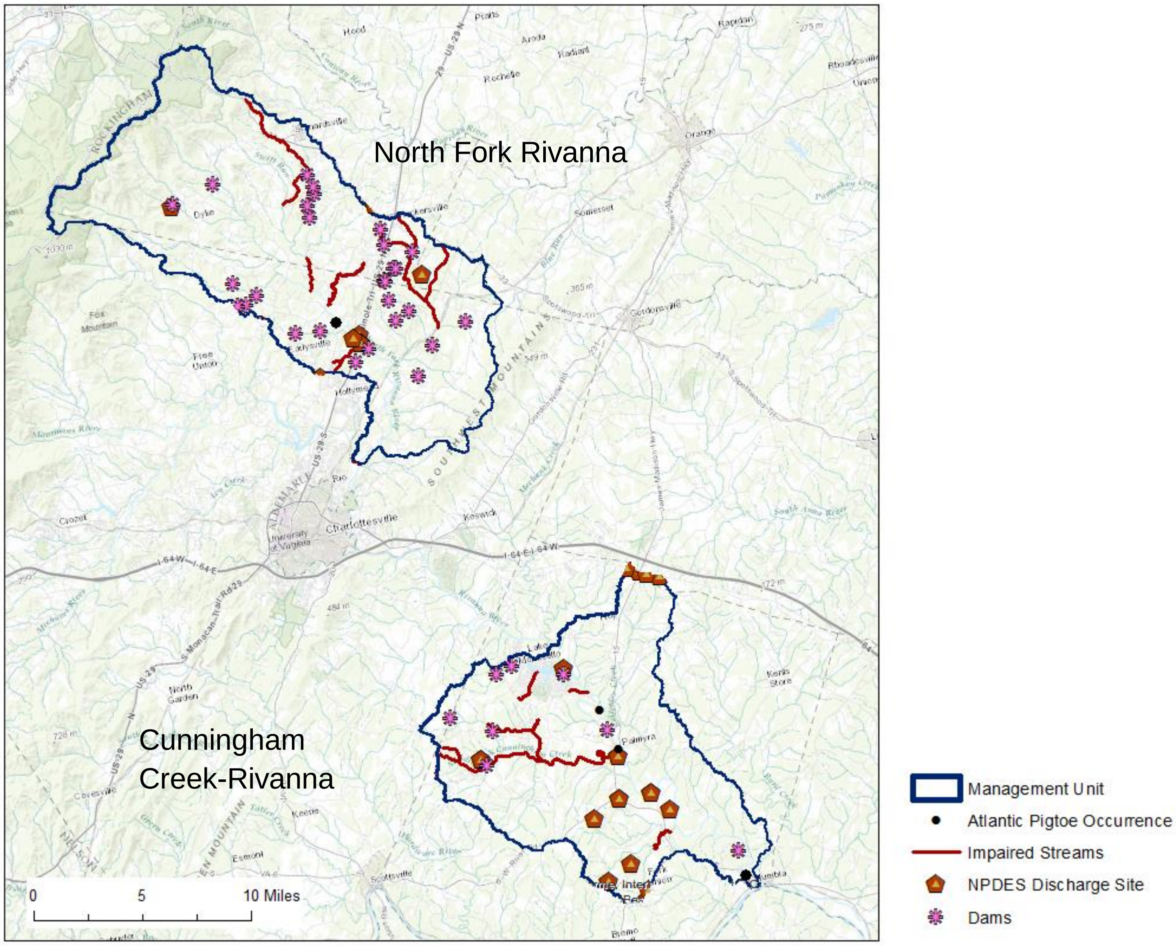
Survey Summary: Only one known survey documented the presence of Atlantic Pigtoe in 2005.

Water Quality Summary: Based on 2012 data, there is one stream reach, totaling ~2.2 miles, that is impaired for aquatic life in the Mill Creek watershed. Cause of impairment is due to pH, from atmospheric deposition. There are four non-major NPDES discharges in the MU.

Land Use Land Cover Summary: (note, Mill Creek is part of the larger Calfpasture River Basin)



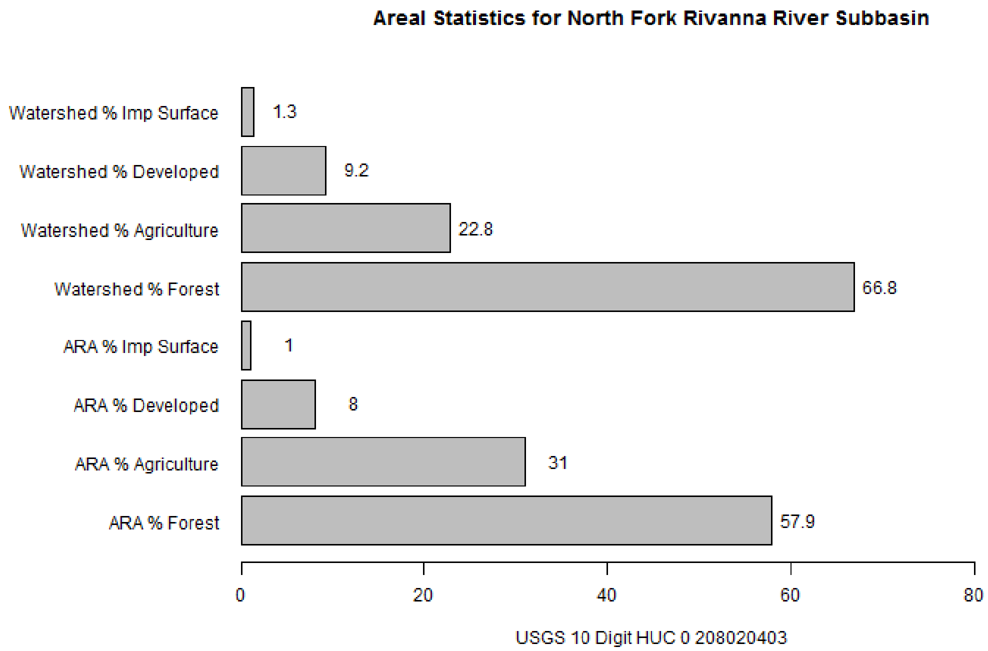
<u>Rivanna River Management Unit</u>

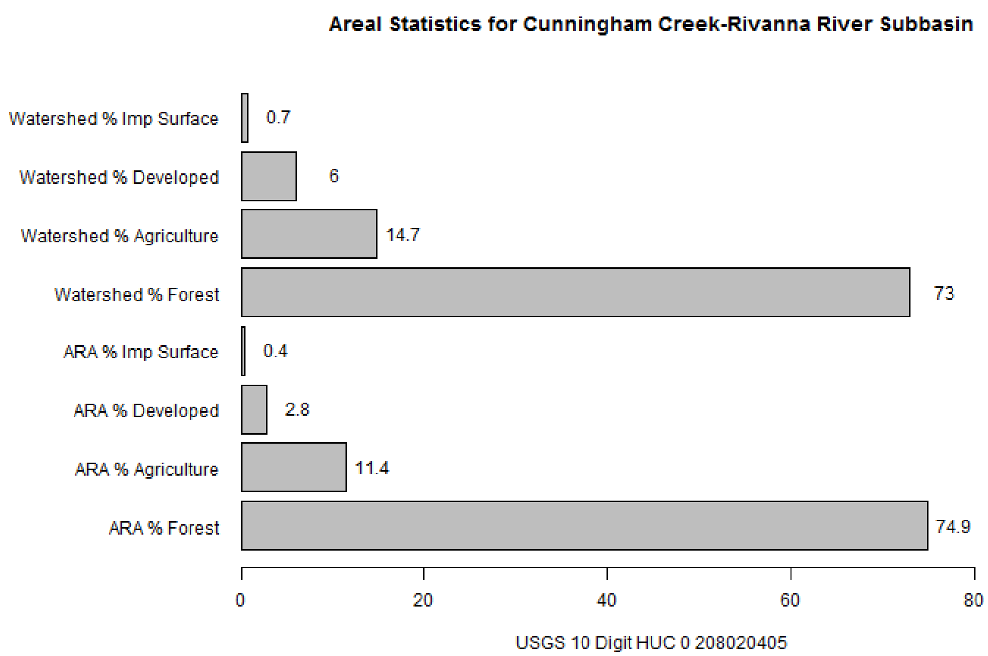


Survey Summary: Surveys in the late 1990s documented the presence of Atlantic Pigtoes in the Rivanna River. Ten live individuals and 183 shells have been found in this MU, which was once considered a stronghold (Alderman and Alderman 2014, p.21).

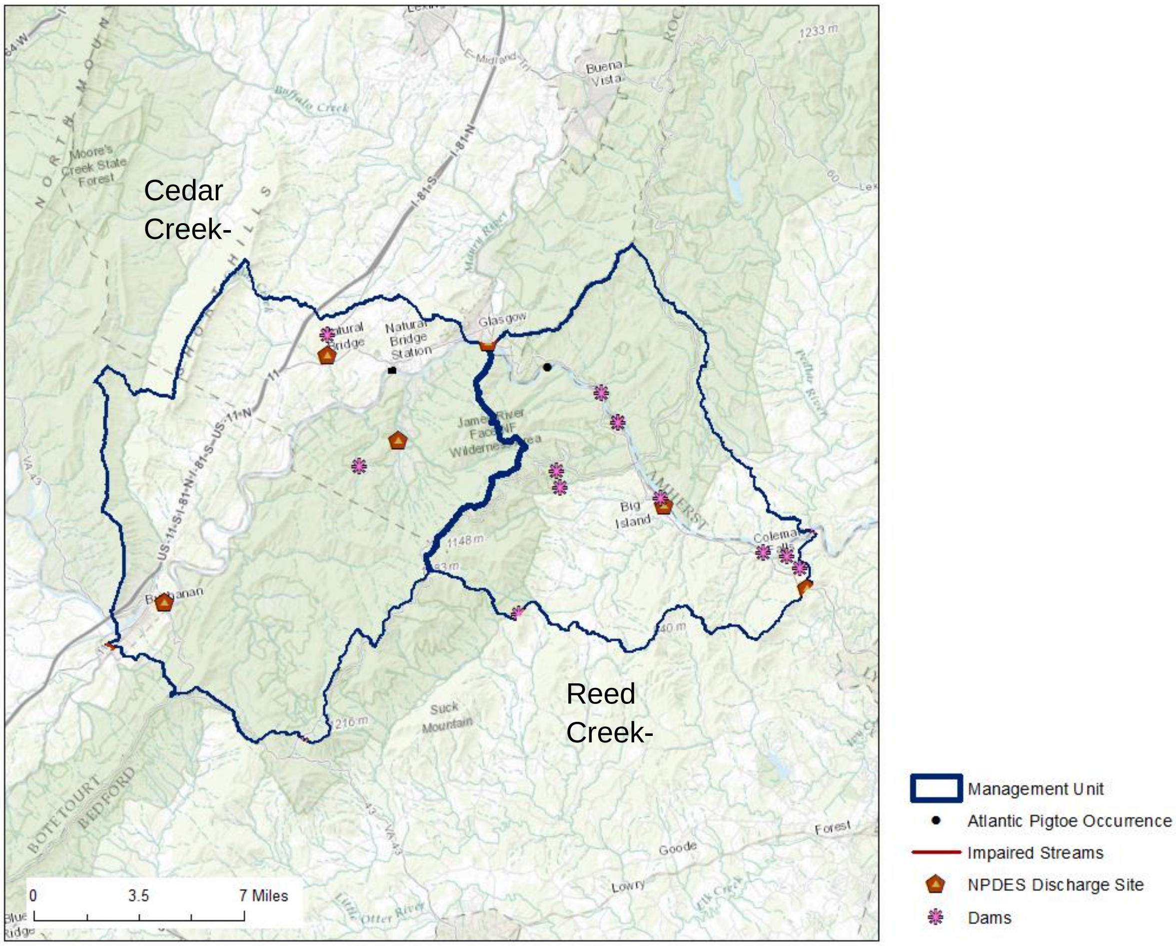
Water Quality Summary: Based on 2012 data, there are 13 stream reaches, totaling ~48 miles that are impaired for aquatic life in the Rivanna watershed (in the two HUC10s for this MU). Causes of impairment are primarily due to low benthic-macroinvertebrate aseessment scores from non-point sources. There are 15 non-major NPDES discharges, including several small WTPs and WWTPs and biosolids facilities, and one major (Tenaska) in the MU.

Land Use Land Cover Summary:





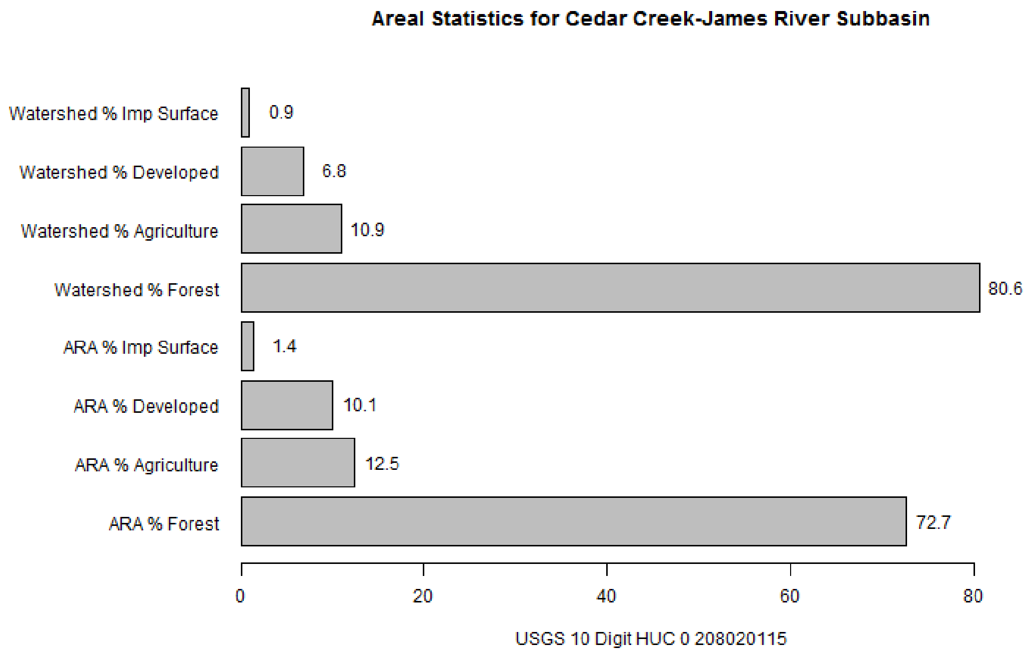
<u>Upper James River Management Unit</u>

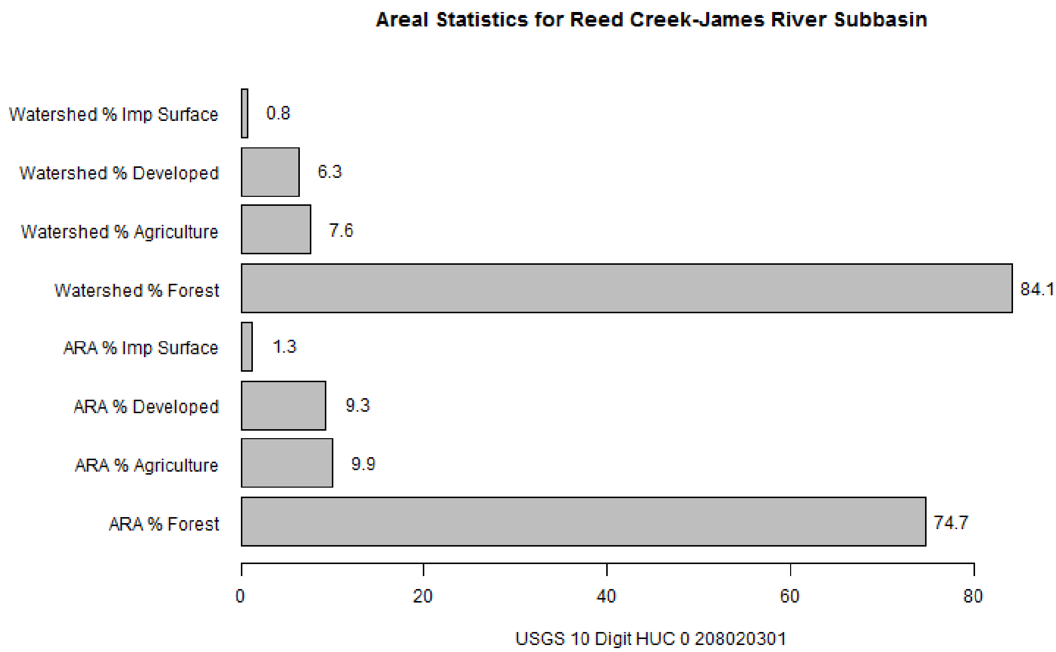


Survey Summary: There is an historical (now extirpated) record in the Upper James River near Gilmore Mills, and in 2005 a relic shell was observed. No additional survey effort since 2005 has been undertaken in this MU to verify whether or not the species is extant.

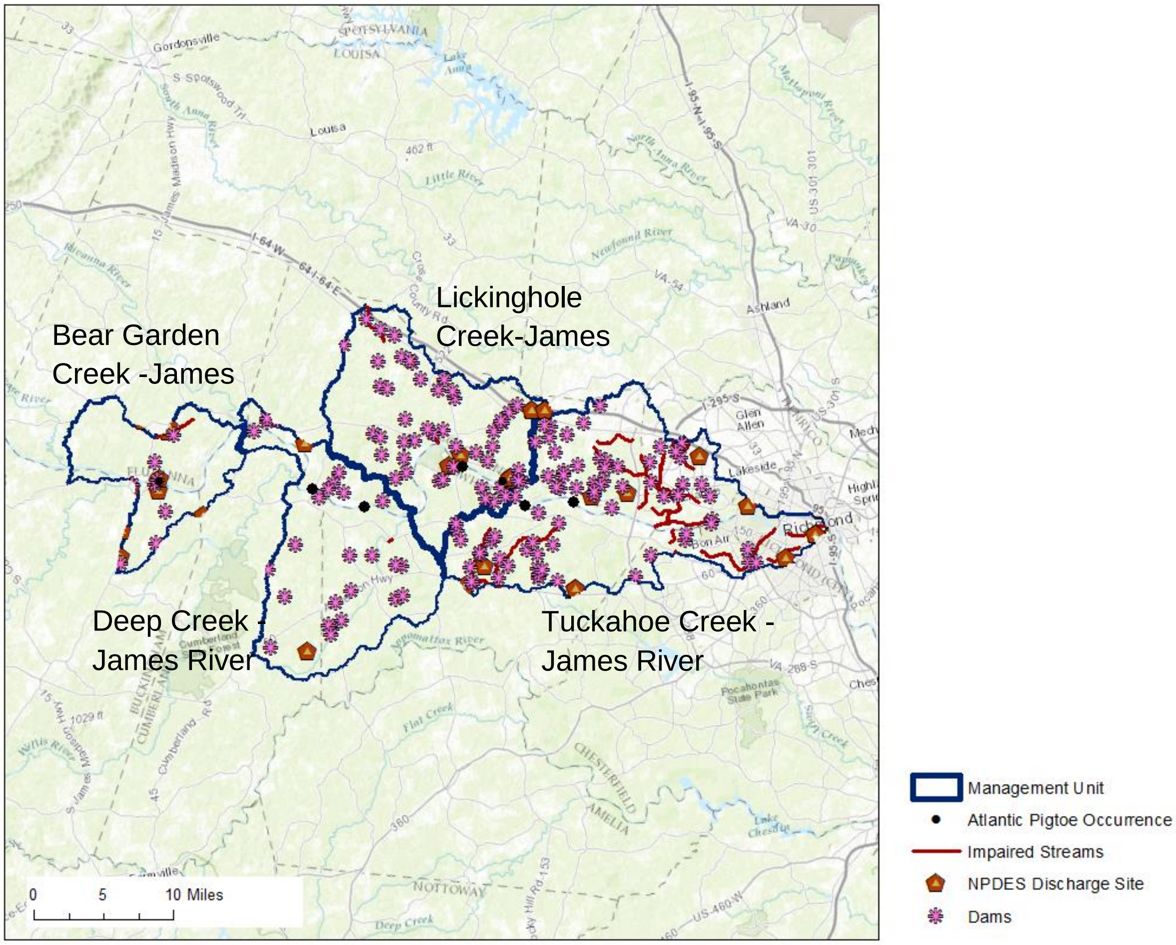
Water Quality Summary: Based on the 2012 data, there are no impaired stream reaches in this MU, however there are five non-major and one major (Georgia Pacific Big Island Mill) NPDES discharges in the MU.

Land Use Land Cover Summary:





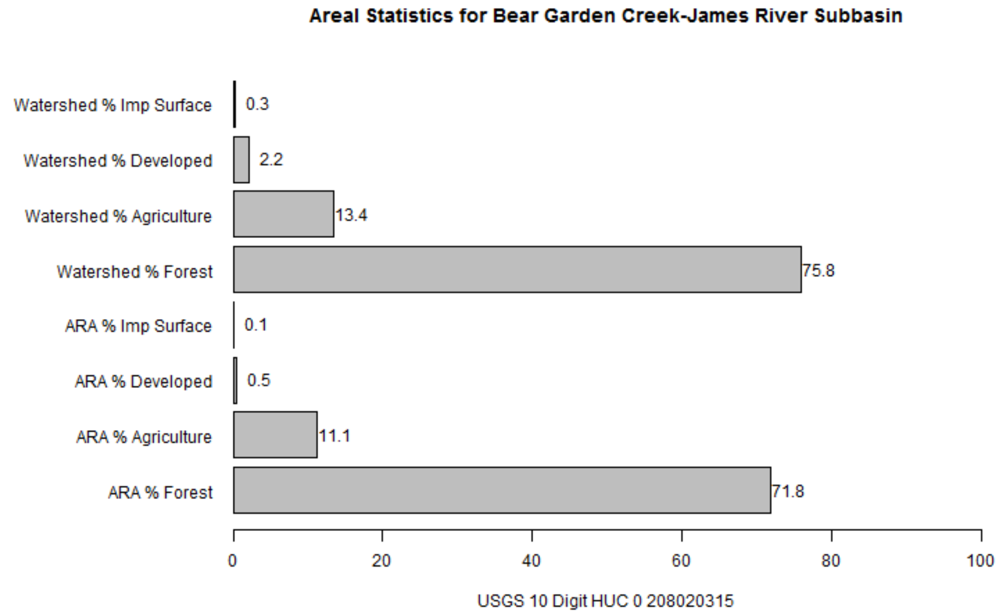
<u>Middle James River Management Unit</u>

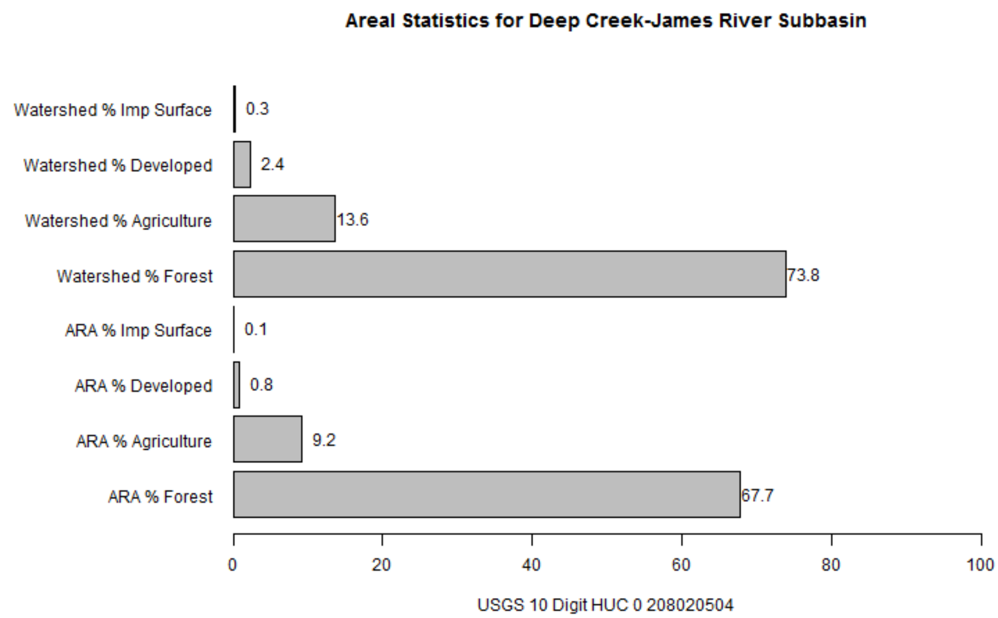


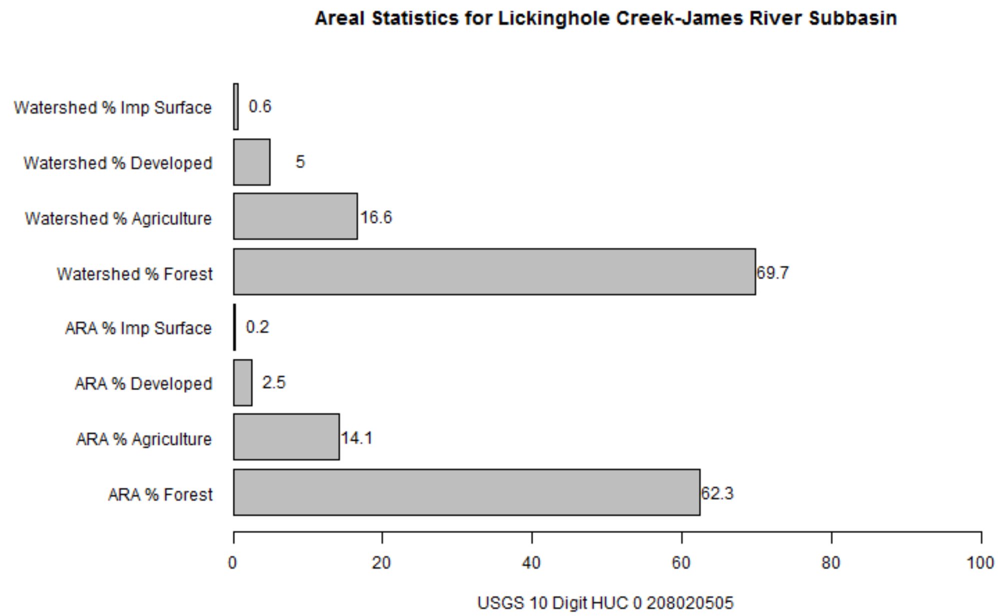
Survey Summary: A few surveys have been completed in the past decade, however the most recent survey in 2012 only documented one shell (survey noted shell was in good condition, but fell apart at the surface). Based on known surveys, a total of 64 live and 135 shells of Atlantic Pigtoe have been observed in this MU (Alderman and Alderman 2014, p.21).

Water Quality Summary: Based on the 2012 data, there are 25 impaired stream reaches totaling ~70 miles in this MU, mostly concentrated in the lower part of the watershed as the river gets closer to Richmond. There are many causes of impairment, including low DO, pH, fecal coliform, low benthic-macroinvertebrate assessment scores, and E.coli; some sources are due to natural conditions, however non-point sources and municipal point source discharges are the main impairment culprits. There are 19 non-major (including several package WWTPs) and 2 major (Bear Garden Generating Station and Dominion Resources Bremo Power Station) NPDES discharges in the MU.

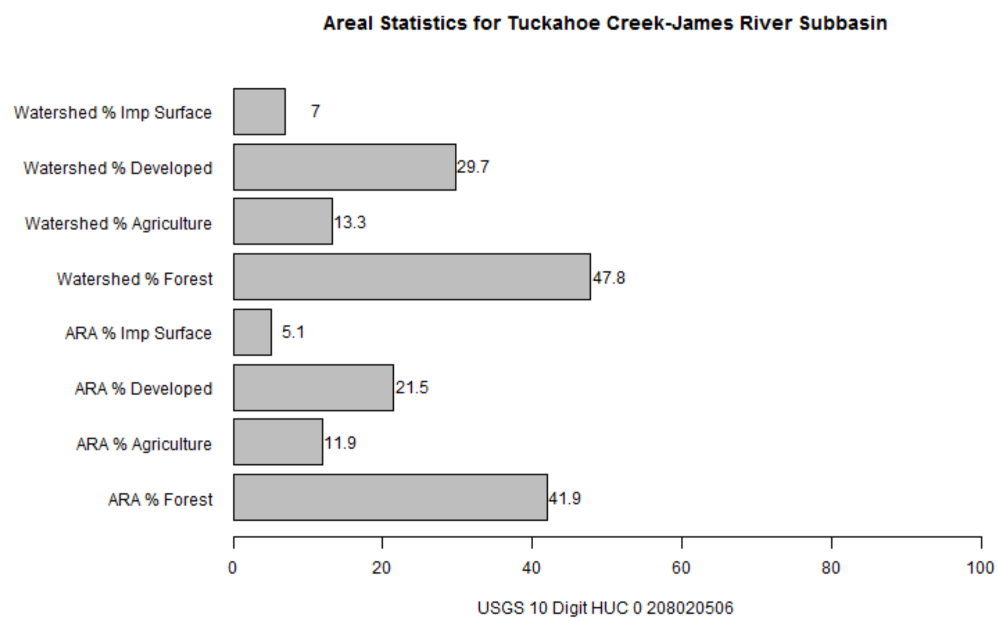
Land Use Land Cover Summary:





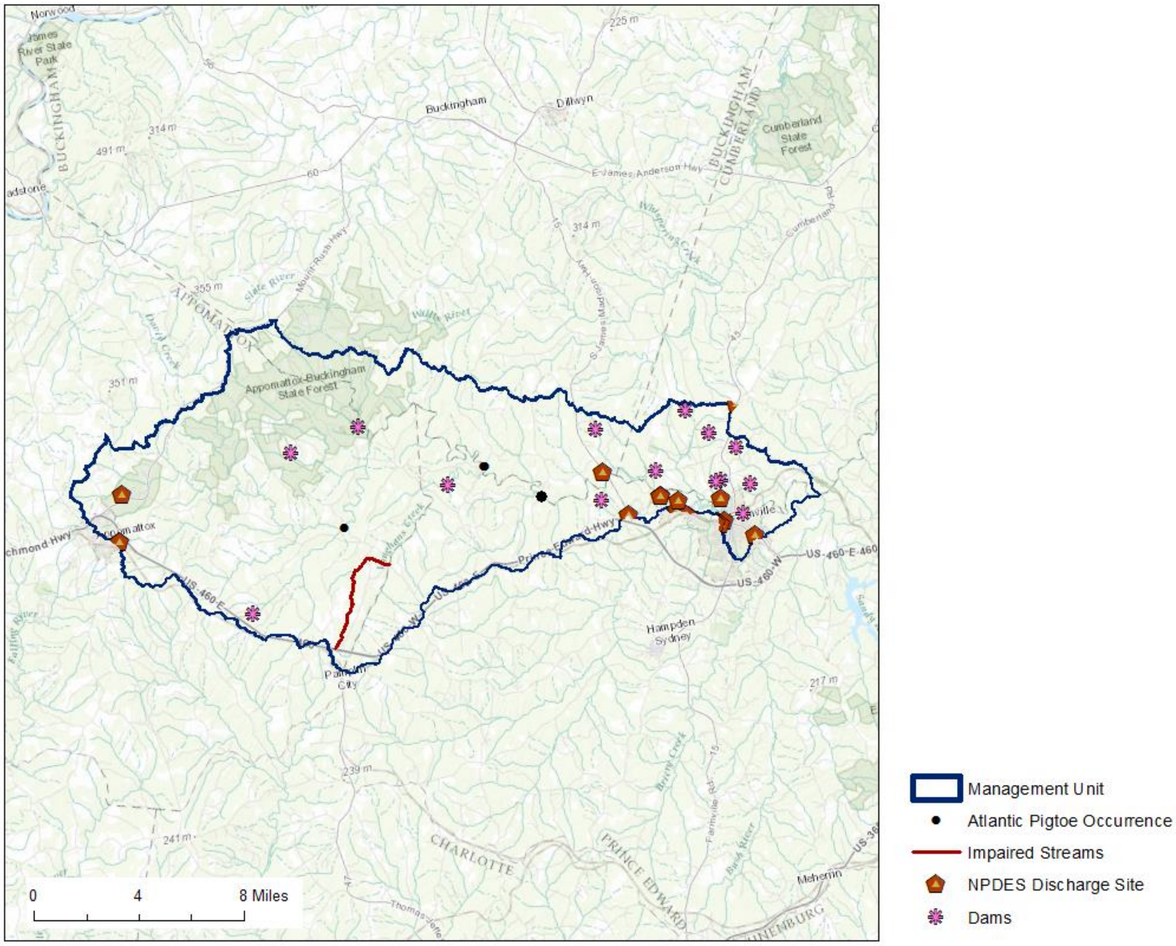


Areal Statistics for Lickinghole Creek-James River Subbasin
Watershed % Imp Surface
0.6
Watershed % Developed
5
Watershed % Agriculture
16.6
Watershed % Forest
69.7
ARA % Imp Surface
0.2
ARA % Developed
2.5
ARA % Agriculture
14.1
ARA % Forest
62.3
0
20
40
60
80
100
USGS 10 Digit HUC 0 208020505



Areal Statistics for Tuckahoe Creek-James River Subbasin
Watershed % Imp Surface
7
Watershed % Developed
29.7
Watershed % Agriculture
13.3
Watershed % Forest
47.8
ARA % Imp Surface
5.1
ARA % Developed
21.5
ARA % Agriculture
11.9
ARA % Forest
41.9
0
20
40
60
80
100
USGS 10 Digit HUC 0 208020506

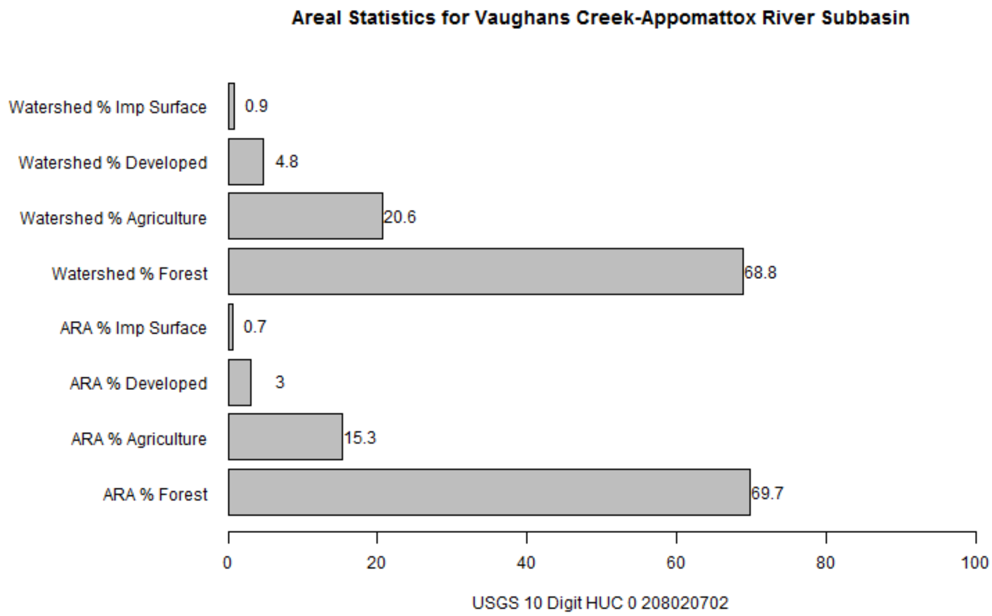
Appamattox River Management Unit



Survey Summary: First documented in this MU in 1989 and last seen in 2003, Atlantic Pigtoe abundances are "rare" in this MU. A total of 12 live and 13 shells have been observed in this MU (Alderman and Alderman 2014, p.21).

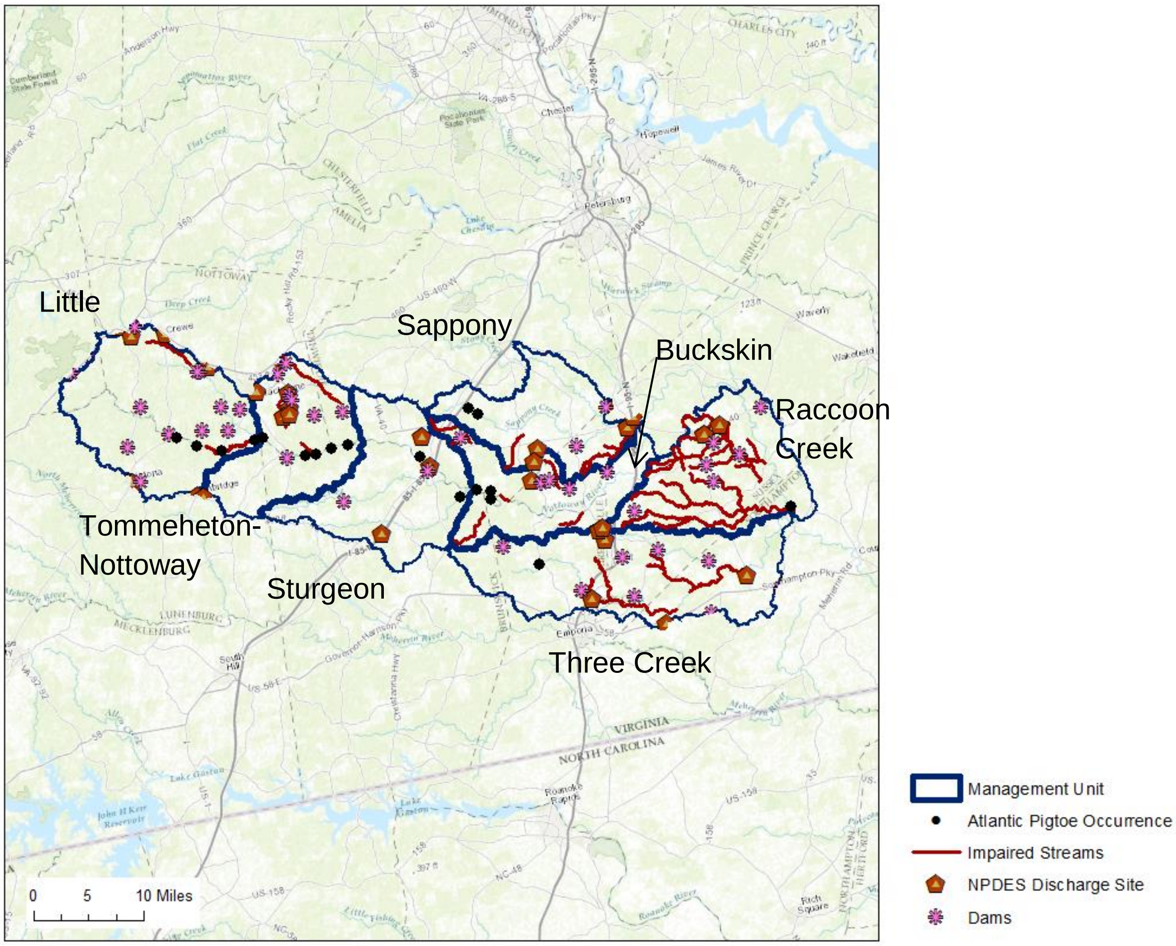
Water Quality Summary: Based on the 2012 data, there is one impaired stream reach totaling ~5 miles in this MU. The main causes of impairment are low benthic-macroinvertebrate assessment scores and E.coli due to wastes from pets, wildlife other than waterfowl, and livestock. There are 11 non-major (including biosolid facilities) and one major (Farmville WWTP) NPDES discharges in the MU.

Land Use Land Cover Summary:



Chowan River Population
Consists of two MUs: Nottoway River; Meherrin River

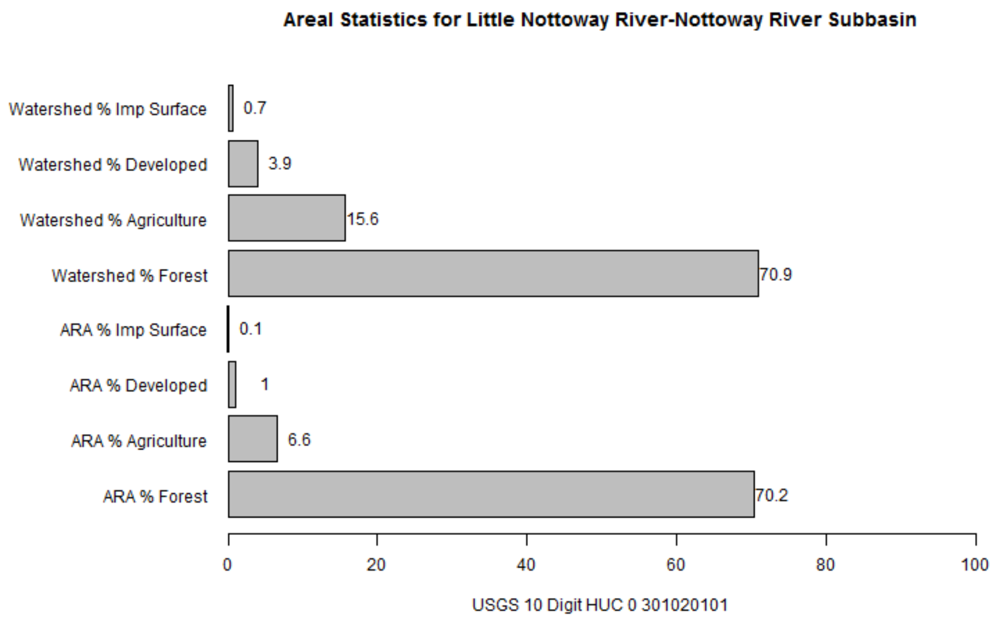
<u>Nottoway River Management Unit</u>

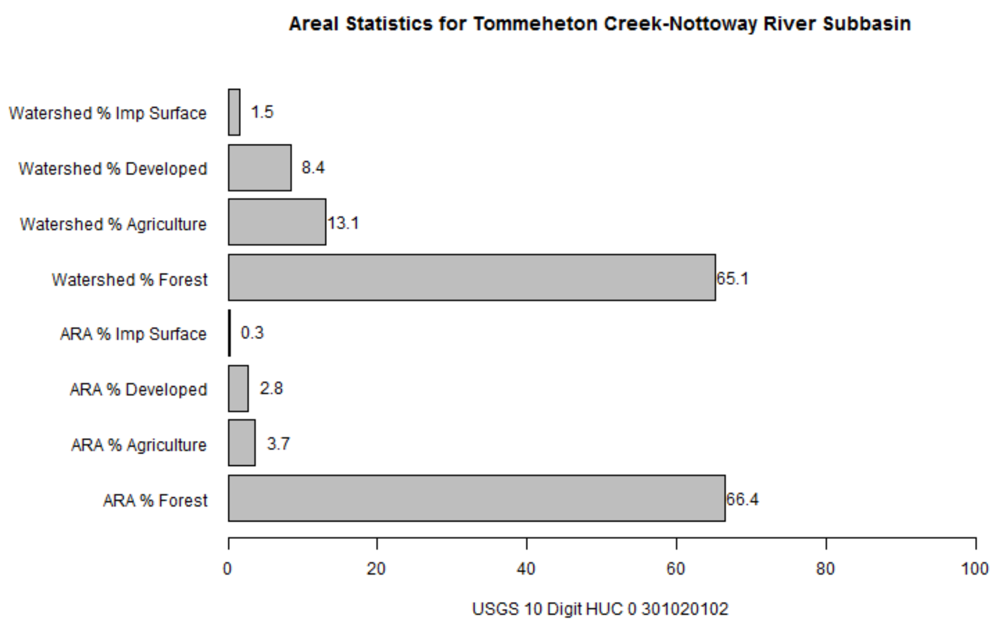


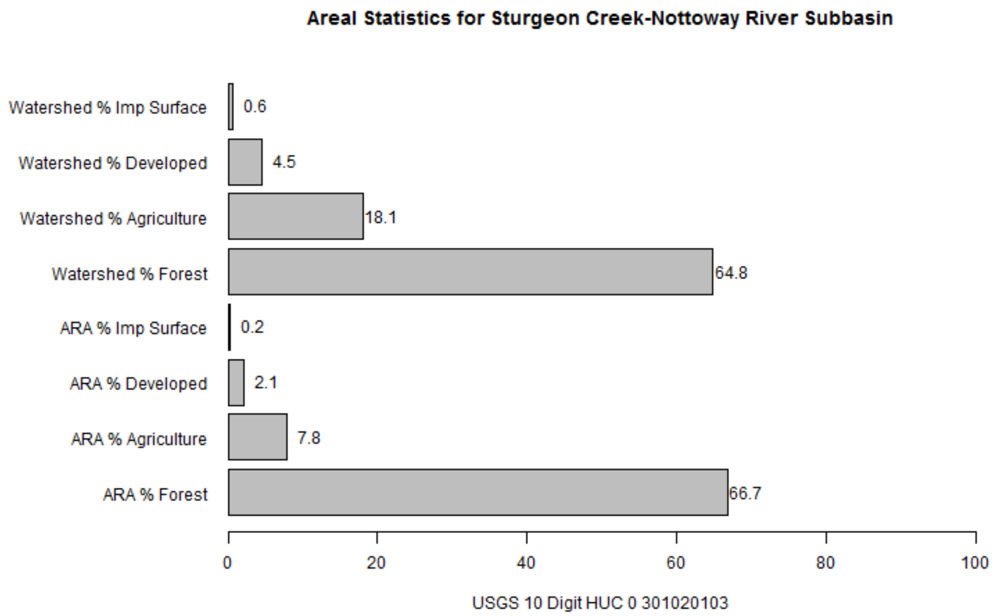
Survey Summary: Nearly 35 survey efforts have documented several Atlantic Pigtoes in this MU, first seen in 1993 and last seen in 2012. While abundances were recorded as "common" in the late 1990s, more recent surveys indicate abundances are "rare". A total of 256 live and 127 shells of Atlantic Pigtoe have been documented in this MU, a former stronghold for the species (Alderman and Alderman 2014, p.21).

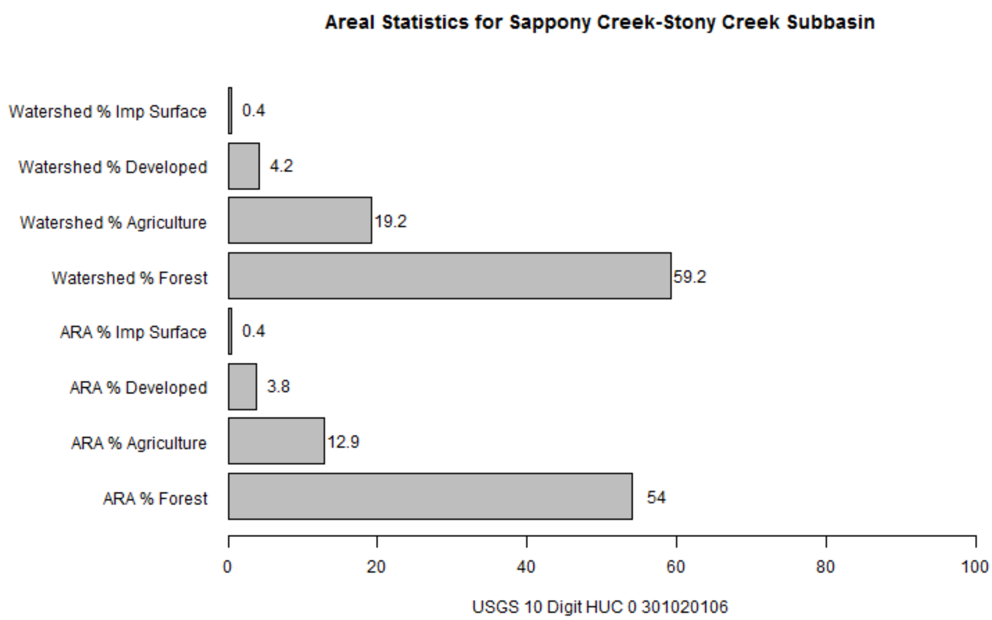
Water Quality Summary: Based on the 2012 data, there are 28 impaired stream reaches totaling ~199 miles in this MU. Causes of impairment are low DO, low benthic-macroinvertebrate assessment scores, pH, E.coli and mercury, with sources identified as urban stormwater, non-point sources, and atmospheric deposition. There are 22 non-major and 2 major NPDES discharges, including several WTPs and package WWTPs.

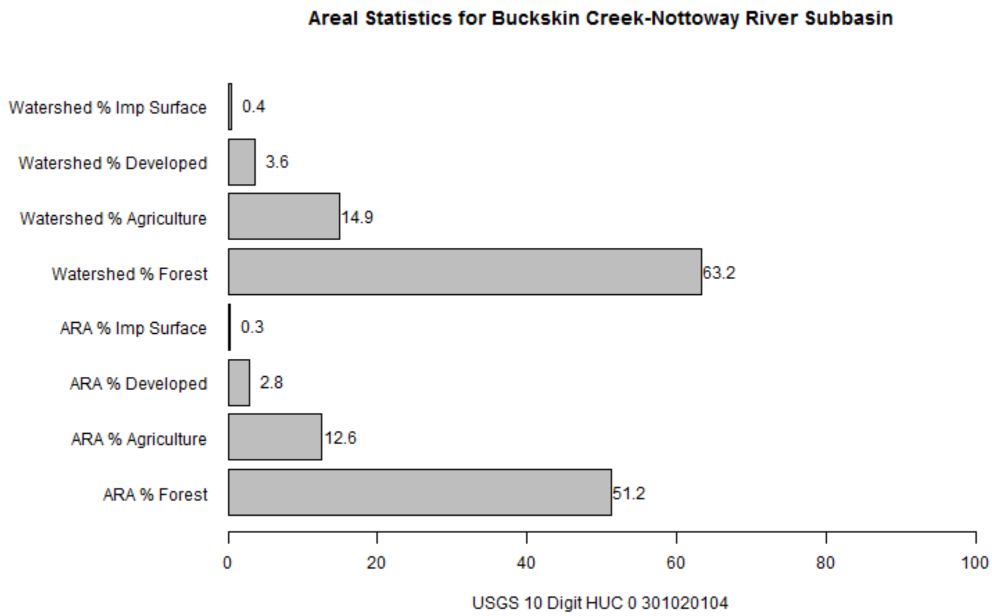
Land Use Land Cover Summary:

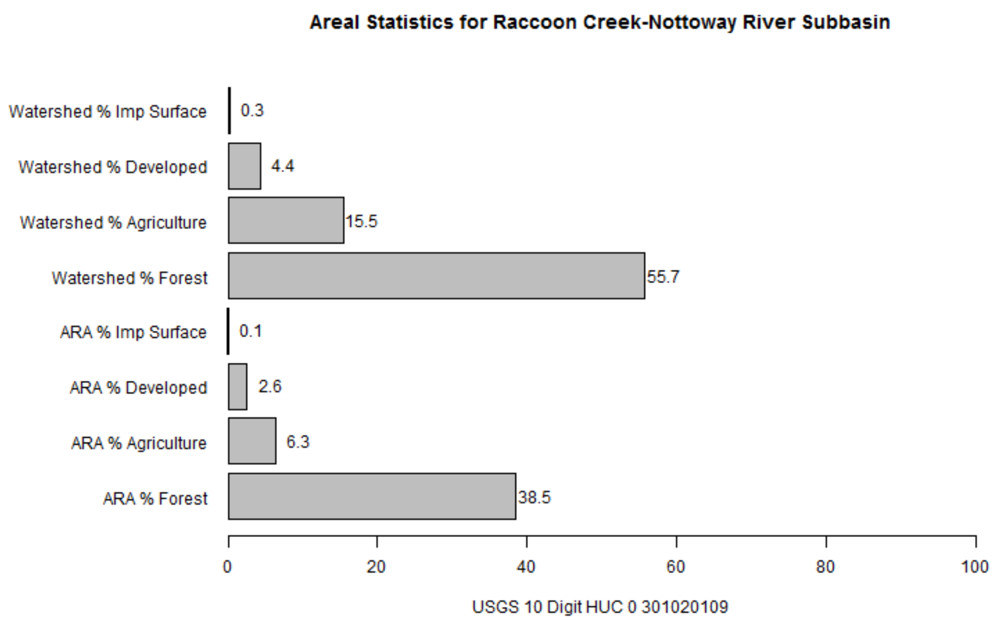




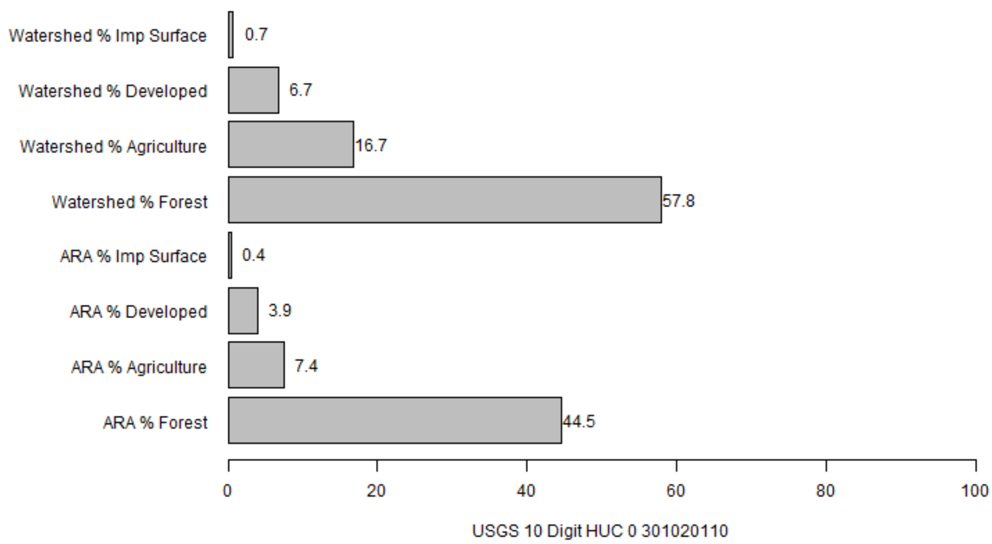

Areal Statistics for Sturgeon Creek-Nottoway River Subbasin
Watershed % Imp Surface
Watershed % Developed
Watershed % Agriculture
Watershed % Forest
ARA % Imp Surface
ARA % Developed
ARA % Agriculture
ARA % Forest
0.6
4.5
18.1
64.8
0.2
2.1
7.8
66.7
0
20
40
60
80
100
USGS 10 Digit HUC 0 301020103


Areal Statistics for Sappony Creek-Stony Creek Subbasin
Watershed % Imp Surface
Watershed % Developed
Watershed % Agriculture
Watershed % Forest
ARA % Imp Surface
ARA % Developed
ARA % Agriculture
ARA % Forest
0.4
4.2
19.2
59.2
0.4
3.8
12.9
54
0
20
40
60
80
100
USGS 10 Digit HUC 0 301020106

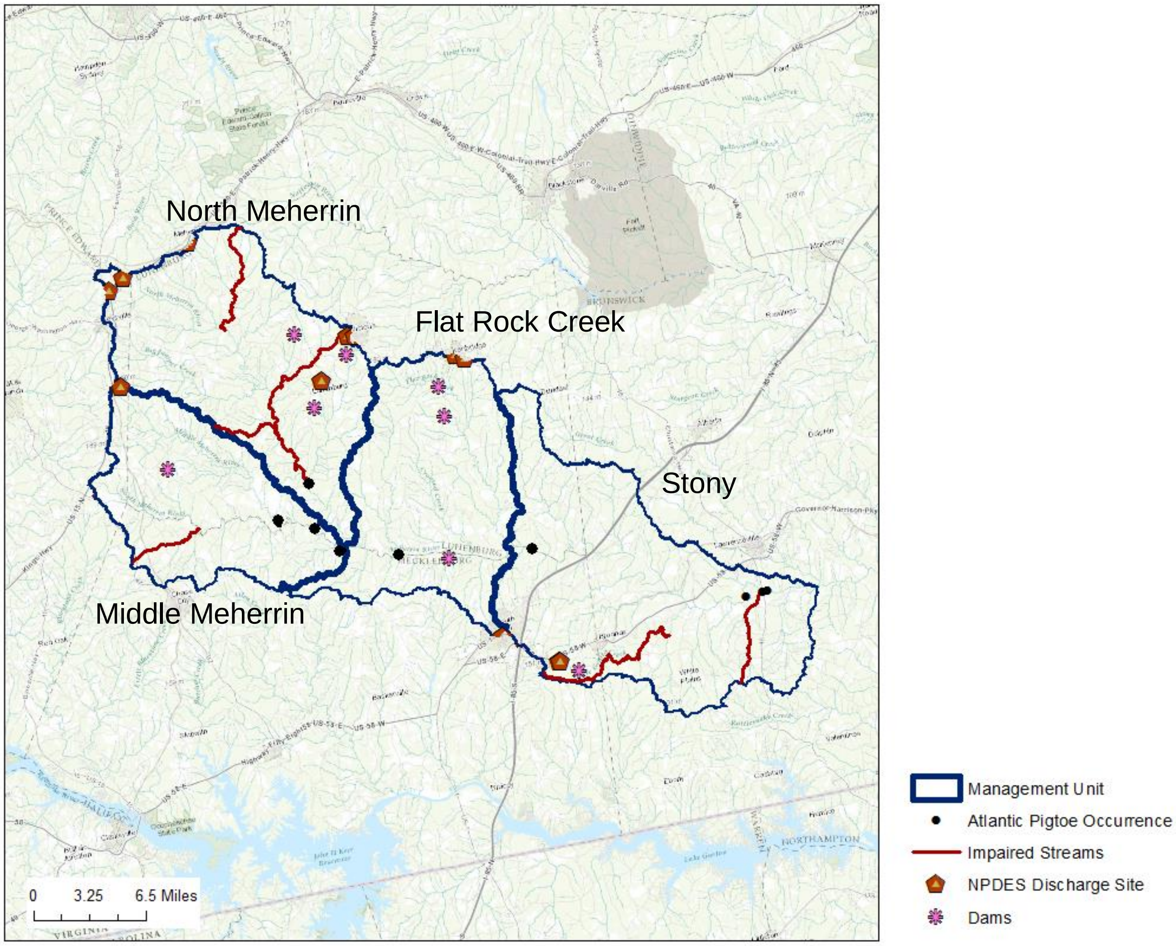

Areal Statistics for Buckskin Creek-Nottoway River Subbasin
Watershed % Imp Surface
Watershed % Developed
Watershed % Agriculture
Watershed % Forest
ARA % Imp Surface
ARA % Developed
ARA % Agriculture
ARA % Forest
0.4
3.6
14.9
63.2
0.3
2.8
12.6
51.2
0
20
40
60
80
100
USGS 10 Digit HUC 0 301020104


Areal Statistics for Raccoon Creek-Nottoway River Subbasin
Watershed % Imp Surface
Watershed % Developed
Watershed % Agriculture
Watershed % Forest
ARA % Imp Surface
ARA % Developed
ARA % Agriculture
ARA % Forest
0.3
4.4
15.5
55.7
0.1
2.6
6.3
38.5
0
20
40
60
80
100
USGS 10 Digit HUC 0 301020109

Areal Statistics for Three Creek Subbasin



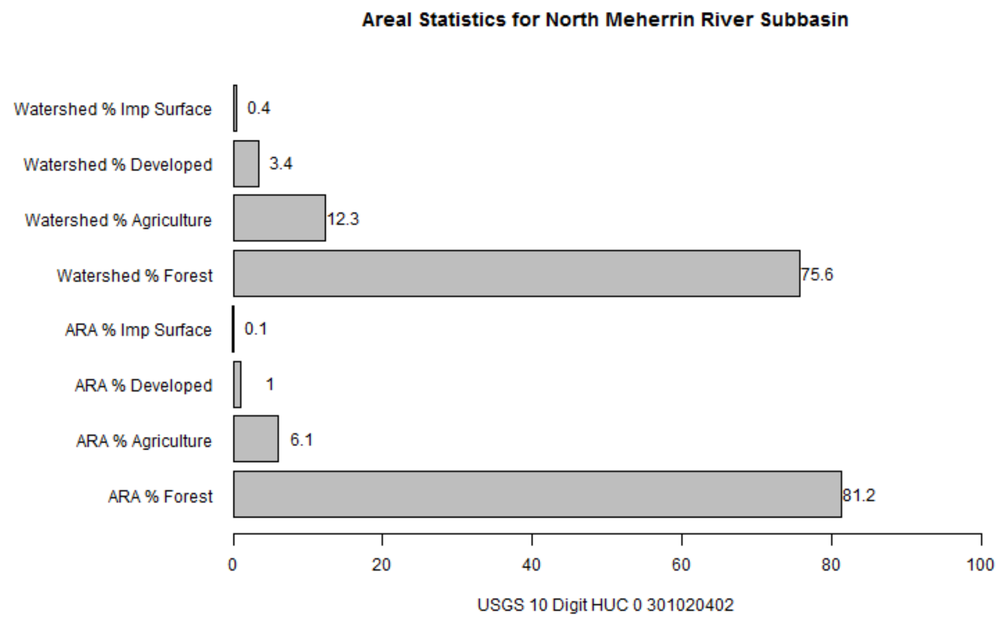
Meherrin River Management Unit

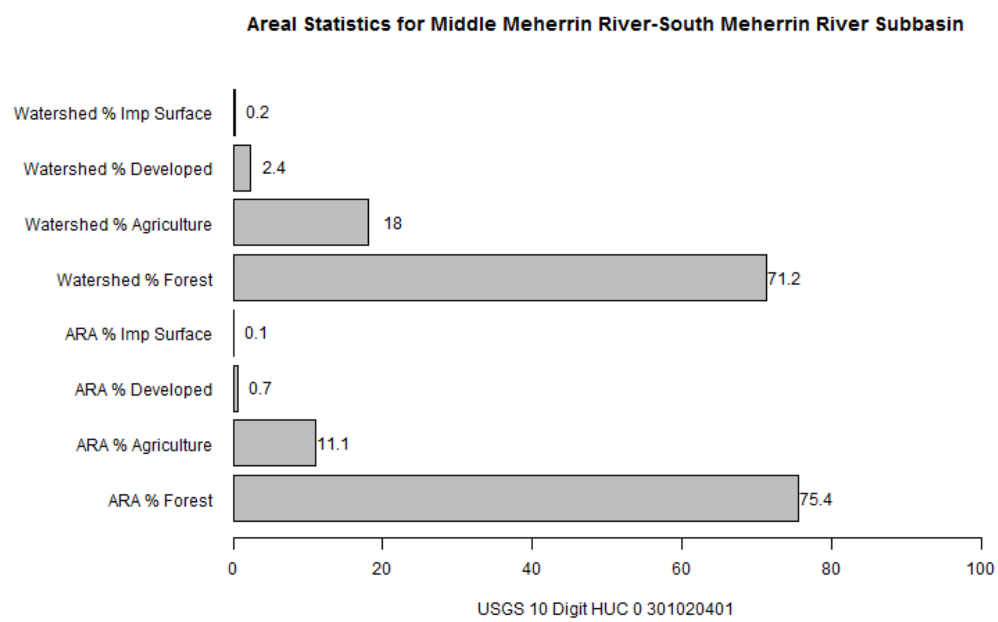


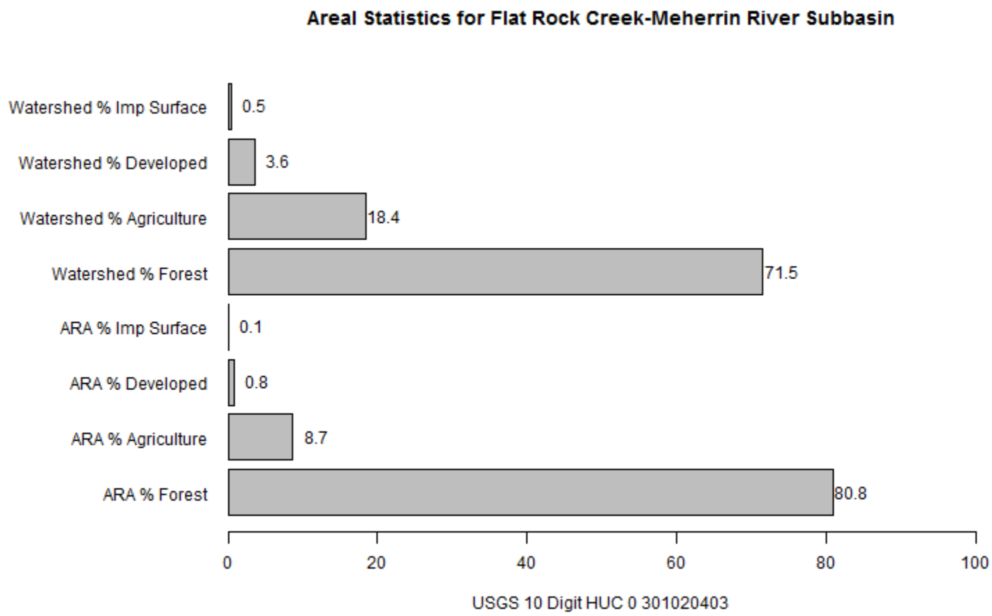
Survey Summary: Several surveys have documented Atlantic Pigtoes in the Meherrin River, although their abundances have been "rare". The species was first seen in 1993 and most recently seen in 2014. A total of 18 live and 19 shells have been observed in this MU (Alderman and Alderman 2014, p.20).

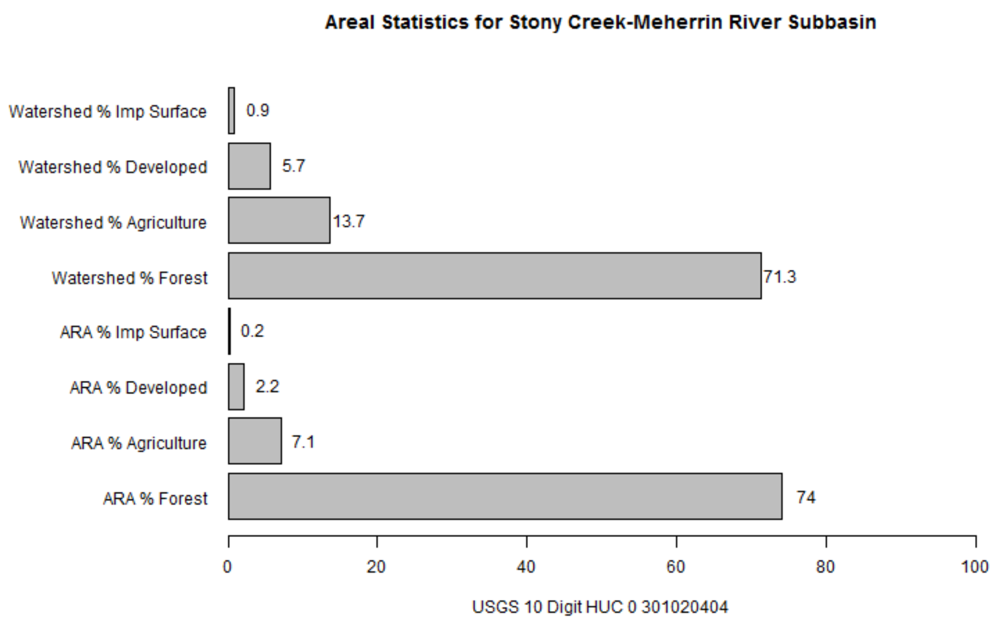
Water Quality Summary: Based on the 2012 data, there are seven impaired stream reaches totaling ~51 miles in this MU. Primary causes of impairment are low benthic-macroinvertebrate assessment scores, low DO, and pH, and sources of impairment are unknown. There are nine non-major NPDES discharges in this MU.

Land Use Land Cover Summary:



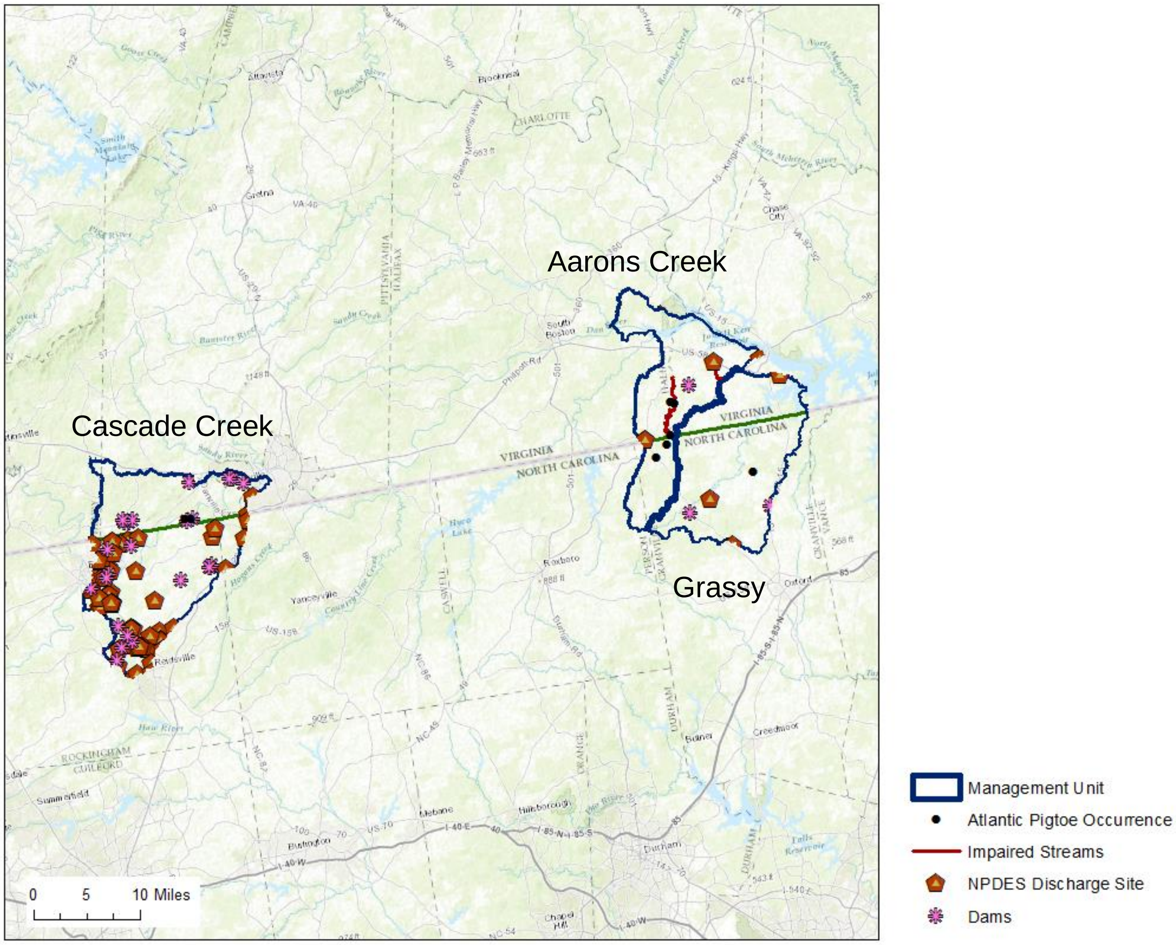



Areal Statistics for Flat Rock Creek-Meherrin River Subbasin
Watershed % Imp Surface
0.5
Watershed % Developed
3.6
Watershed % Agriculture
18.4
Watershed % Forest
71.5
ARA % Imp Surface
0.1
ARA % Developed
0.8
ARA % Agriculture
8.7
ARA % Forest
80.8
0
20
40
60
80
100
USGS 10 Digit HUC 0 301020403


Areal Statistics for Stony Creek-Meherrin River Subbasin
Watershed % Imp Surface
0.9
Watershed % Developed
5.7
Watershed % Agriculture
13.7
Watershed % Forest
71.3
ARA % Imp Surface
0.2
ARA % Developed
2.2
ARA % Agriculture
7.1
ARA % Forest
74
0
20
40
60
80
100
USGS 10 Digit HUC 0 301020404

Roanoke River Population
Consists of two MUs: Dan River Basin and Roanoke River.

<u>Dan River Management Unit</u>

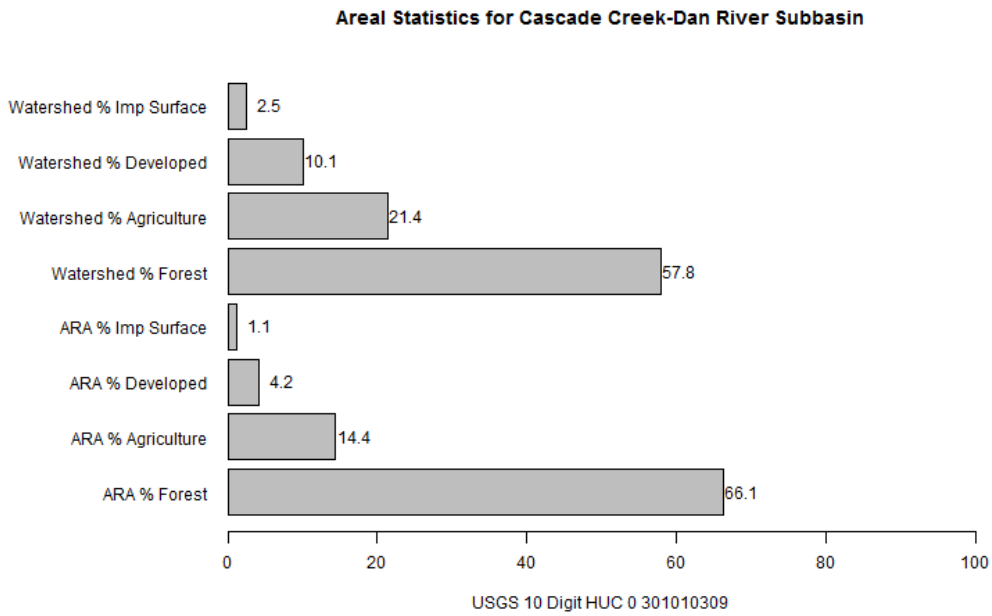


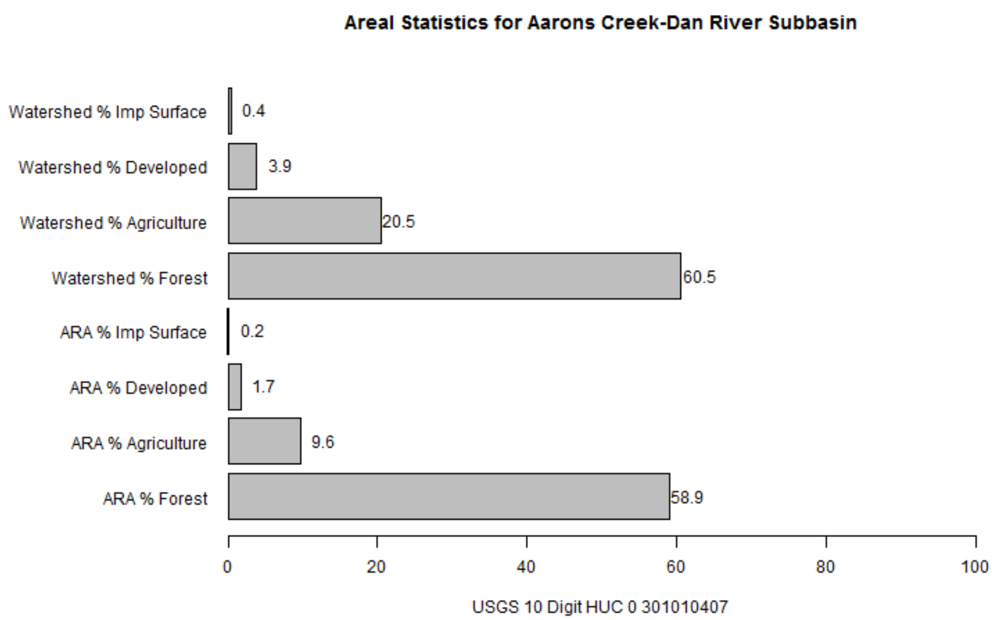
Survey Summary: Surveys in the late 1990s documented the species in Aaron's Creek and it was last seen there in 2007; a survey in 2003 documented the species in Grassy Creek, with abundance being described as "rare". A total of seven live and three shells have been observed in this MU (Alderman and Alderman 2014, p.20), most recently seen in the Dan River in 2014. Country Line Creek (Caswell County) has not been included in this MU because the specimen that was once identified as an Atlantic Pigtoe has not been confirmed via genetic analysis, and shell morphology does not definitively identify it as a pigtoe (S.McRae (USFWS) pers. obs.).

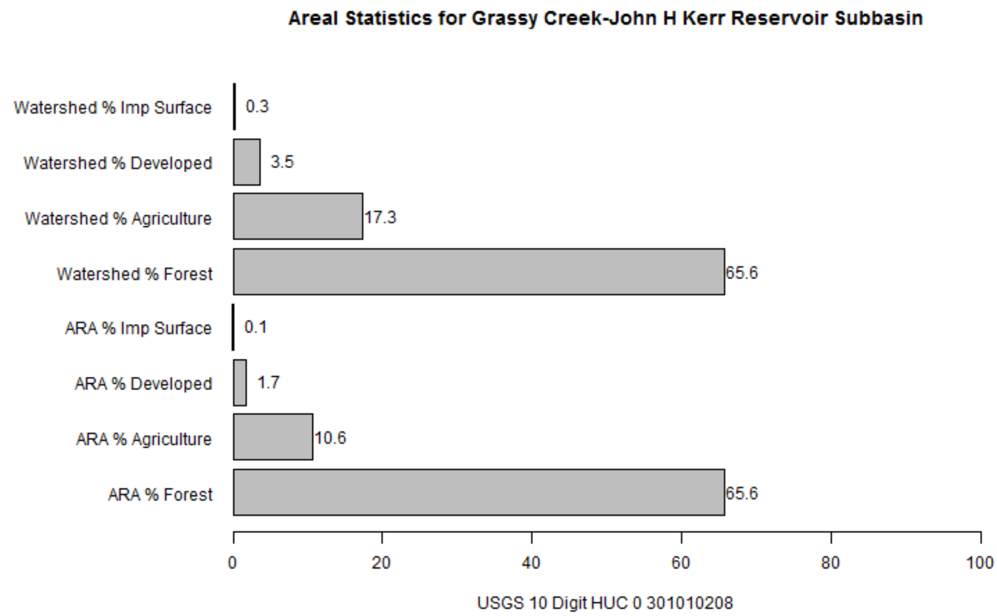
Water Quality Summary: Based on the 2012 data, there are two impaired stream reaches totaling ~12 miles in the Aarons Creek watershed of this MU. Causes of impairment are low DO, low benthic-macroinvertebrate assessment scores, fecal coliform and E.coli caused by municipal and other point sources. There are 61 non-major and 2 major (including Duke Power Dan River

Steam Station) NPDES discharges in this MU, with the majority of smaller discharges in the Cascade Creek watershed near Reidsville, NC.

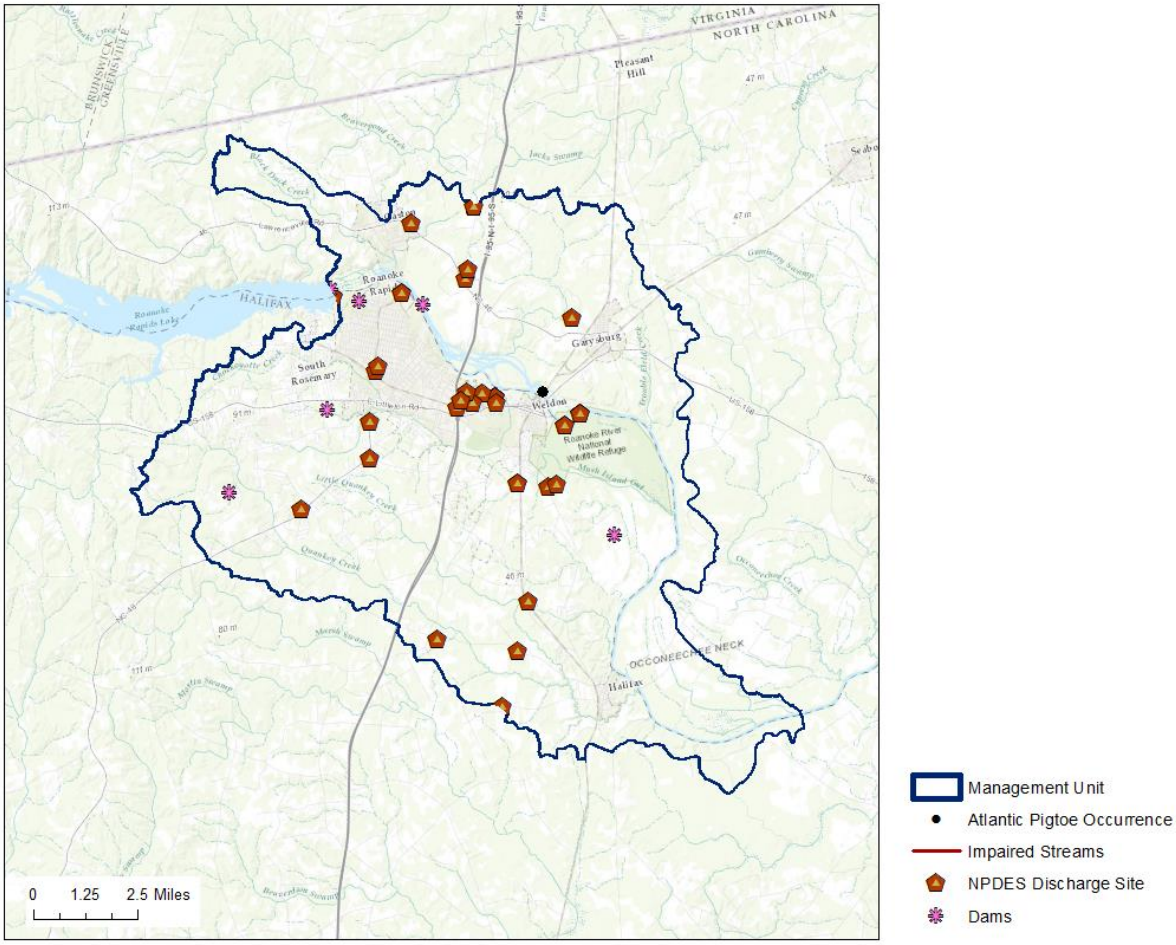
Land Use Land Cover Summary:






Areal Statistics for Grassy Creek-John H Kerr Reservoir Subbasin
Watershed % Imp Surface
0.3
Watershed % Developed
3.5
Watershed % Agriculture
17.3
Watershed % Forest
65.6
ARA % Imp Surface
0.1
ARA % Developed
1.7
ARA % Agriculture
10.6
ARA % Forest
65.6
0
20
40
60
80
100
USGS 10 Digit HUC 0 301010208

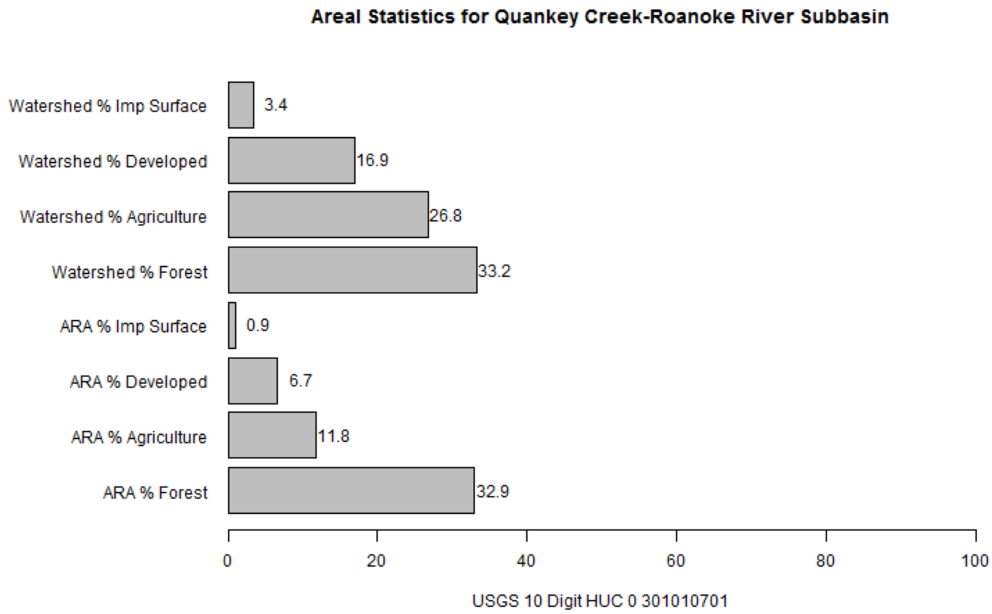
Roanoke River Management Unit



Survey Summary: Two shells were observed in 1959; the species is believed to be extirpated from this MU.

Water Quality Summary: Based on NC's 2014 data, there are no impaired stream segments in this MU. There are 4 non-major and 3 major (Roanoke Rapids WWTP, Weldon WWTP, and Kapstone Kraft Paper) NPDES discharges in this MU.

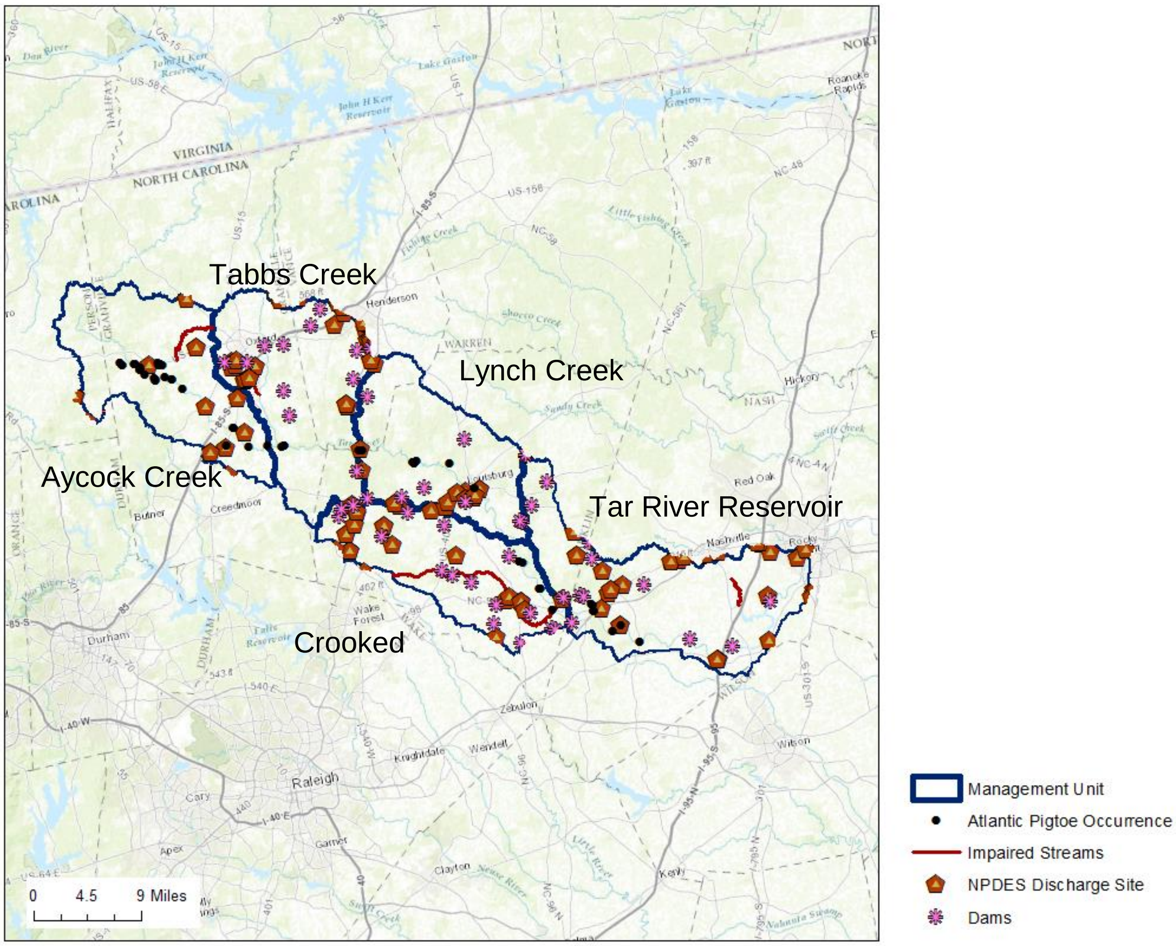
Land Use Land Cover Summary:



Tar River Population

Consists of four MUs: Upper/Middle Tar River, Lower Tar River, Fishing Creek Subbasin, Sandy-Swift Creek

<u>Upper/Middle Tar Management Unit</u>

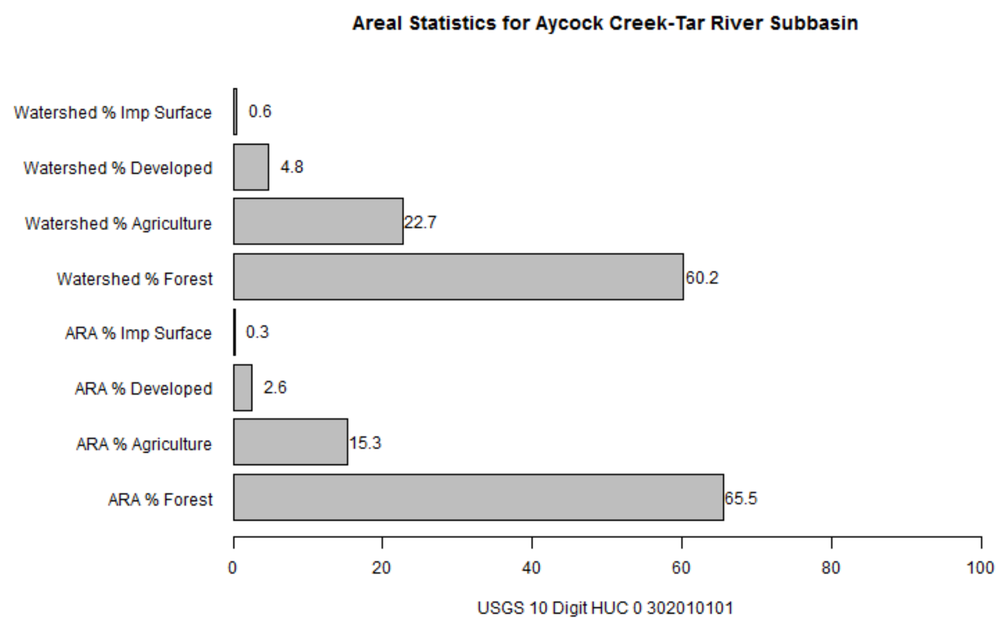


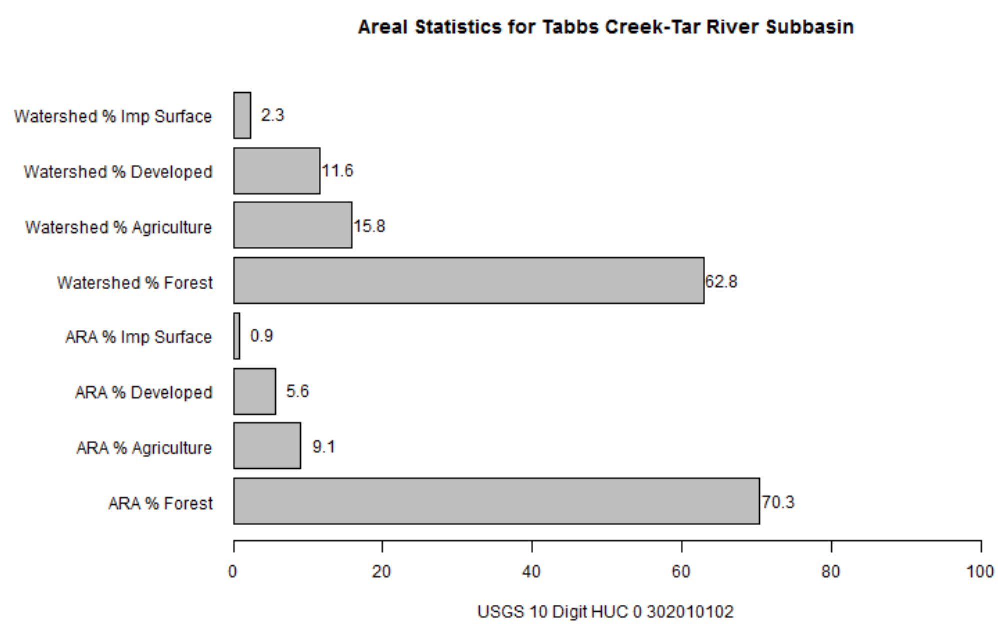
Survey Summary: This MU includes several tributaries (Bear Swamp Creek, Crooked Creek, Cub Creek, Shelton Creek) and the mainstem of the upper and middle Tar River. Many surveys have occurred in this MU – the Atlantic Pigtoe was first documented in 1965, and most recently seen in 2016. Most surveys document a handful of individuals, with the most being 13 (seen in Shelton Creek in 2014). Pigtoe abundances have been described as “rare” or “uncommon” in this MU, however recruitment was documented as recent as 2014. A total of 184 live and 96 shells have been observed over time in this MU (Alderman and Alderman 2014, p.20).

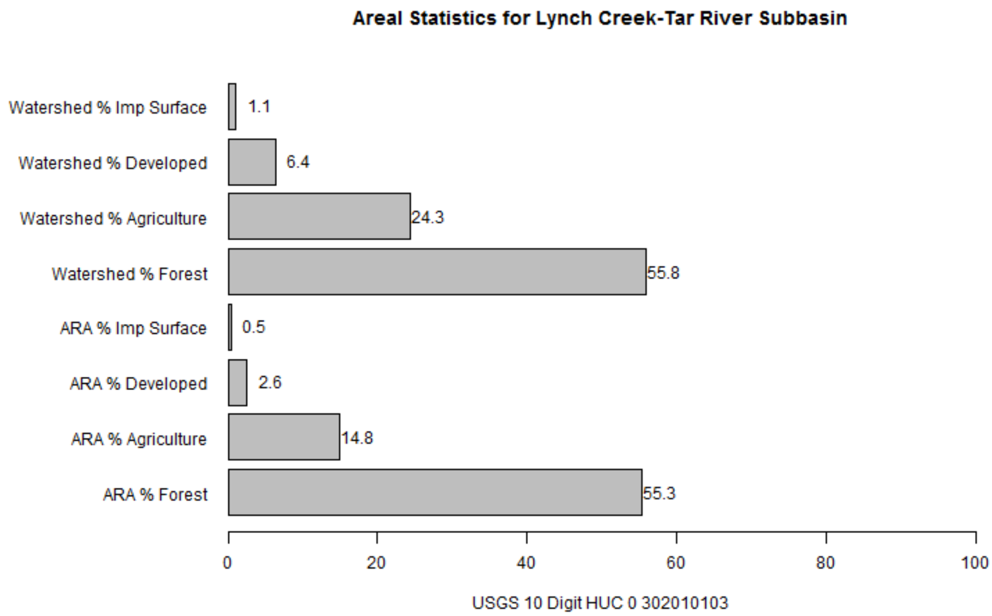
Water Quality Summary: Based on 2014 data, there are six impaired stream reaches totaling ~32 miles in this MU. Causes of impairment are low DO and low benthic-macroinvertebrate assessment scores, and the entire basin is classified as Nutrient Sensitive Waters (NCDEQ 2016d, pp.115-117). There are 70 non-major NPDES discharges, including several package

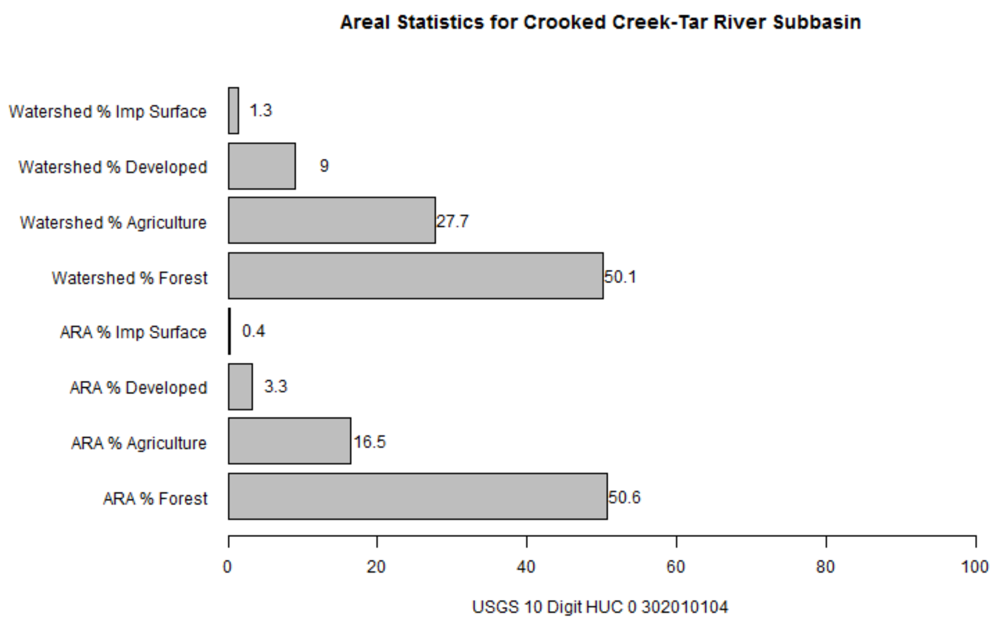
WWTPs and biosolids facilities, and 3 major (Oxford WWTP, Louisburg WWTP, and Franklin County WWTP) NPDES discharges in this MU.

Land Use Land Cover Summary:

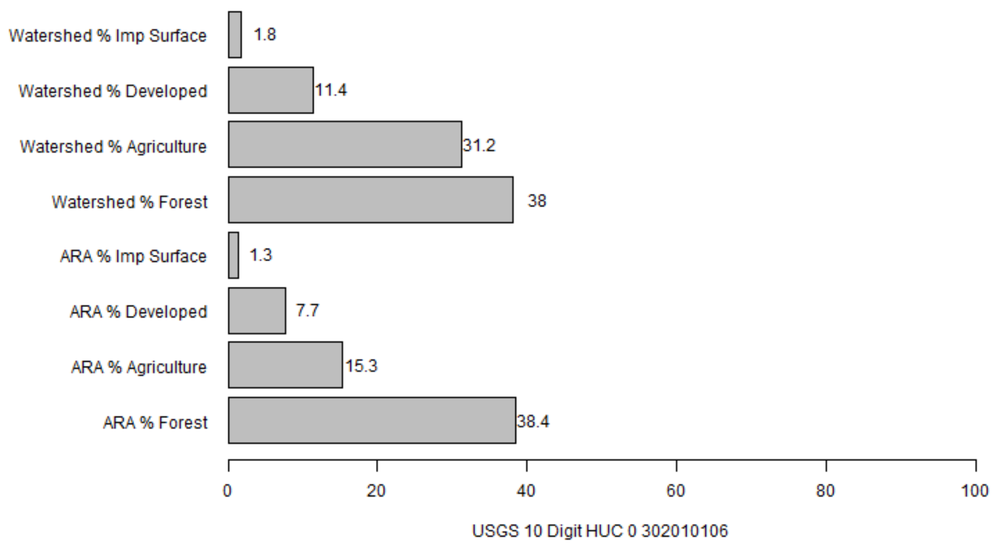




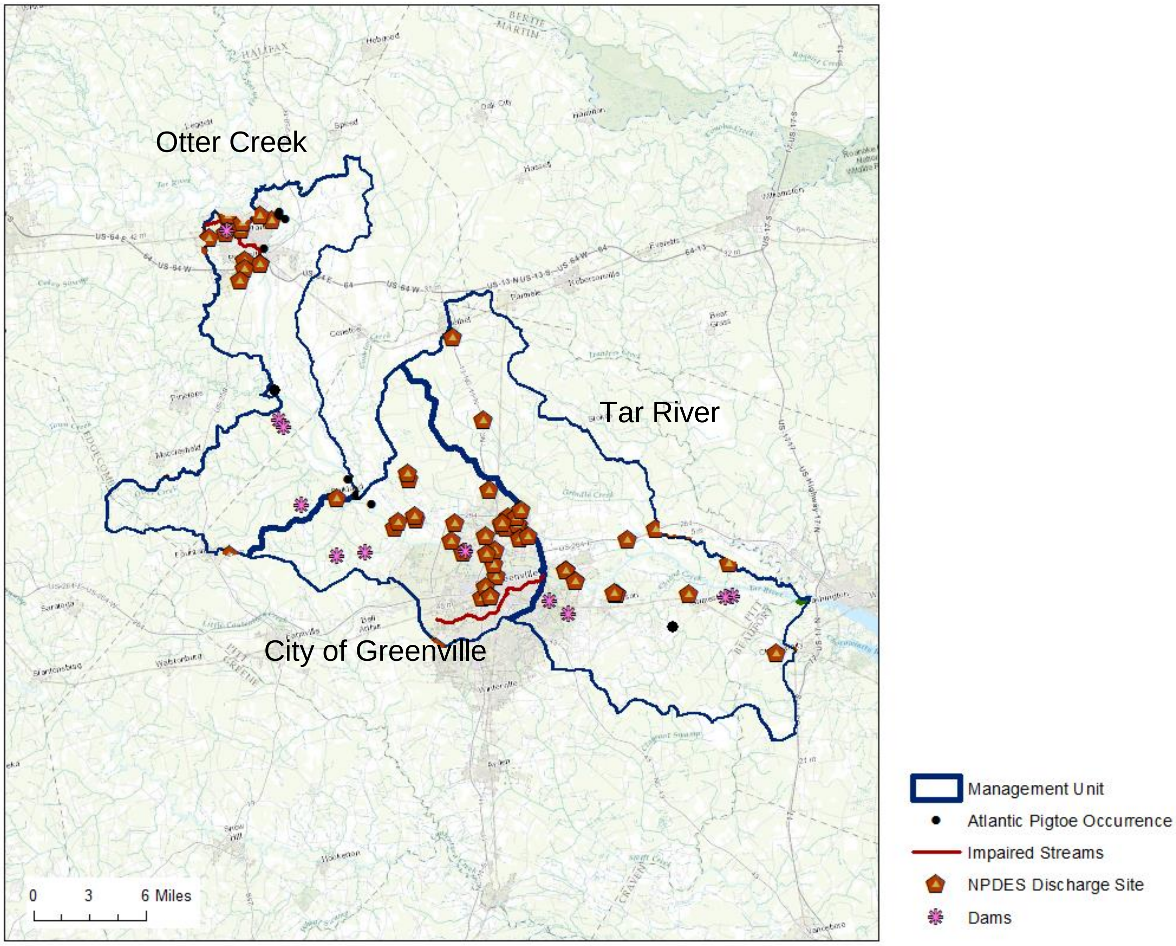

Areal Statistics for Lynch Creek-Tar River Subbasin
Watershed % Imp Surface
Watershed % Developed
Watershed % Agriculture
Watershed % Forest
ARA % Imp Surface
ARA % Developed
ARA % Agriculture
ARA % Forest
1.1
6.4
24.3
55.8
0.5
2.6
14.8
55.3
0
20
40
60
80
100
USGS 10 Digit HUC 0 302010103


Areal Statistics for Crooked Creek-Tar River Subbasin
Watershed % Imp Surface
Watershed % Developed
Watershed % Agriculture
Watershed % Forest
ARA % Imp Surface
ARA % Developed
ARA % Agriculture
ARA % Forest
1.3
9
27.7
50.1
0.4
3.3
16.5
50.6
0
20
40
60
80
100
USGS 10 Digit HUC 0 302010104

Areal Statistics for Tar River Reservoir-Tar River Subbasin



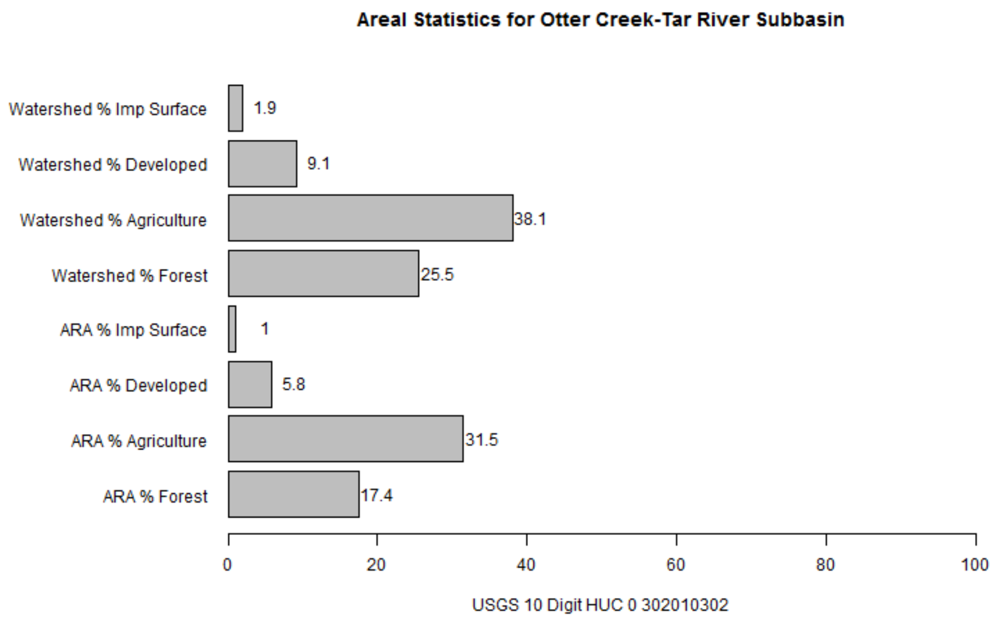
Lower Tar Management Unit

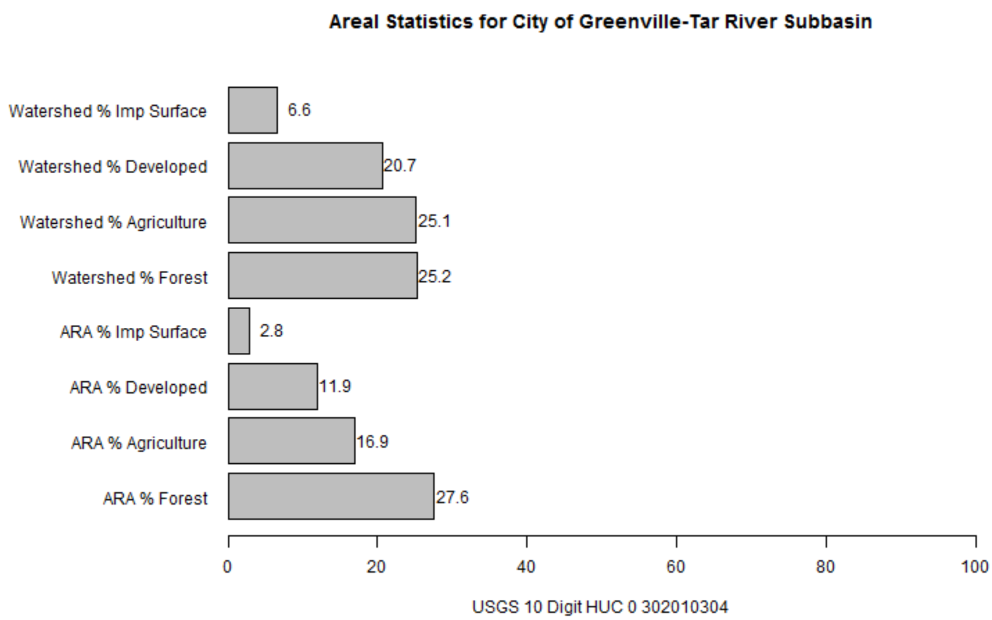


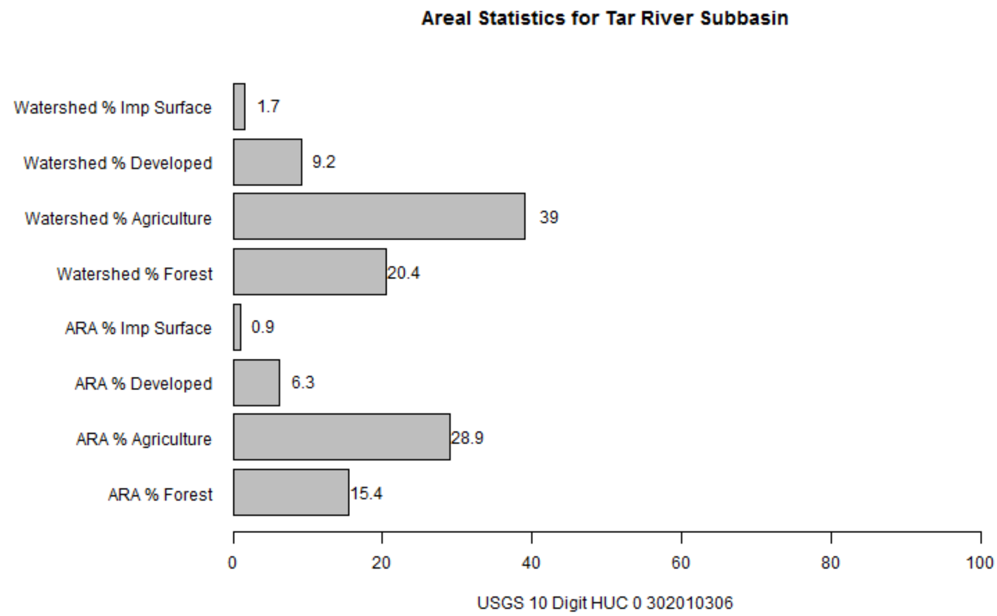
Survey Summary: The Atlantic Pigtoe was first documented in this MU in the 1978, and was last observed in 2013 with recent reproduction documented (T.Black (NCWRC) email to S.McRae (USFWS) on 10/19/2016). A total of 14 live and 38 shells have been observed in this MU (Alderman and Alderman 2014, p.20).

Water Quality Summary: Based on the 2014 data, there are two impaired stream reaches totaling ~11 miles in this MU. Causes are indicated by very low benthic-macroinvertebrate assessment scores, and the entire basin is classified as Nutrient Sensitive Waters. There are 52 non-major and 2 major (Tarboro WWTP and Grenville WWTP) NPDES discharges in this MU.

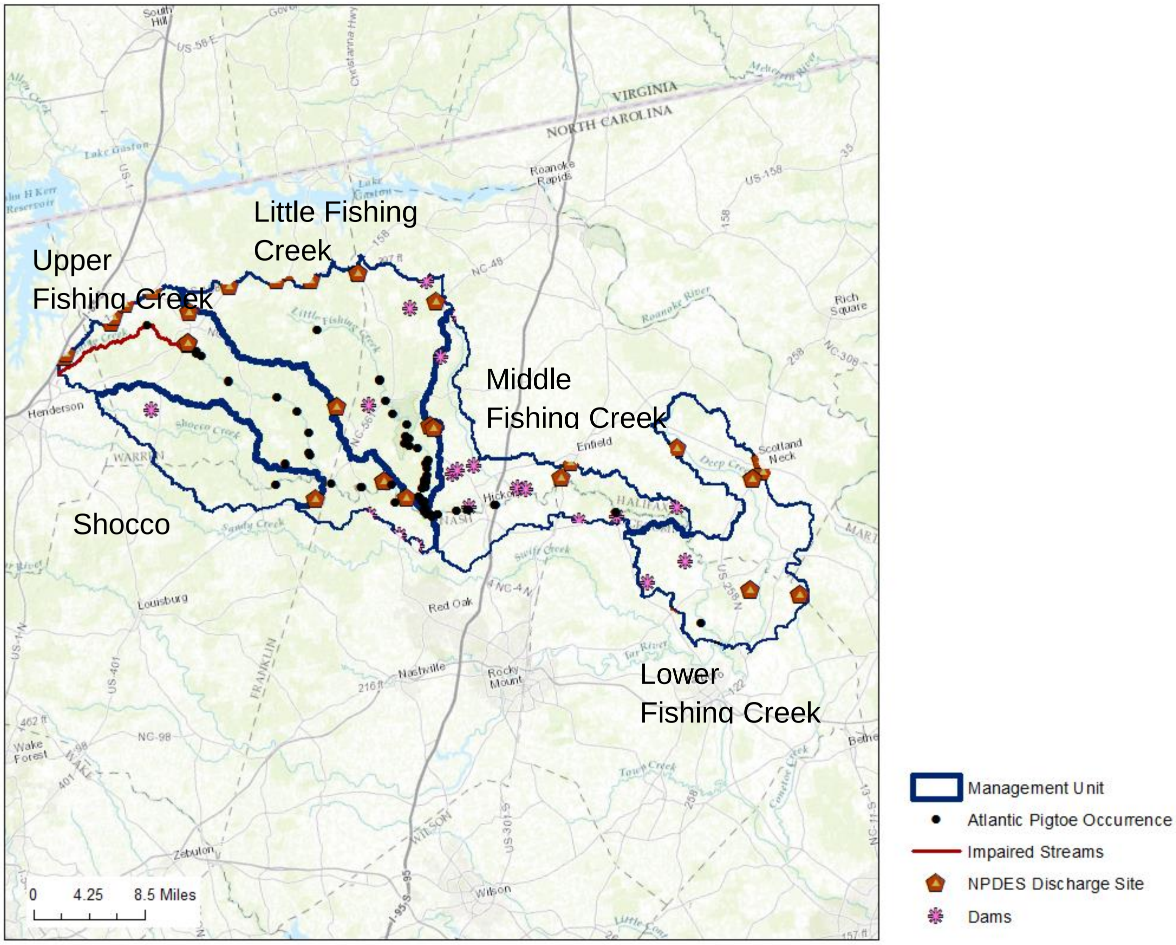
Land Use Land Cover Summary:






Areal Statistics for Tar River Subbasin
Watershed % Imp Surface
1.7
Watershed % Developed
9.2
Watershed % Agriculture
39
Watershed % Forest
20.4
ARA % Imp Surface
0.9
ARA % Developed
6.3
ARA % Agriculture
28.9
ARA % Forest
15.4
0
20
40
60
80
100
USGS 10 Digit HUC 0 302010306

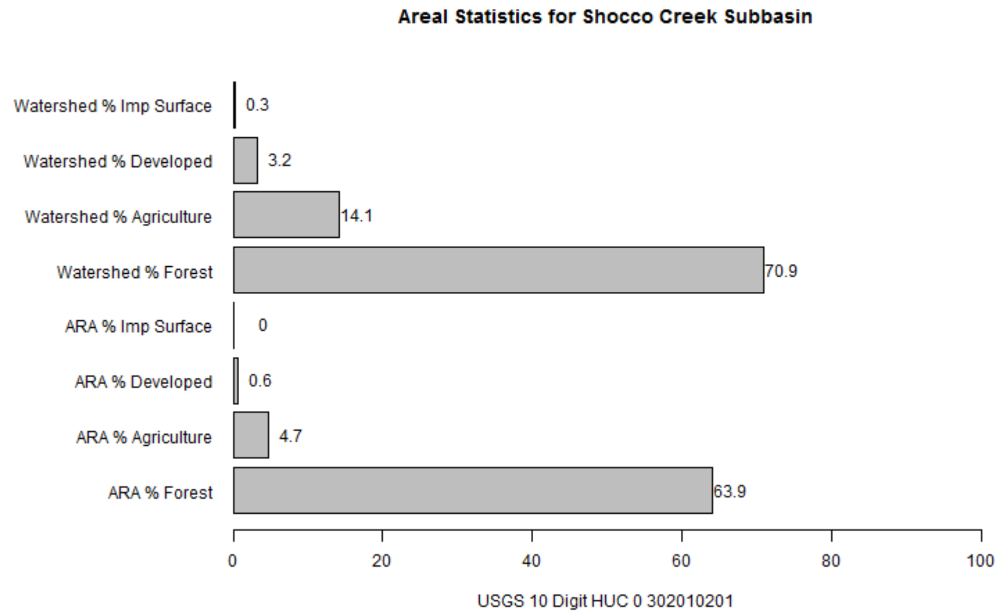
Fishing Creek Subbasin Management Unit

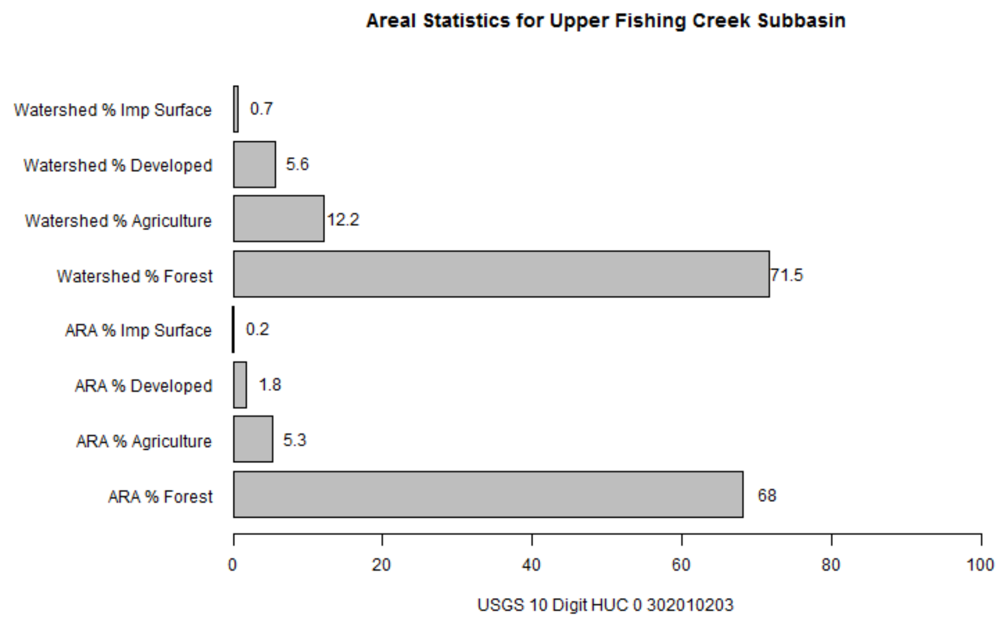


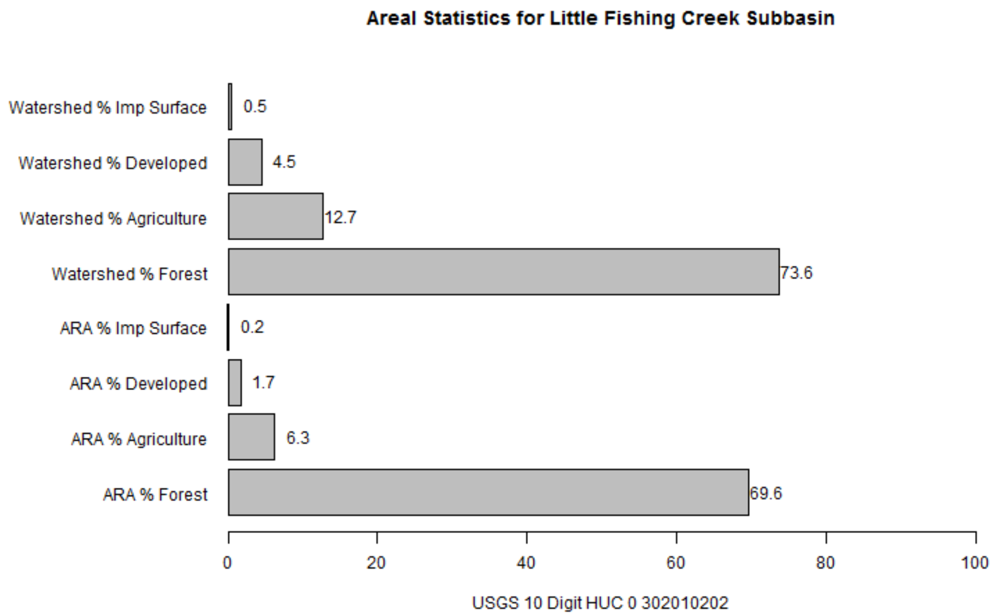
Survey Summary: This MU includes Fishing Creek, Little Fishing Creek, Shocco Creek and Maple Branch. Many surveys have occurred in this subbasin; the species was first documented in 1988 and most recently seen in 2016. Most survey efforts document under 10 individuals, although as many as 38 live individuals have been seen in one survey (Little Fishing Creek in 2014). Evidence of recruitment is often observed in this MU. As of 2016, a total of 608 live and 188 shells have been observed in this MU (NCWRC 2016).

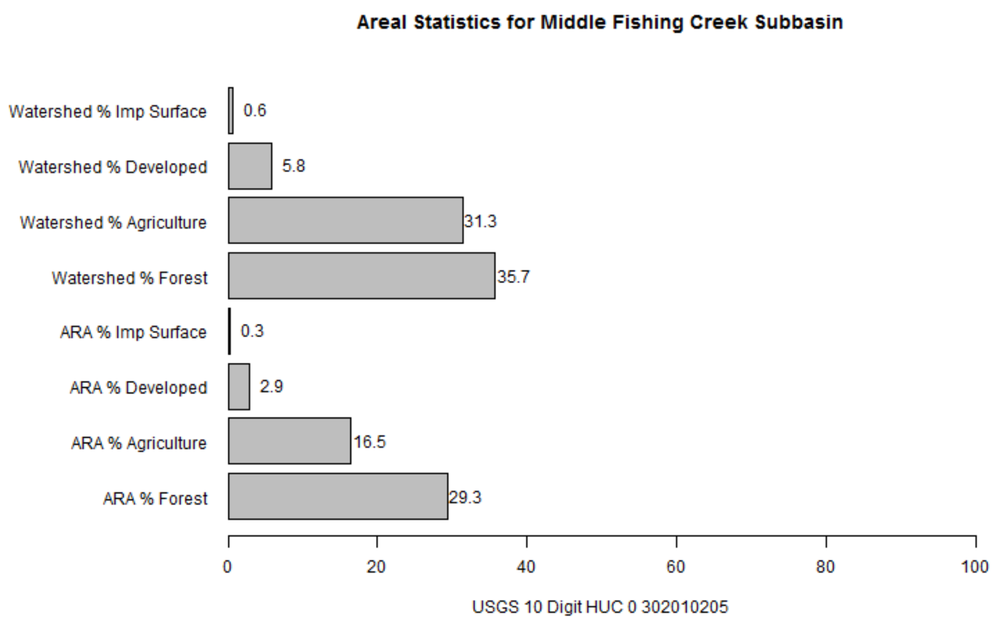
Water Quality Summary: Based on 2014 data, there is one impaired stream reach totaling ~14 miles in this MU. Cause of impairment is due to low DO. There are 22 non-major and one (Warrenton WWTP) NPDES discharges in this MU.

Land Use Land Cover Summary:

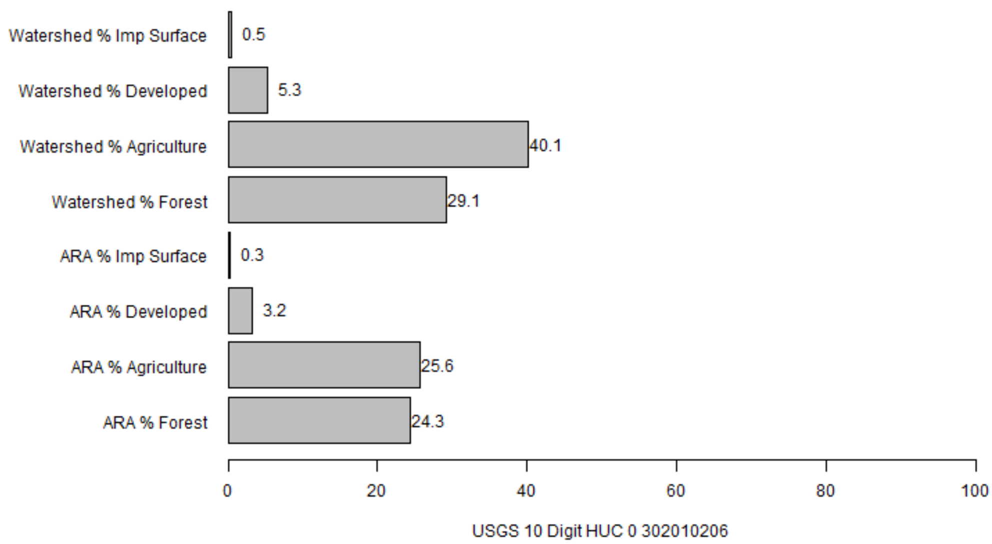




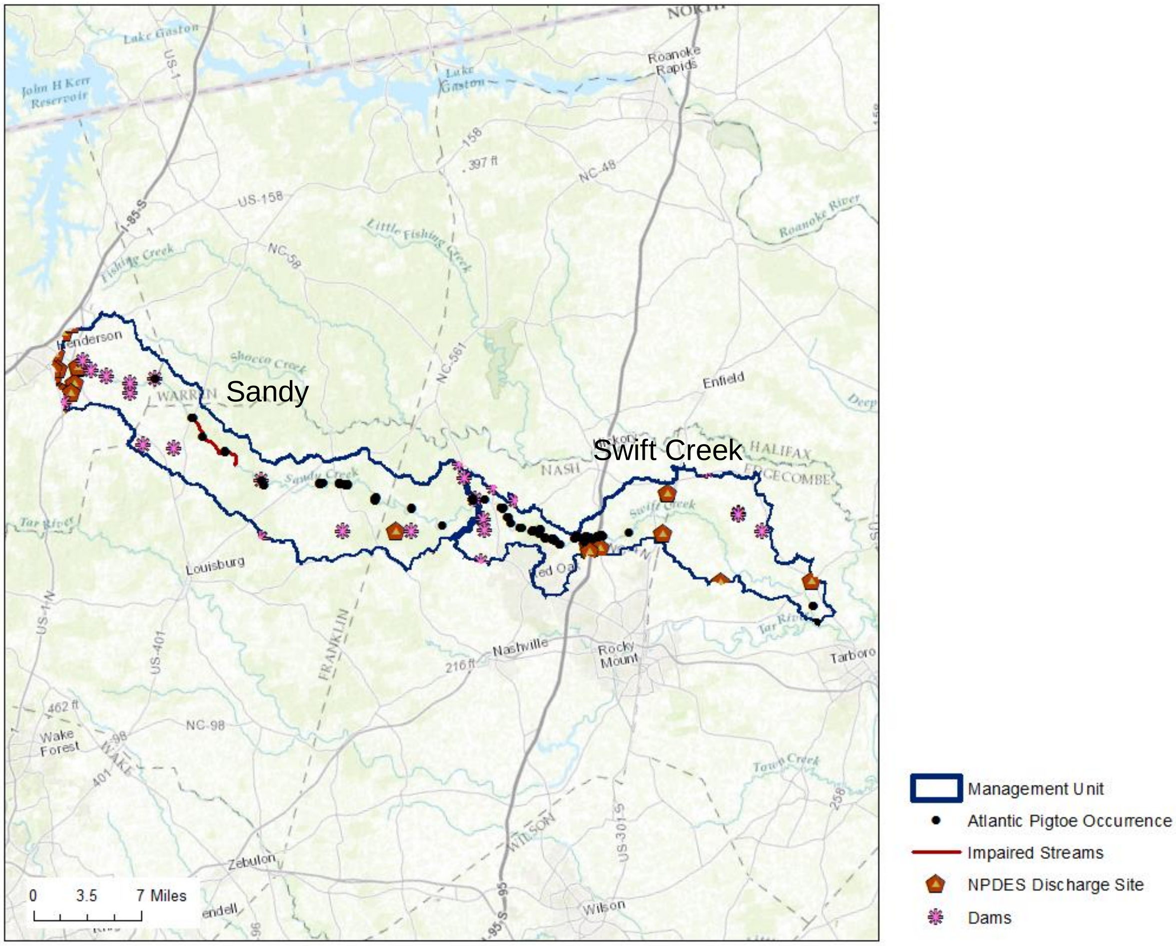

Areal Statistics for Little Fishing Creek Subbasin
Watershed % Imp Surface
0.5
Watershed % Developed
4.5
Watershed % Agriculture
12.7
Watershed % Forest
73.6
ARA % Imp Surface
0.2
ARA % Developed
1.7
ARA % Agriculture
6.3
ARA % Forest
69.6
0
20
40
60
80
100
USGS 10 Digit HUC 0 302010202


Areal Statistics for Middle Fishing Creek Subbasin
Watershed % Imp Surface
0.6
Watershed % Developed
5.8
Watershed % Agriculture
31.3
Watershed % Forest
35.7
ARA % Imp Surface
0.3
ARA % Developed
2.9
ARA % Agriculture
16.5
ARA % Forest
29.3
0
20
40
60
80
100
USGS 10 Digit HUC 0 302010205

Areal Statistics for Lower Fishing Creek Subbasin



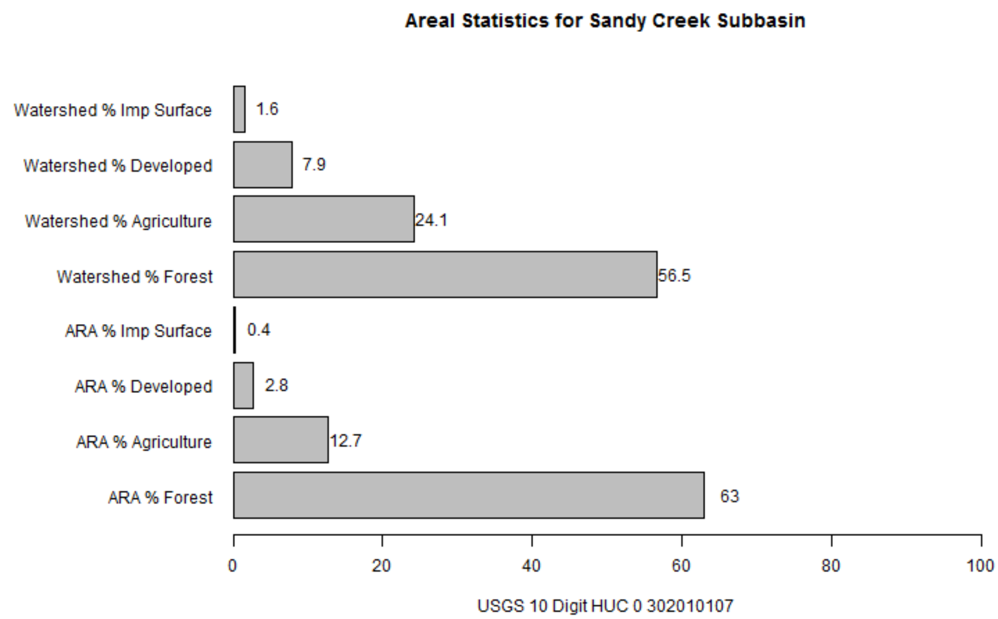
Sandy-Swift Creek Management Unit

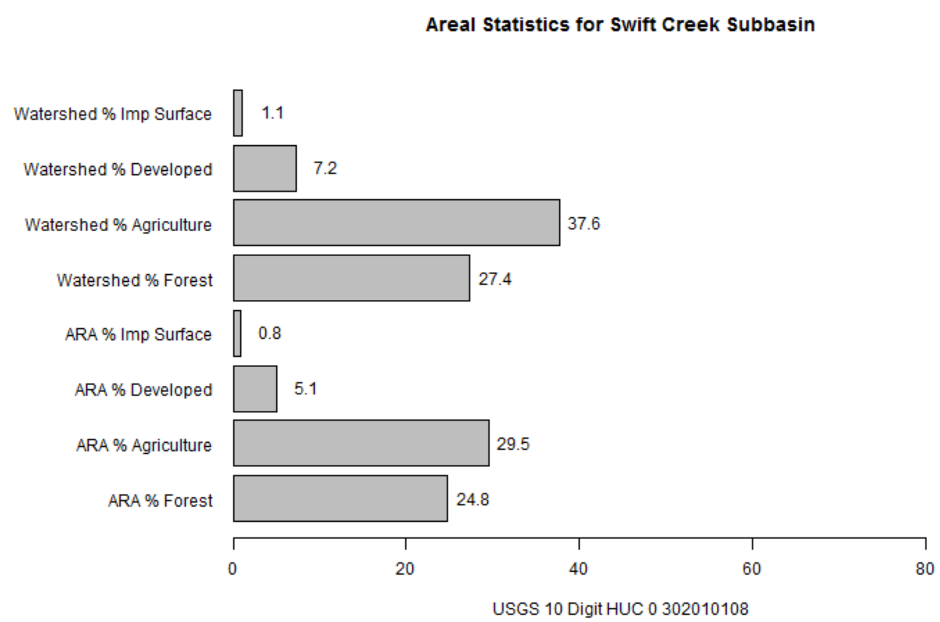


Survey Summary: Many surveys have observed Atlantic Pigtoes in this MU. The species was first documented in 1987 and seen as recently as 2016. Abundances have been described as "uncommon" with most surveys documenting less than five individuals, with the most being 23 seen in 1992. Recruitment was documented as recent as 2012. As of 2012, 475 live individuals and 1,576 shells have been observed over time in this MU (Alderman and Alderman 2014, p.20).

Water Quality Summary: Based on 2014 data, there is one impaired stream reach totaling ~5 miles in this MU. Cause of impairment is due to low benthic-macroinvertebrate assessment score. There are 21 non-major NPDES discharges in this MU. The entire Sandy Creek HUC and the upper portion of the Swift Creek HUC are designated as an ORW Special Management Strategy Area, which is a classification intended to protect unique and special waters having excellent water quality and being of exceptional or national ecological or recreational significance (NCDEQ 2016d).

Land Use Land Cover Summary:

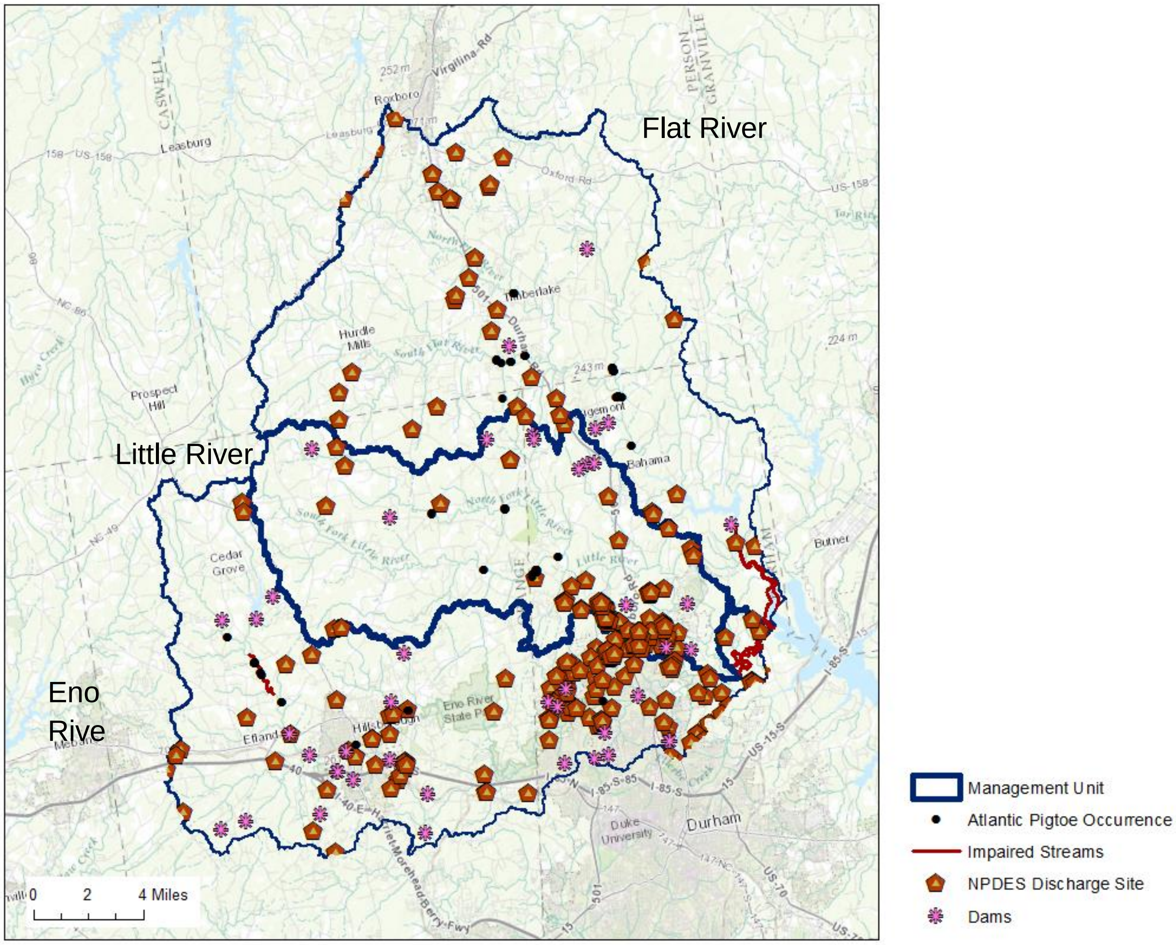




Neuse River Population

Consists of two MUs: Upper Neuse River Basin; Middle Neuse River Basin

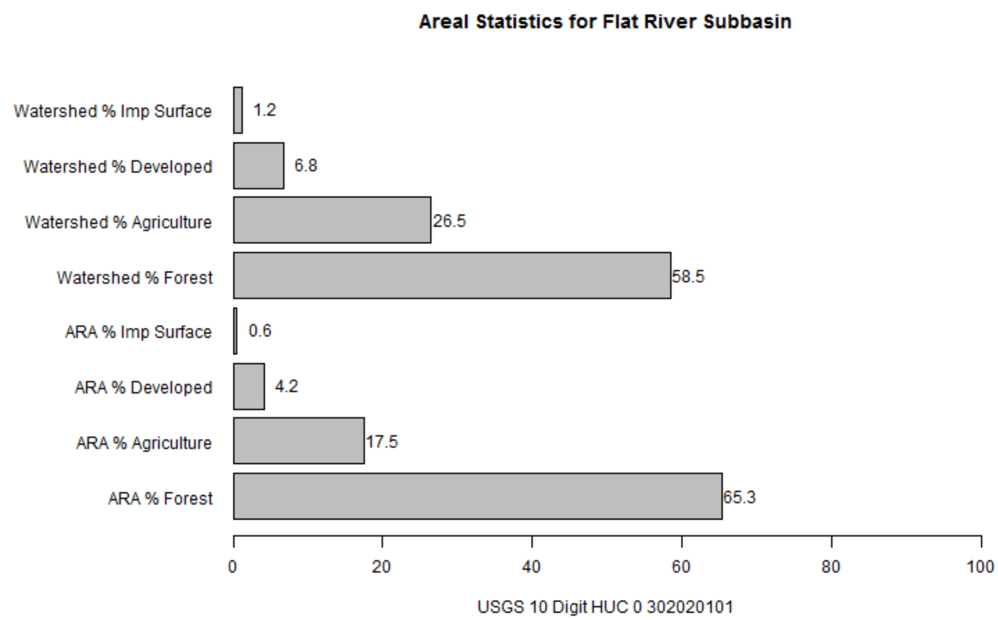
<u>Upper Neuse River Basin Management Unit</u>

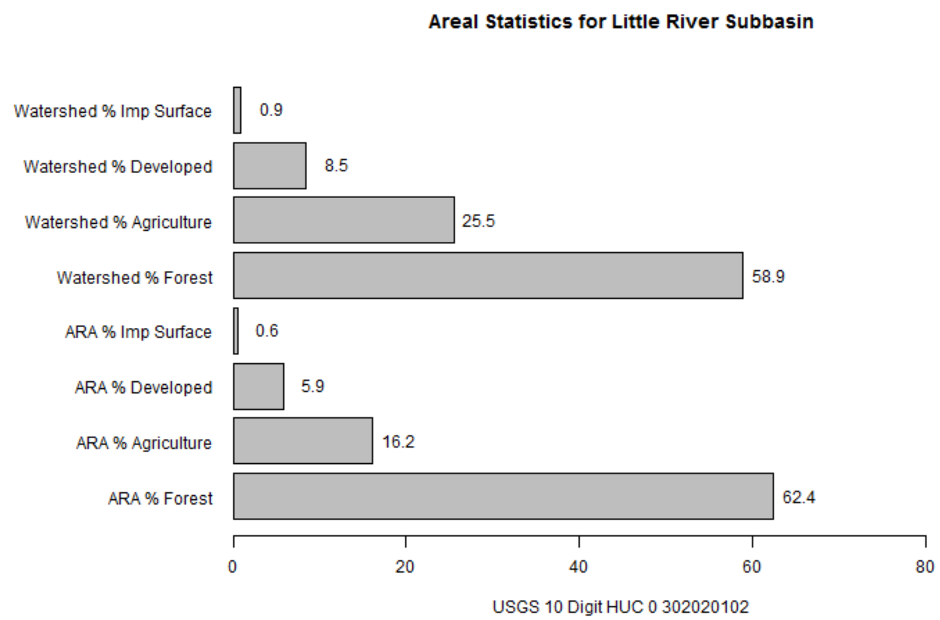


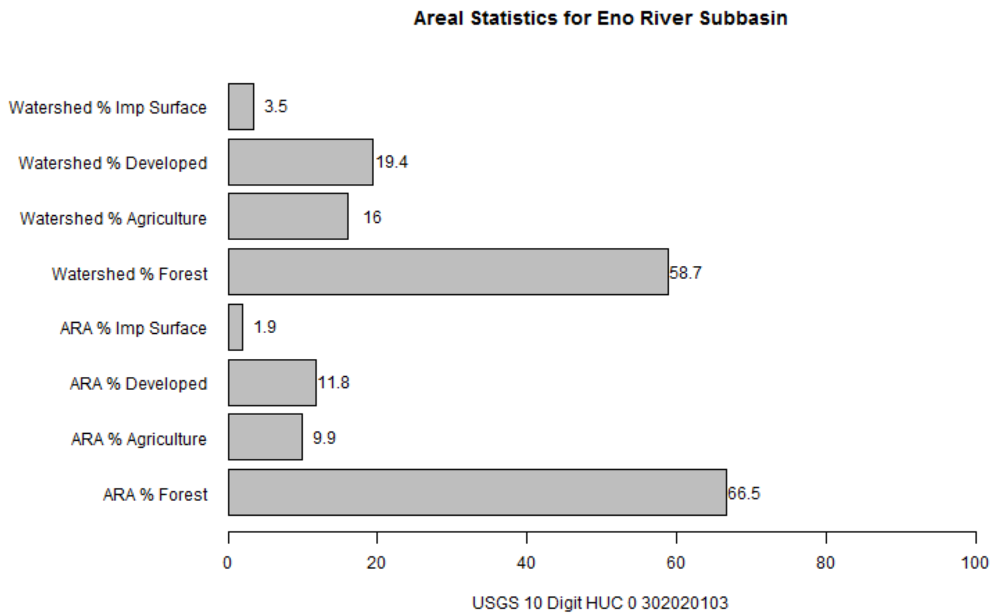
Survey Summary: This MU includes Deep Creek and the Flat, Little, and Eno rivers in the upper Neuse River Basin. Several surveys have documented Atlantic Pigtoes in this MU – it was first documented in 1974 and seen as recently as 2011. Although seen consistently, very few individuals are usually documented during a survey effort, however as many as 22 have been seen in one survey effort on the Eno River (in 1995), and as many as 28 have been seen in the South Flat River (in 2001). Reproduction and recruitment have been documented, as broodstock for captive propagation have been collected from Deep Creek. A total of 139 live individuals and 34 shells have been observed in this MU (Alderman and Alderman 2014, p.20).

Water Quality Summary: Based on the 2014 data, there are three impaired stream reaches totaling ~4 miles in this MU. Causes of impairment are low benthic-macroinvertebrate assessment scores and low DO, and the entire basin is classified as Nutrient Sensitive Waters. There are 329 non-major and one major (Hillsborough WWTP) NPDES discharges in this MU.

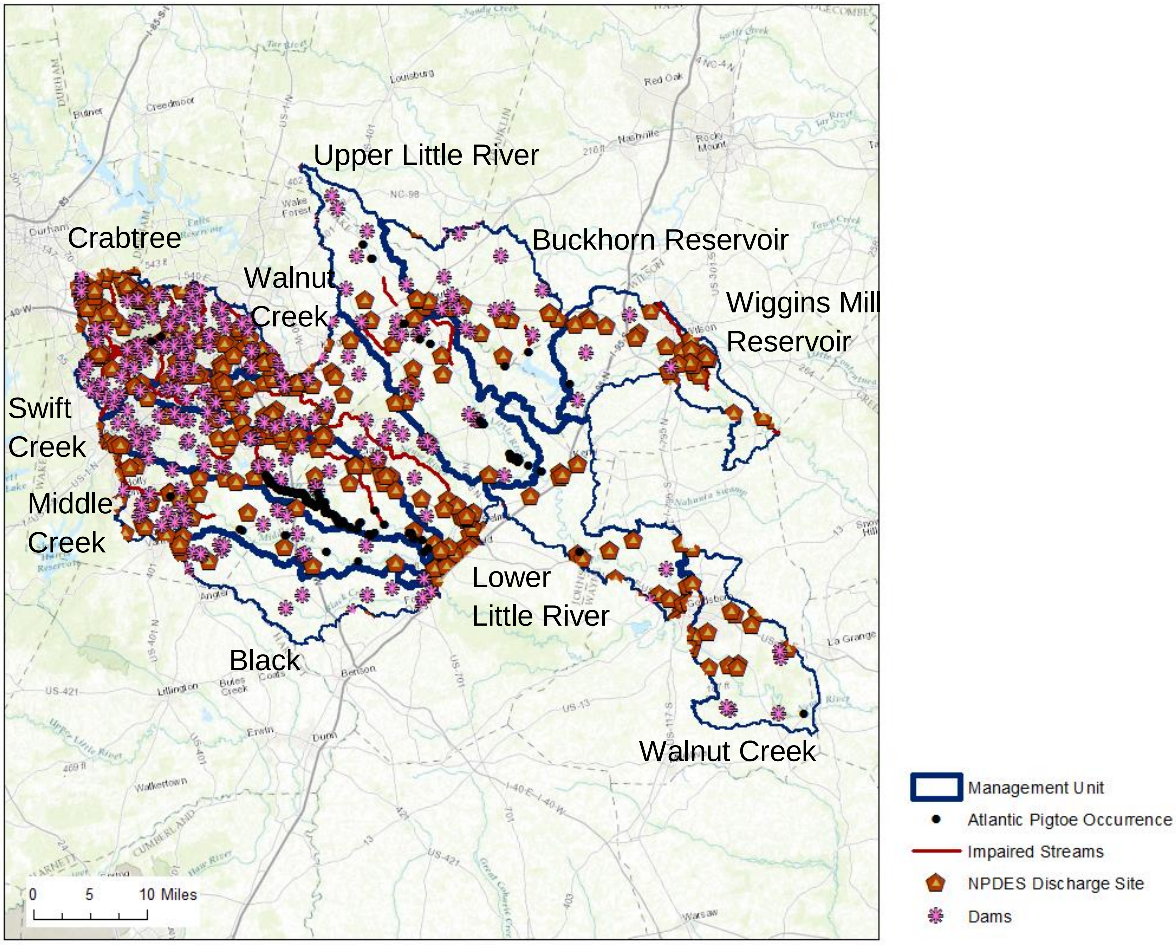
Land Use Land Cover Summary:






Areal Statistics for Eno River Subbasin
Watershed % Imp Surface
3.5
Watershed % Developed
19.4
Watershed % Agriculture
16
Watershed % Forest
58.7
ARA % Imp Surface
1.9
ARA % Developed
11.8
ARA % Agriculture
9.9
ARA % Forest
66.5
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020103

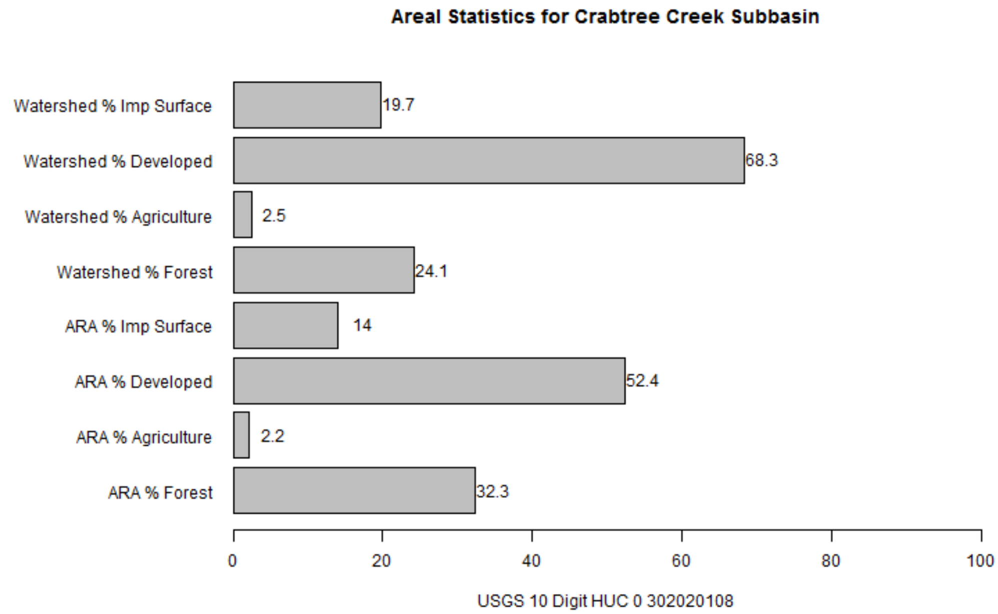
Middle Neuse River Basin Management Unit

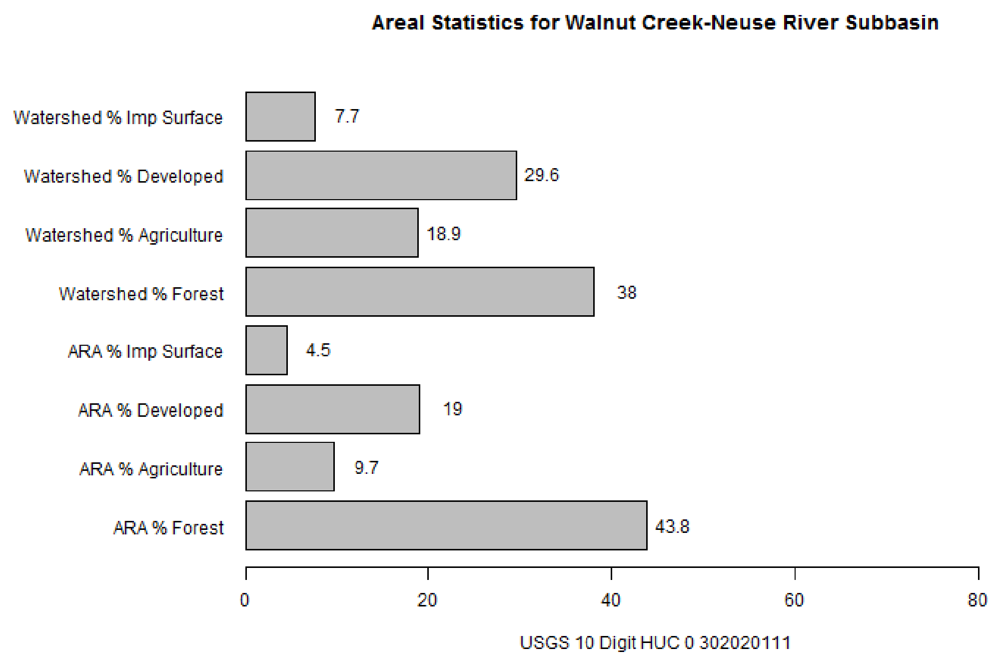


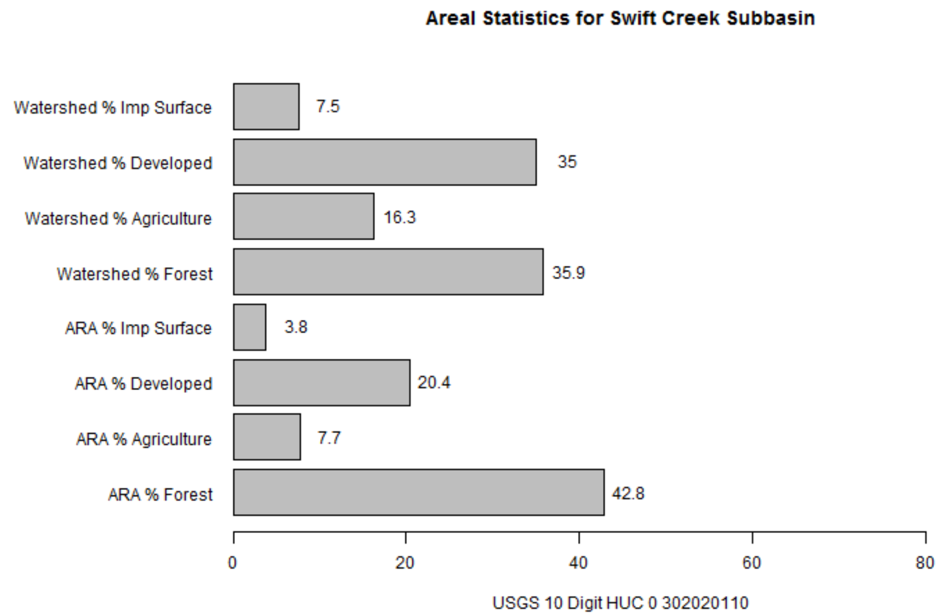
Survey Summary: This MU includes the tributaries Crabtree Creek, Walnut Creek, Swift Creek, Middle Creek, Little River, and Contentnea Creek, as well as an historical location on the mainstem of the Neuse River. There have been many survey efforts in this MU over the years, with the species first seen in 1983 and most recently seen in 2014. While Atlantic Pigtoes have been consistently documented in some places (like Little River and Swift Creek), abundances have been described as “rare” and usually only one or two individuals are usually found during a survey effort. The most seen in an effort was seven during the 2015 surveys in Swift Creek. Recruitment has been documented in the Little River as recently as 2011. Only one live and one relic shell material has ever been documented in Contentnea Creek. As of 2014, a total of 396 live individuals and 118 shells (mostly in Swift Creek) have been observed (Alderman and Alderman 2014, p.20).

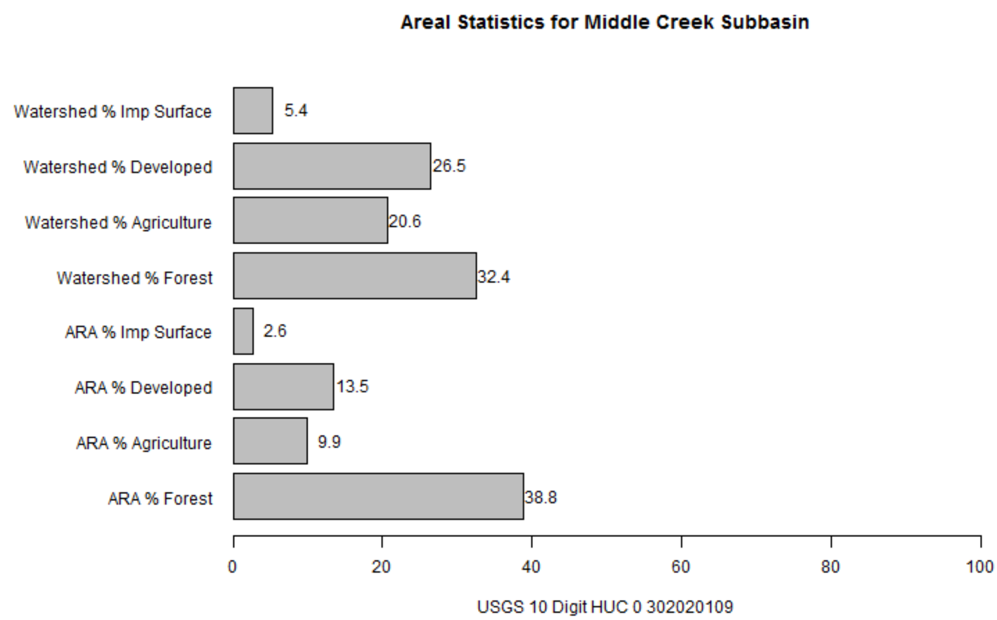
Water Quality Summary: Based on the 2014 data, there are 49 impaired stream reaches totaling ~447 miles in this MU. There are many causes of impairment, including low benthic-macroinvertebrate assessment scores, low pH, poor fish community scores, low DO, PCBs, Copper, and Zinc. There are 349 non-major and 6 major (Apex WRF, Central Johnston county WWTP, Cary WWTP, City of Raleigh, Dempsey Benton WTP, and Terrible Creek WWTP) NPDES discharges in this MU.

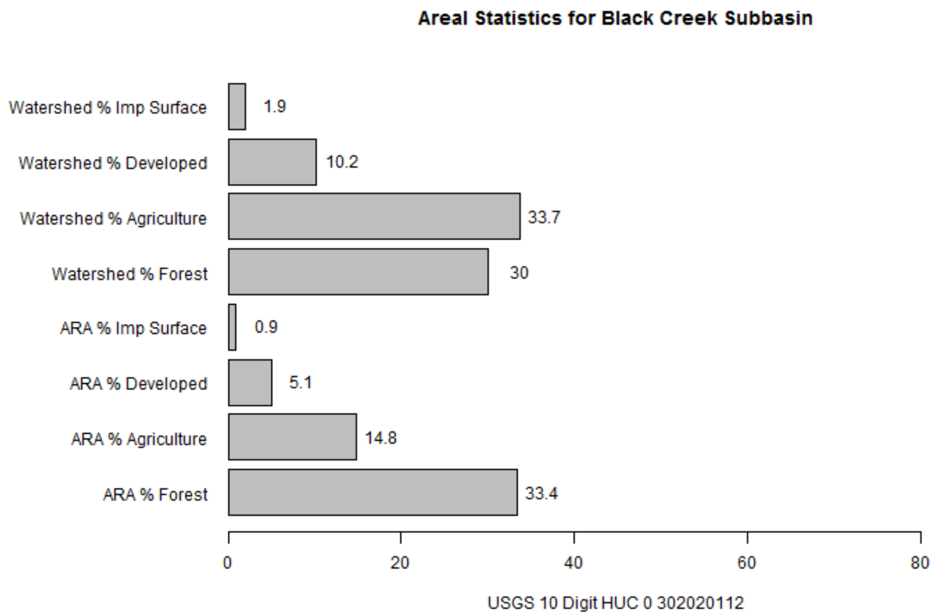
Land Use Land Cover Summary:

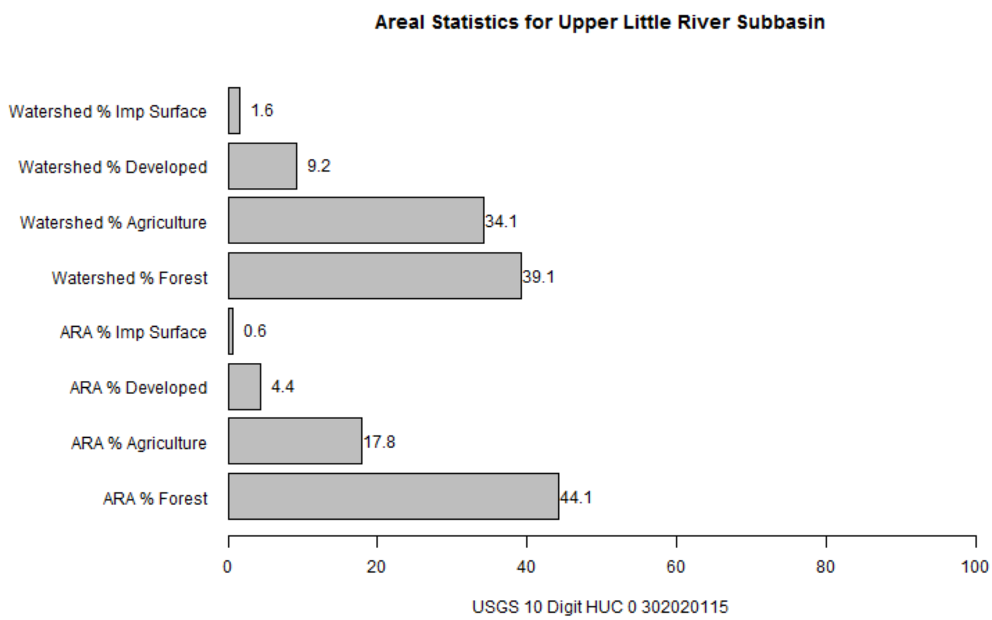


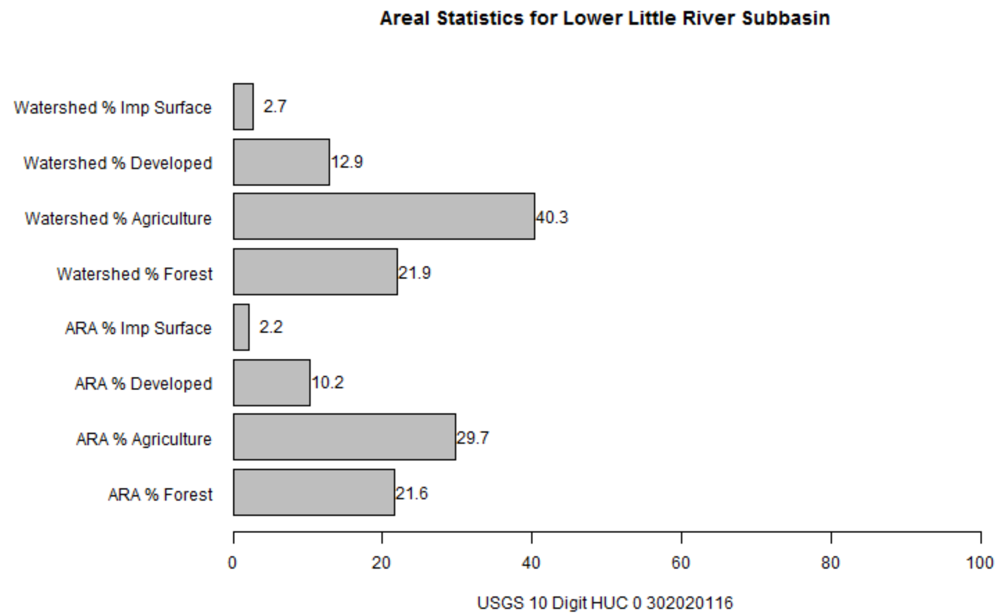


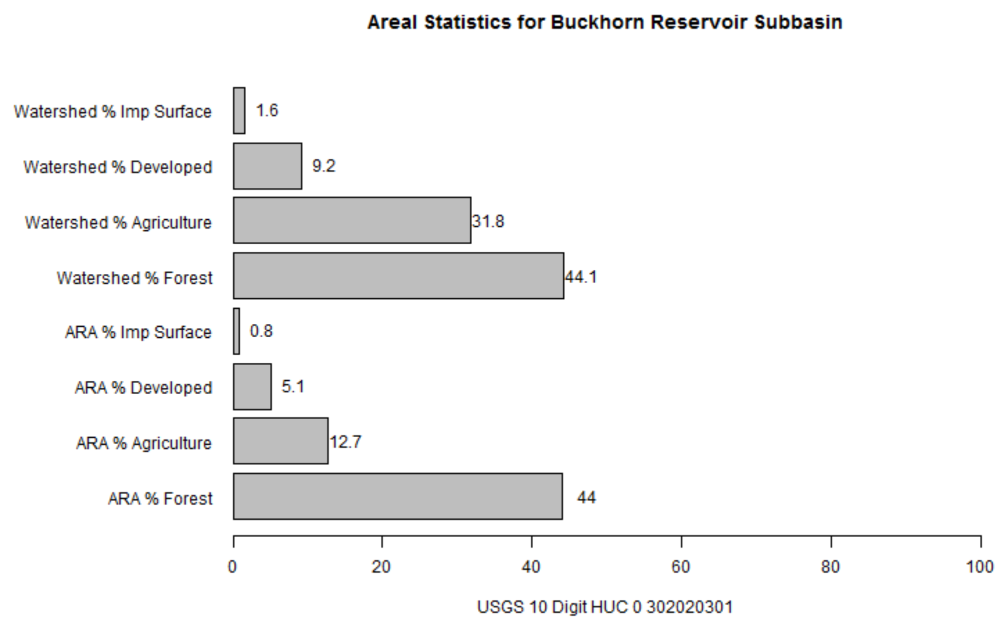

Areal Statistics for Swift Creek Subbasin
Watershed % Imp Surface
7.5
Watershed % Developed
35
Watershed % Agriculture
16.3
Watershed % Forest
35.9
ARA % Imp Surface
3.8
ARA % Developed
20.4
ARA % Agriculture
7.7
ARA % Forest
42.8
0
20
40
60
80
USGS 10 Digit HUC 0 302020110

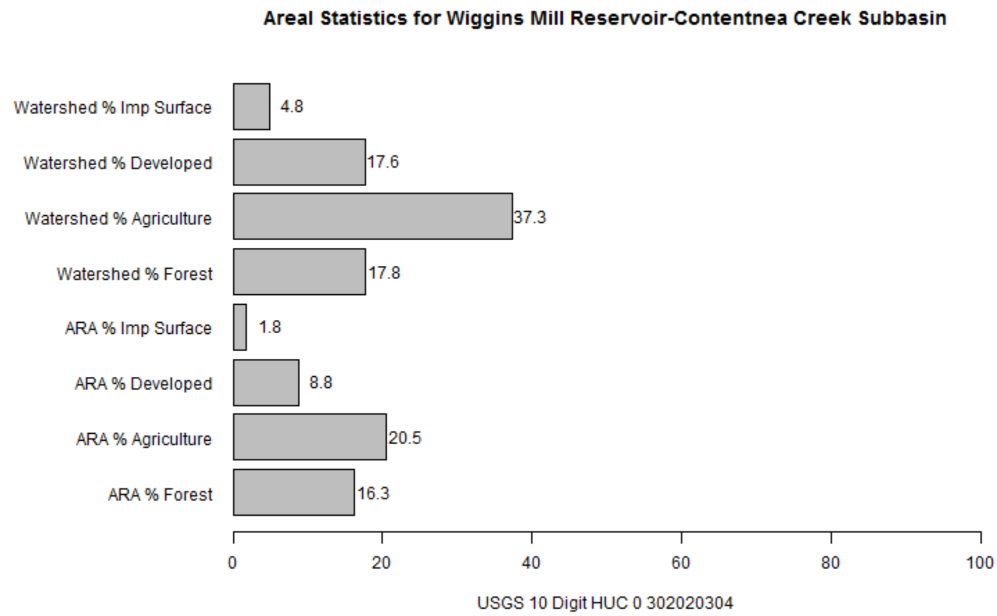

Areal Statistics for Middle Creek Subbasin
Watershed % Imp Surface
5.4
Watershed % Developed
26.5
Watershed % Agriculture
20.6
Watershed % Forest
32.4
ARA % Imp Surface
2.6
ARA % Developed
13.5
ARA % Agriculture
9.9
ARA % Forest
38.8
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020109

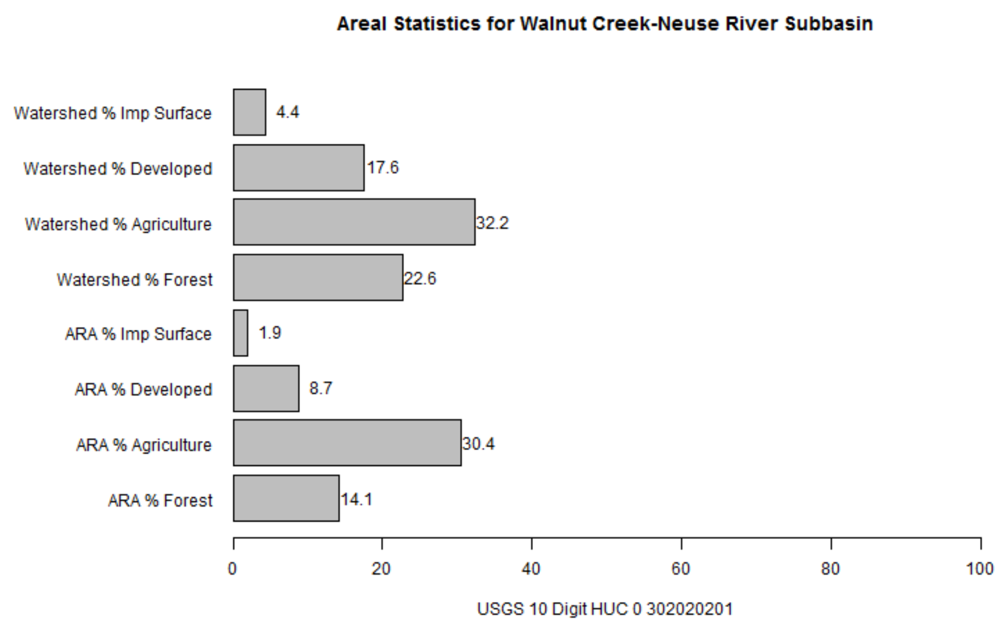

Areal Statistics for Black Creek Subbasin
Watershed % Imp Surface
1.9
Watershed % Developed
10.2
Watershed % Agriculture
33.7
Watershed % Forest
30
ARA % Imp Surface
0.9
ARA % Developed
5.1
ARA % Agriculture
14.8
ARA % Forest
33.4
0
20
40
60
80
USGS 10 Digit HUC 0 302020112


Areal Statistics for Upper Little River Subbasin
Watershed % Imp Surface
1.6
Watershed % Developed
9.2
Watershed % Agriculture
34.1
Watershed % Forest
39.1
ARA % Imp Surface
0.6
ARA % Developed
4.4
ARA % Agriculture
17.8
ARA % Forest
44.1
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020115


Areal Statistics for Lower Little River Subbasin
Watershed % Imp Surface
Watershed % Developed
Watershed % Agriculture
Watershed % Forest
ARA % Imp Surface
ARA % Developed
ARA % Agriculture
ARA % Forest
2.7
12.9
40.3
21.9
2.2
10.2
29.7
21.6
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020116


Areal Statistics for Buckhorn Reservoir Subbasin
Watershed % Imp Surface
Watershed % Developed
Watershed % Agriculture
Watershed % Forest
ARA % Imp Surface
ARA % Developed
ARA % Agriculture
ARA % Forest
1.6
9.2
31.8
44.1
0.8
5.1
12.7
44
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020301

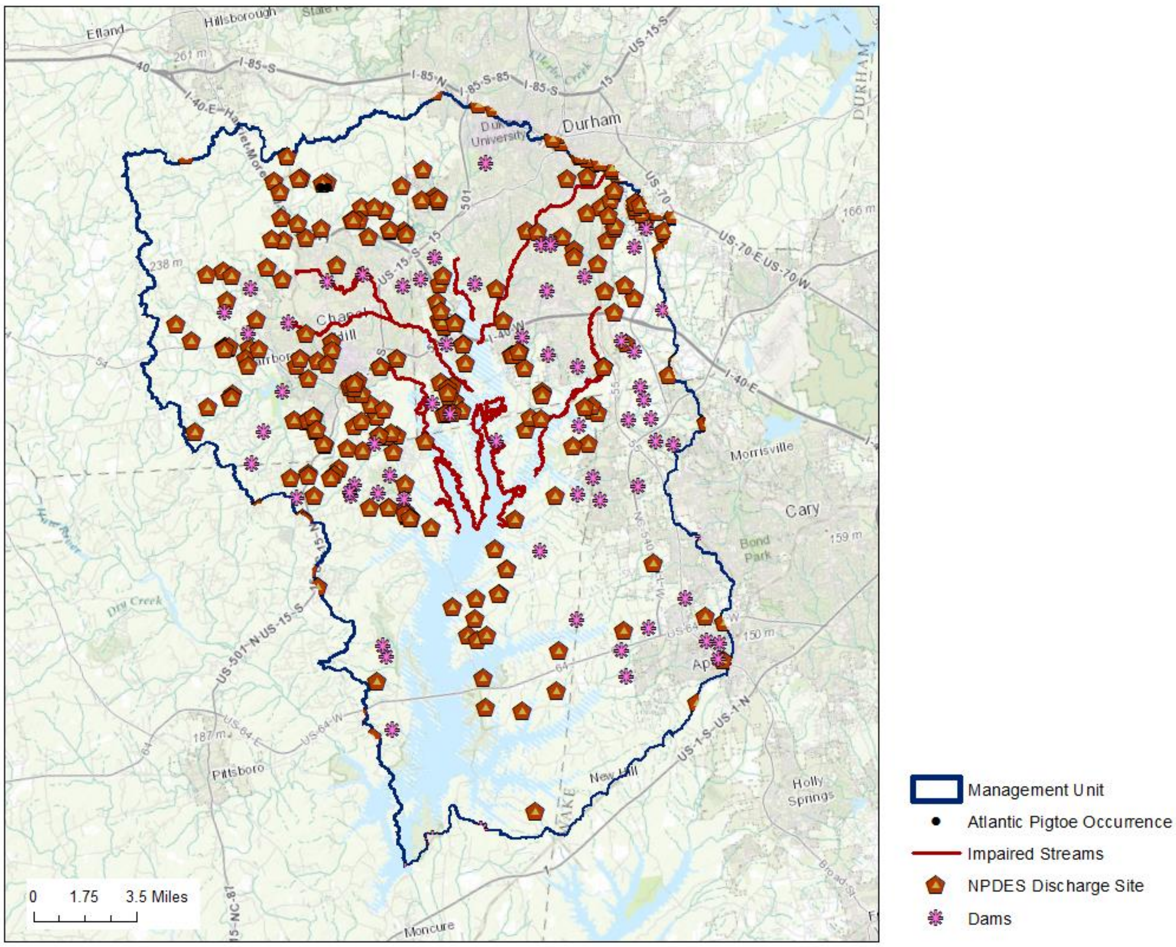

Areal Statistics for Wiggins Mill Reservoir-Contentnea Creek Subbasin
Watershed % Imp Surface
Watershed % Developed
Watershed % Agriculture
Watershed % Forest
ARA % Imp Surface
ARA % Developed
ARA % Agriculture
ARA % Forest
4.8
17.6
37.3
17.8
1.8
8.8
20.5
16.3
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020304


Areal Statistics for Walnut Creek-Neuse River Subbasin
Watershed % Imp Surface
Watershed % Developed
Watershed % Agriculture
Watershed % Forest
ARA % Imp Surface
ARA % Developed
ARA % Agriculture
ARA % Forest
4.4
17.6
32.2
22.6
1.9
8.7
30.4
14.1
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020201

Cape Fear River Population

Consists of four MUs: New Hope Creek; Deep River Subbasin; mainstem Cape Fear; Black River

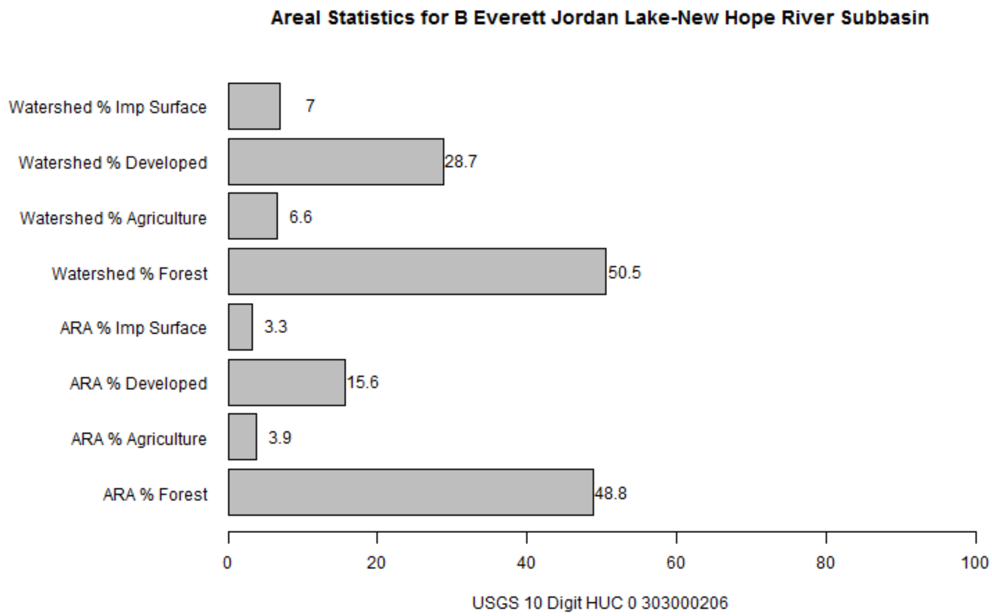
<u>New Hope Creek Management Unit</u>



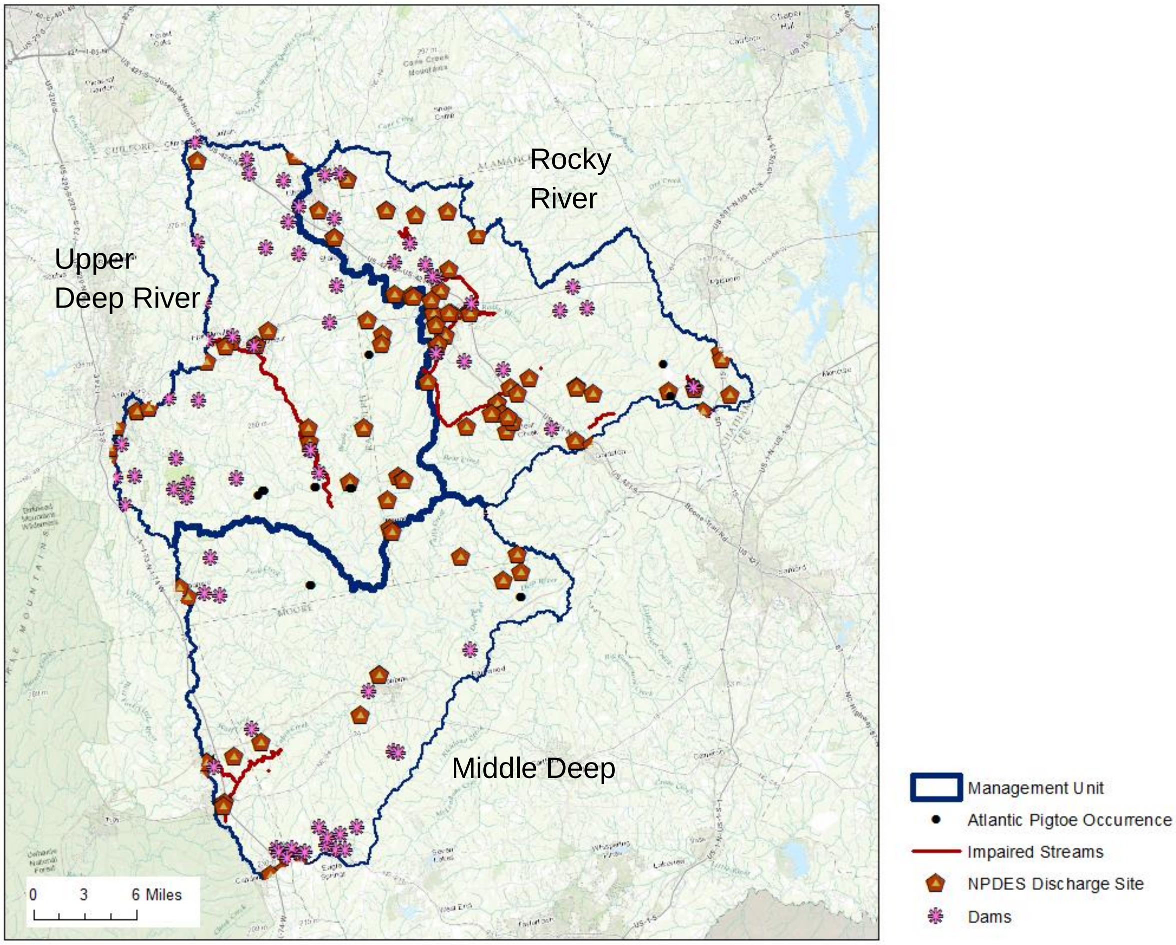
Survey Summary: Several survey efforts in the mid-2000s documented the presence of Atlantic Pigtoe in this MU. A total of 25 live individuals have been documented from this MU (Alderman and Alderman 2014, p.19).

Water Quality Summary: Based on 2014 data, there are 18 impaired stream reaches totaling ~59 miles in this MU. Causes of impairment include low benthic-macroinvertebrate assessment scores, low DO, copper and zinc. There are 237 non-major and three major (Durham County WWTP, Durham WRF, Mason Farm WWTP) NPDES discharges in this MU.

Land Use Land Cover Summary:



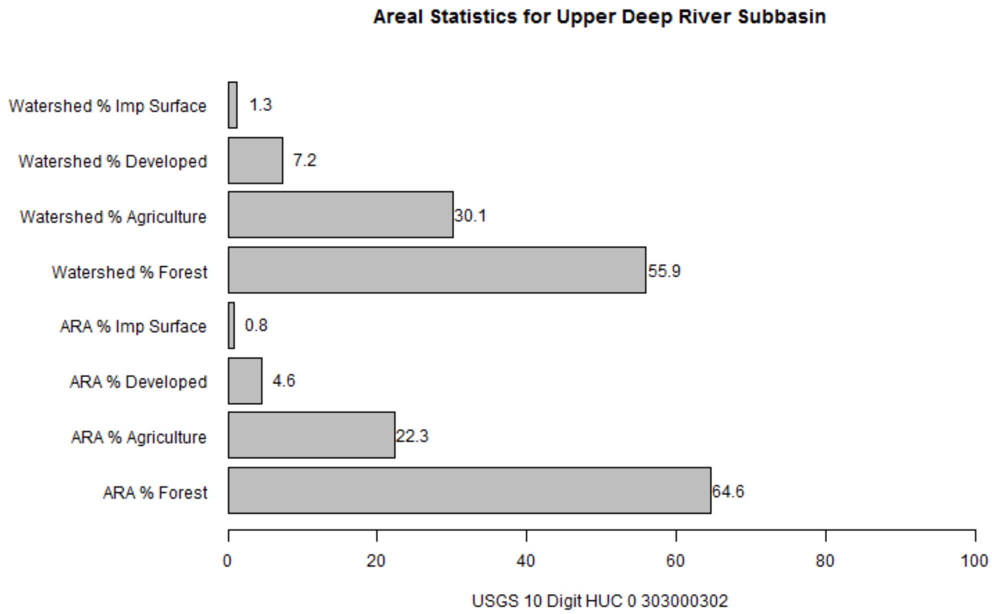
Deep River Subbasin Management Unit

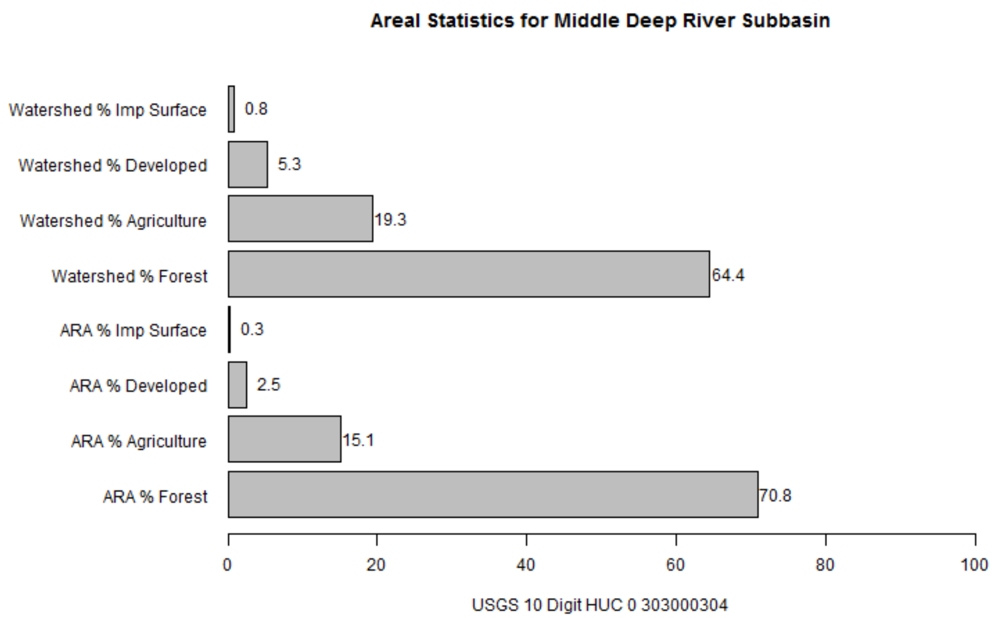


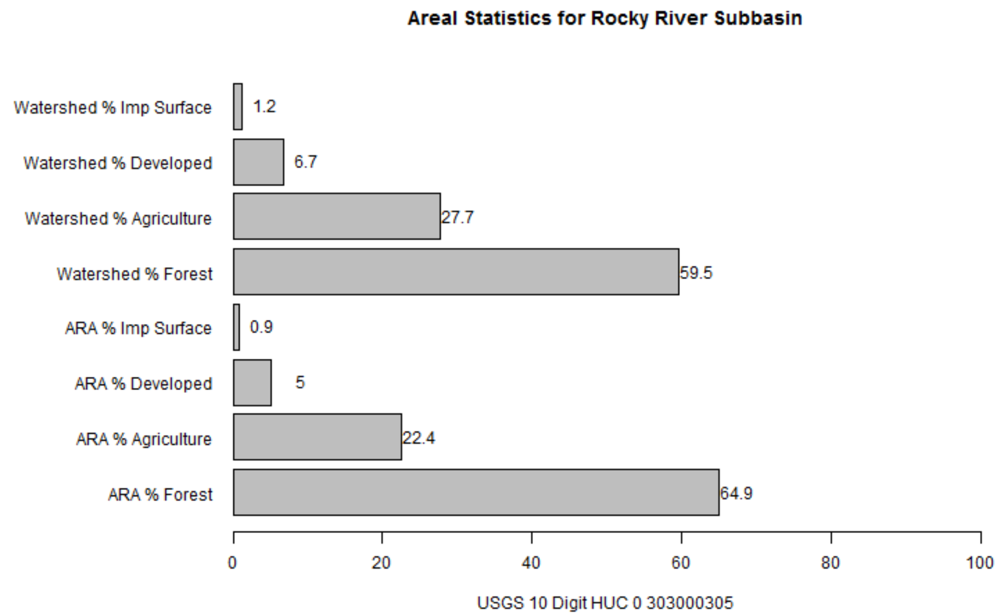
Survey Summary: This MU includes Brush Creek, Fork Creek, and the Rocky and Deep rivers. The species was first observed in this MU in the Rocky River in 1971 and seen as recently as 2010 in Brush Creek. Very few individuals have been observed over time with a total of 14 live and five shells (Alderman and Alderman 2014, p.19).

Water Quality Summary: Based on 2014 data, there are 18 impaired stream reaches totaling ~36 miles in this MU. Causes of impairment are low benthic-macroinvertebrate assessment scores, poor fish community, low DO, low pH, and Copper. There are 89 non-major (including small municipal WWTPs for Siler City, Ramseur, and Star) and one major (Robbins WWTP) NPDES discharges in this MU.

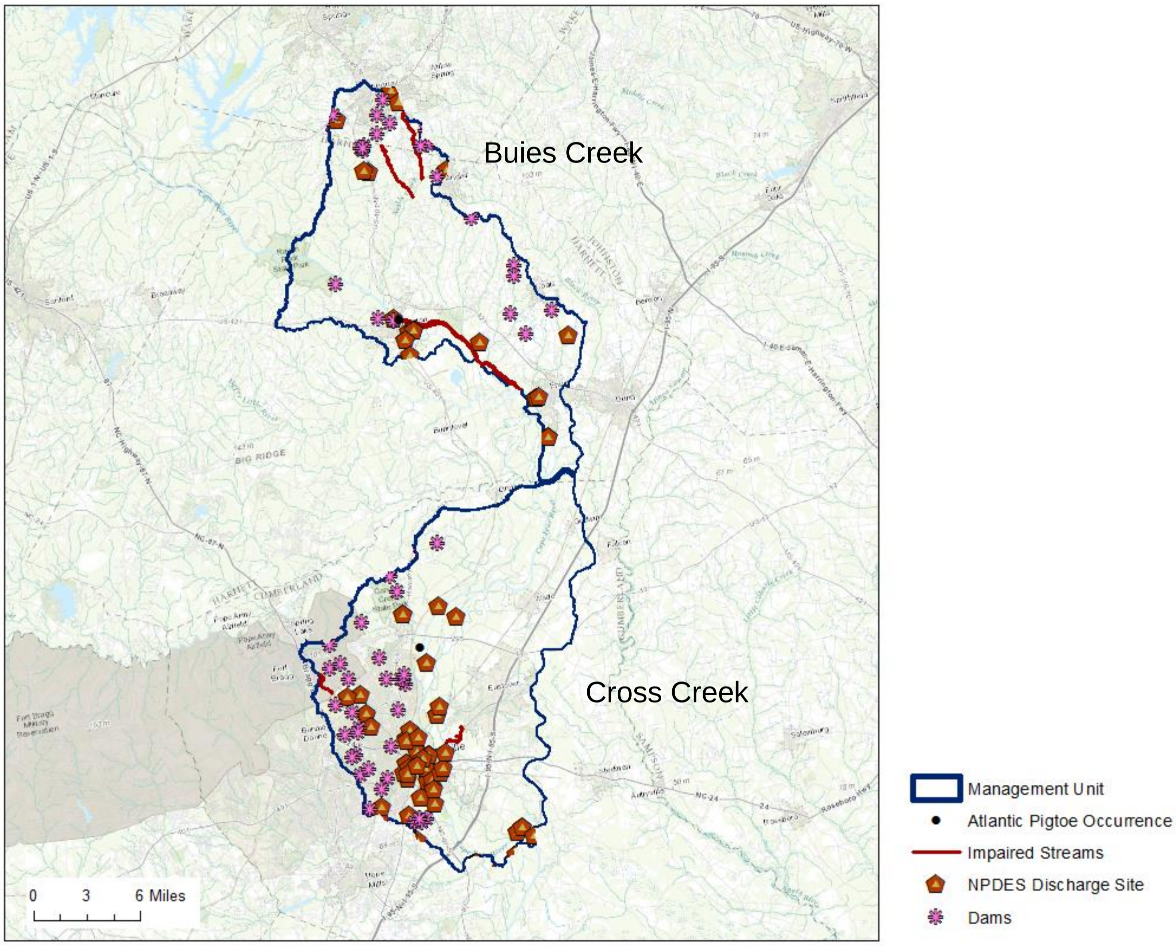
Land Use Land Cover Summary:






Areal Statistics for Rocky River Subbasin
Watershed % Imp Surface
1.2
Watershed % Developed
6.7
Watershed % Agriculture
27.7
Watershed % Forest
59.5
ARA % Imp Surface
0.9
ARA % Developed
5
ARA % Agriculture
22.4
ARA % Forest
64.9
0
20
40
60
80
100
USGS 10 Digit HUC 0 303000305

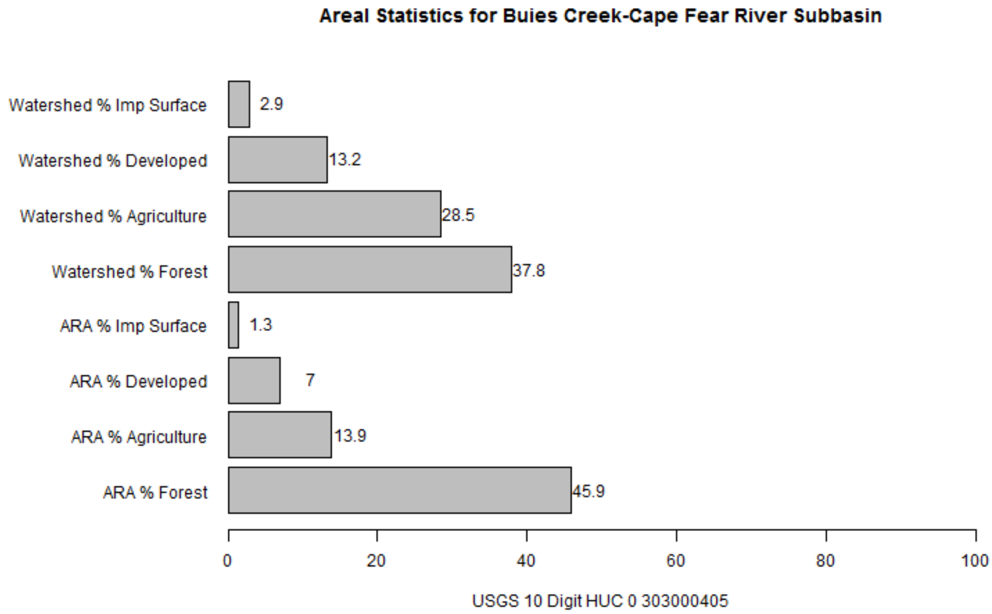
Cape Fear River Management Unit

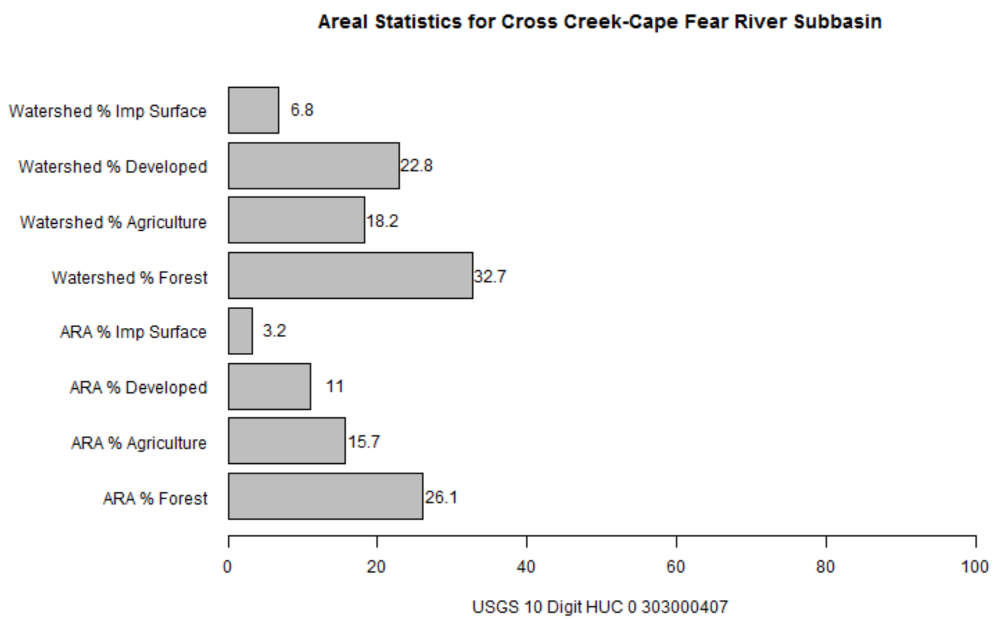


Survey Summary: The Atlantic Pigtoe was first seen in the Cape Fear River in 1969, and the most recent observation was only shell material in 1990. It is believed that the species has been extirpated from this MU.

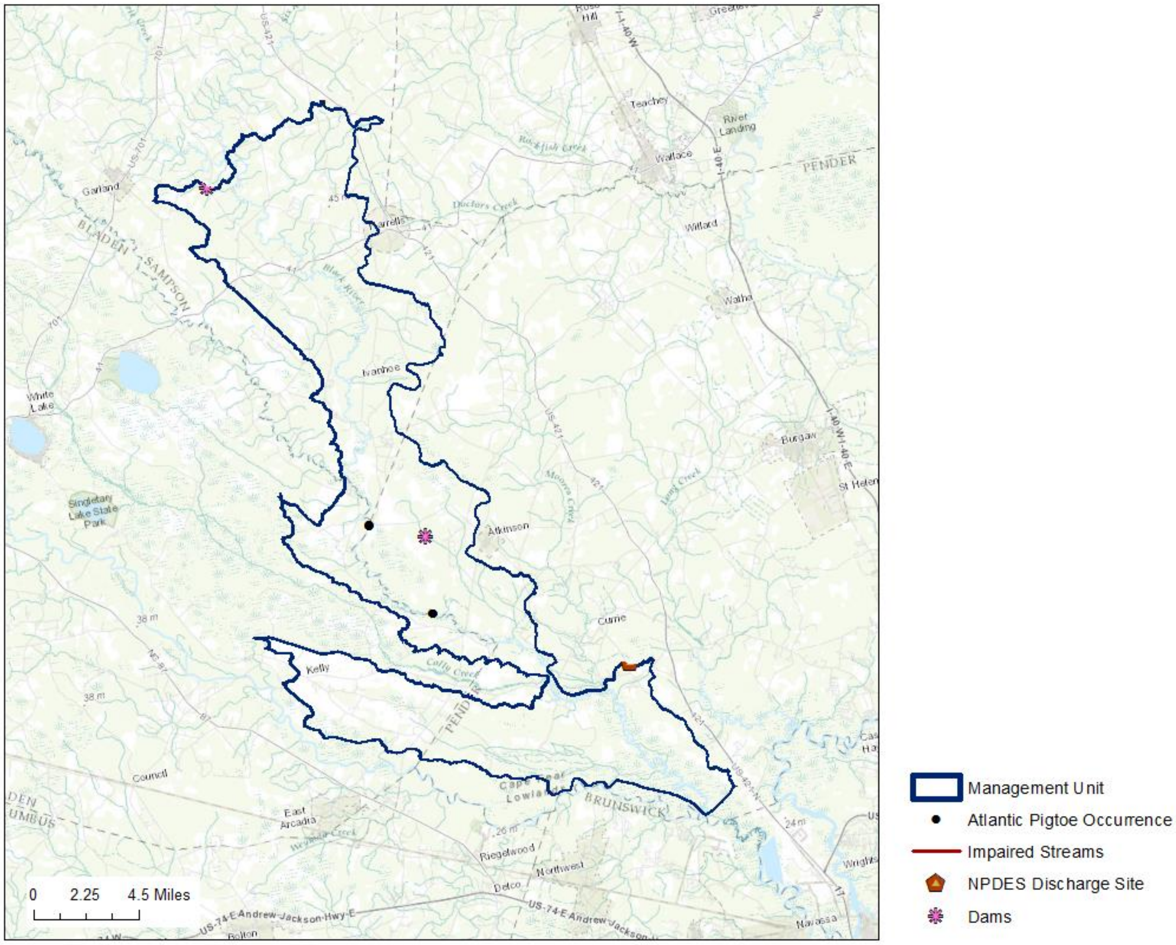
Water Quality Summary: Based on 2014 data, there are 14 impaired stream reaches totaling ~39 miles in this MU. Causes of impairment are low benthic-macroinvertebrate assessment scores, low pH, low DO, copper, mercury, zinc, and arsenic. Recent studies in the upper watershed have found high levels of 1,4-dioxane in the upper watershed (B.Jones (NCWRC) email to S.McRae (USFWS) on 10/18/2016). There are 60 non-major and 5 major (North Harnett Regional WWTP, Erwin WWTP, Fayetteville WRF, Dunn WWTP, and Dak Americas) NPDES discharges in this MU.

Land Use Land Cover Summary:





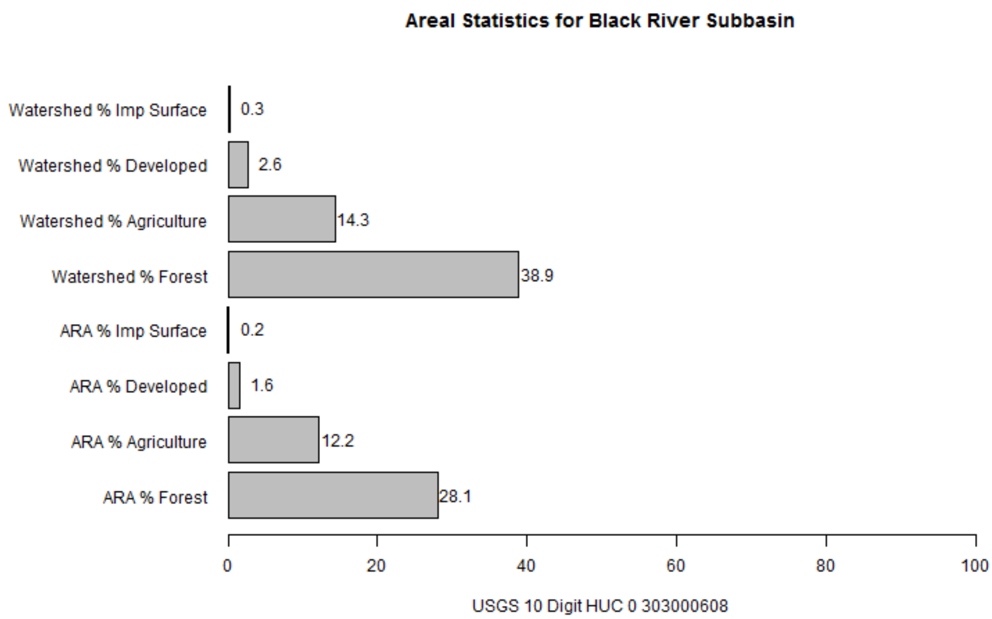
Black River Management Unit



Survey Summary: Early to mid-1990s surveys documented the occurrence of the Atlantic Pigtoe in the Black River, however the species has not been observed since. It is believed to be extirpated from this MU.

Water Quality Summary: According to 2014 data, there are no impaired stream and no NPDES discharges in this MU.

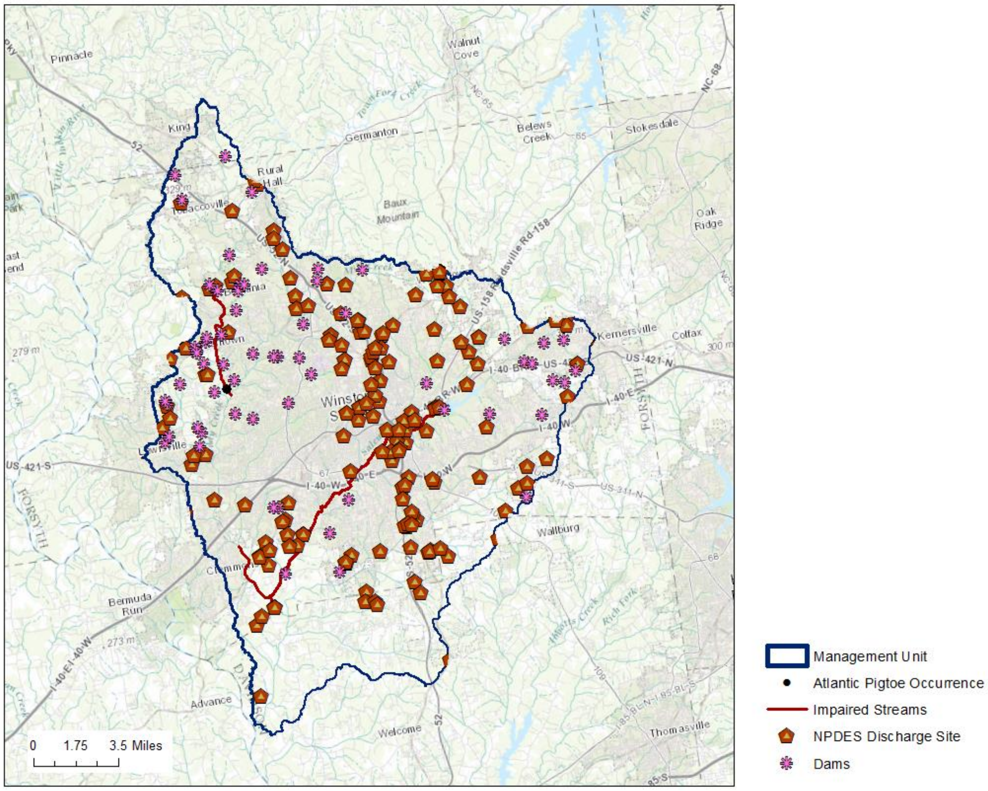
Land Use Land Cover Summary:



Yadkin-Pee Dee River Population

Consists of three MUs: Muddy Creek; Uwharrie/Little rivers; Goose/Lanes creeks

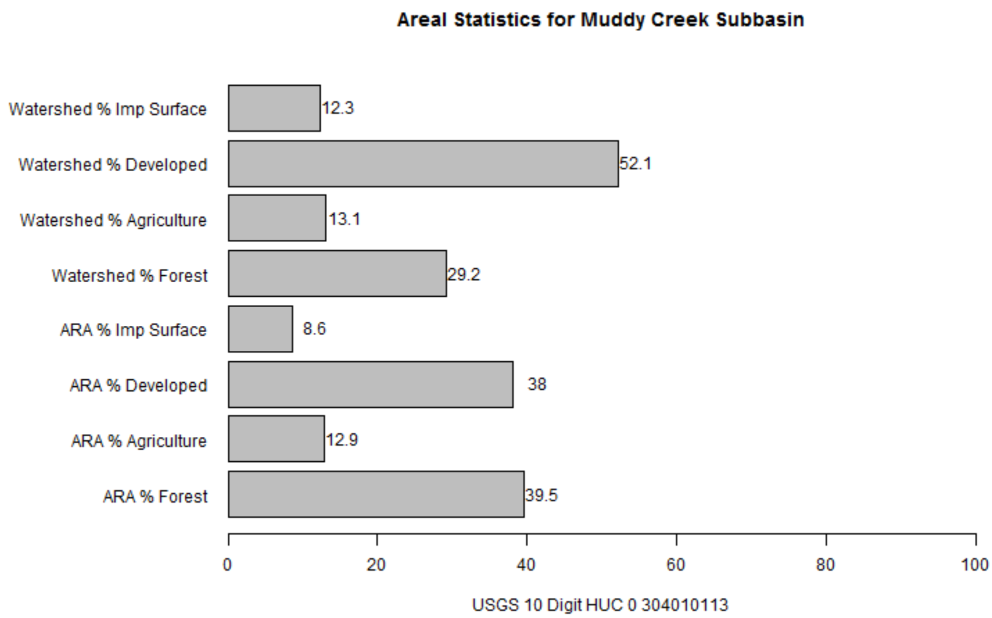
<u>Muddy Creek Management Unit</u>



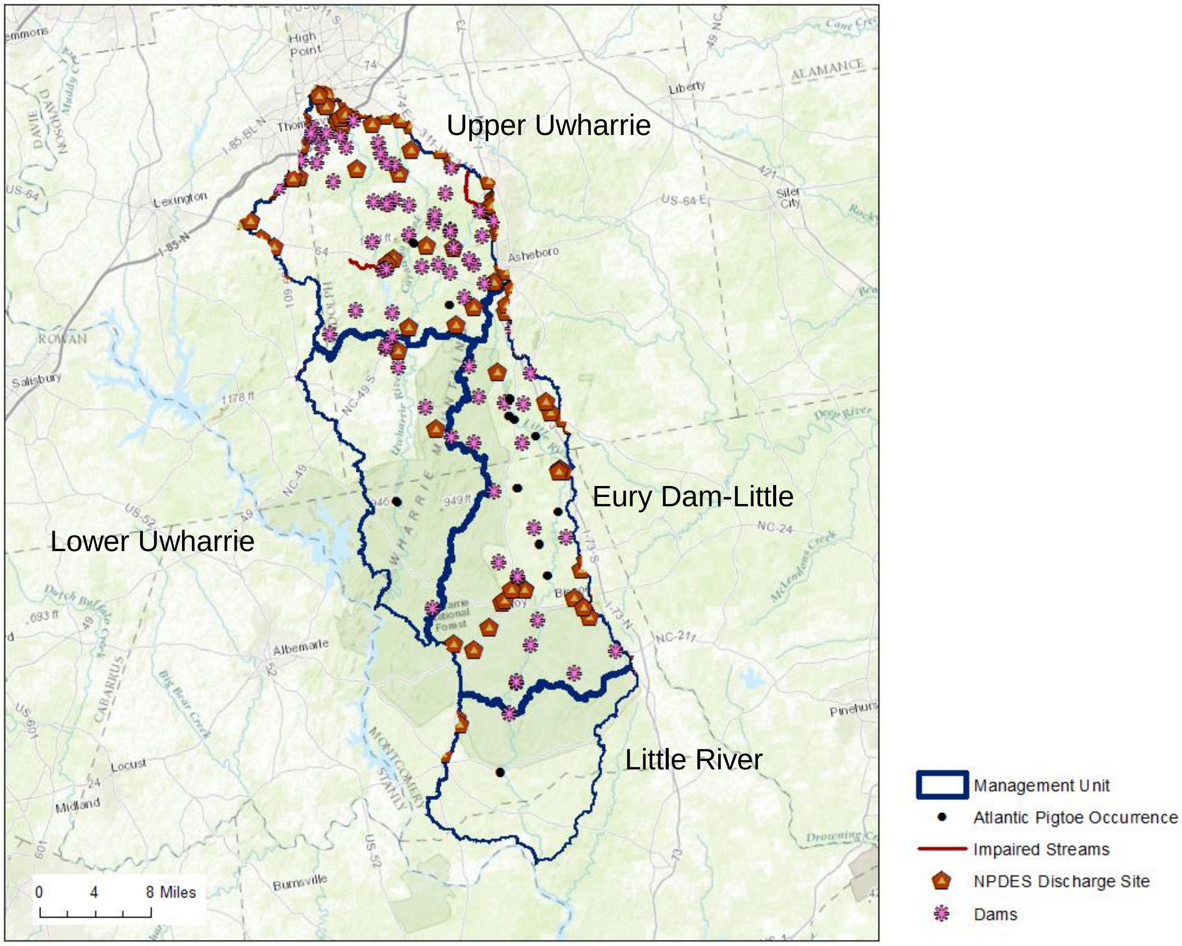
Survey Summary: Shell specimens from the 1800s document the species from an unknown creek in Forsyth County (Alderman and Alderman 2014, p.19). NCWRC staff photographed museum specimens from Yadkin River (Harvard Museum of Comparative Zoology MCZ 376121).

Water Quality Summary: There are 10 impaired stream reaches totaling ~33 miles in this MU. Causes of impairment are low benthic-macroinvertebrate assessment scores, turbidity, zinc and copper. There are 173 non-major and two major (Muddy Creek WWTP and Winston-Salem WWTP) NPDES discharges in this MU.

Land Use Land Cover Summary:



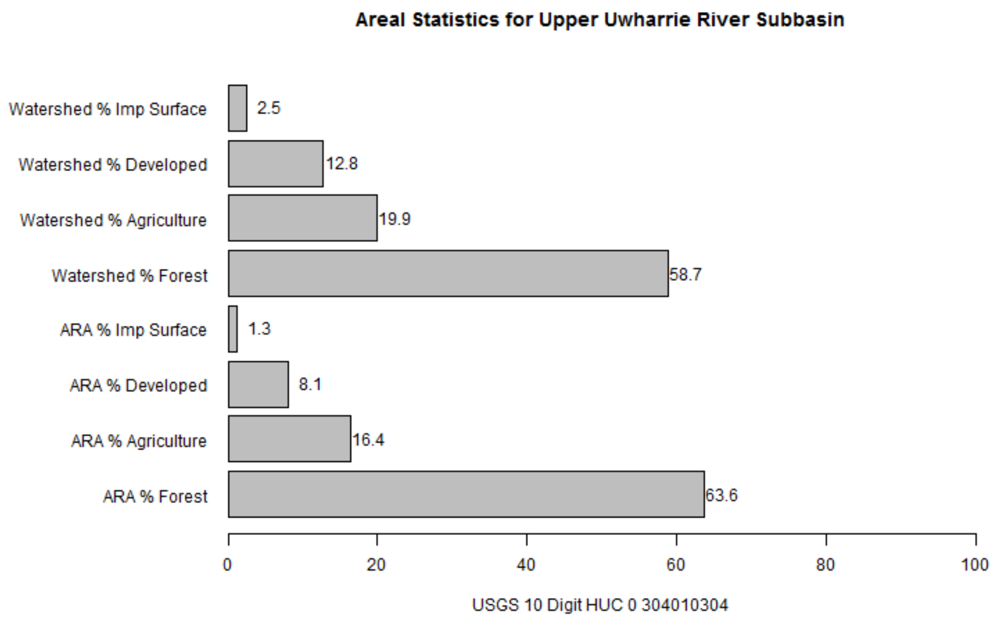
Uwharrie/Little rivers Management Unit

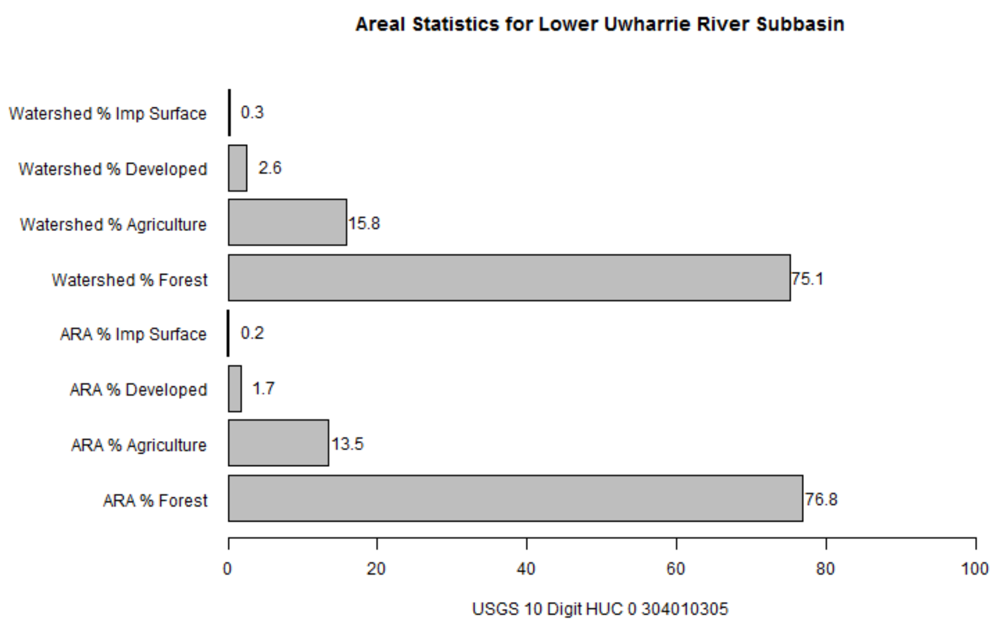


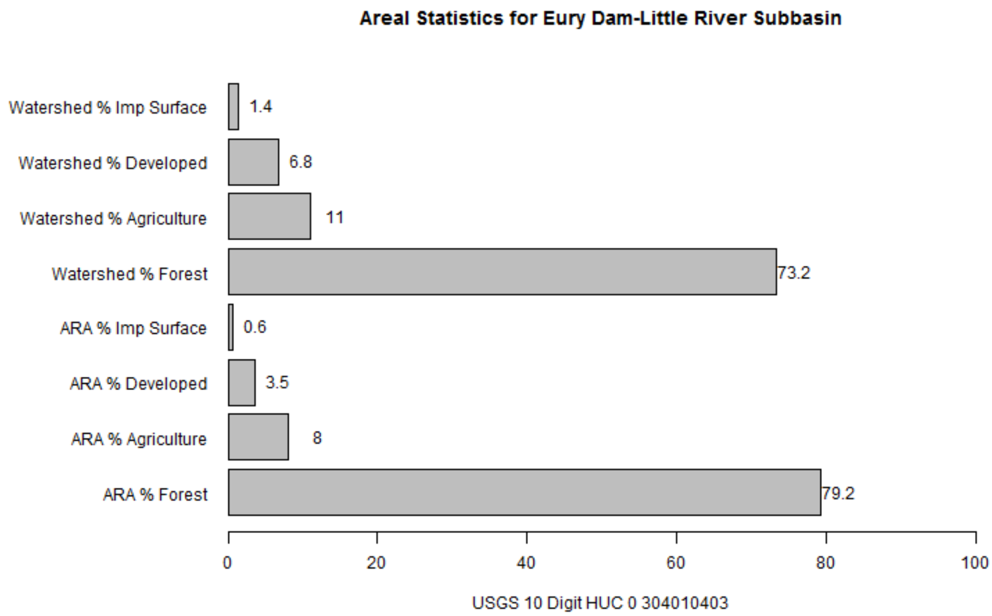
Survey Summary: The species was first observed in this MU in 1987 and most recently in 2010. Most survey efforts document one or two individuals, with the most documented at 6 in the Little River (2010). A total of 26 live and 13 shells have been observed over time in this MU (Alderman and Alderman 2014, p.19).

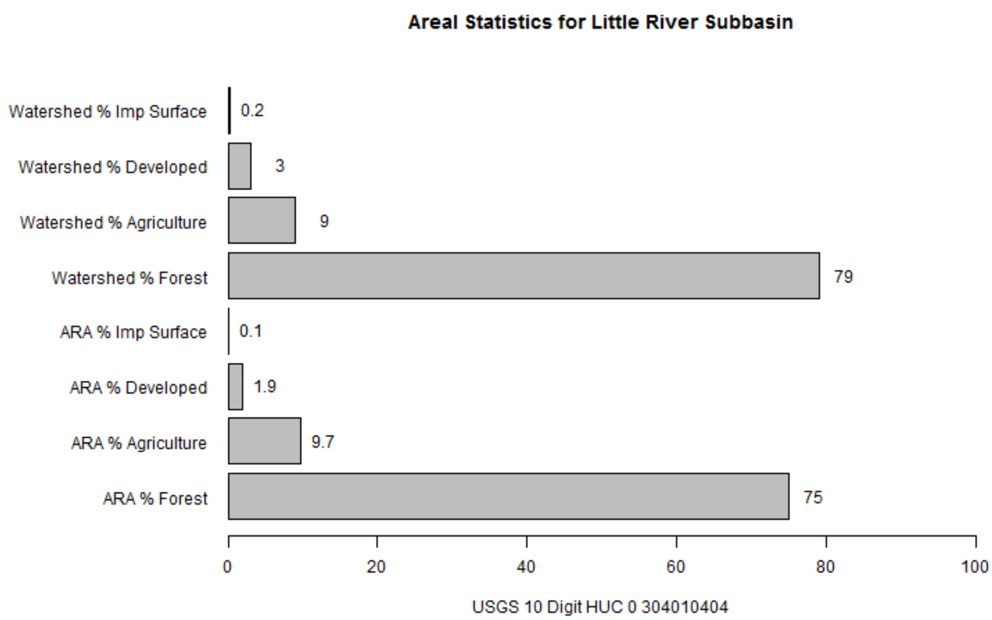
Water Quality Summary: Based on 2014 data, there are two impaired stream reaches totaling ~6 miles in this MU. Causes of impairment are low benthic-macroinvertebrate assessment scores and arsenic. There are 79 non-major and one major (Troy WWTP) NPDES discharges in this MU.

Land Use Land Cover Summary:

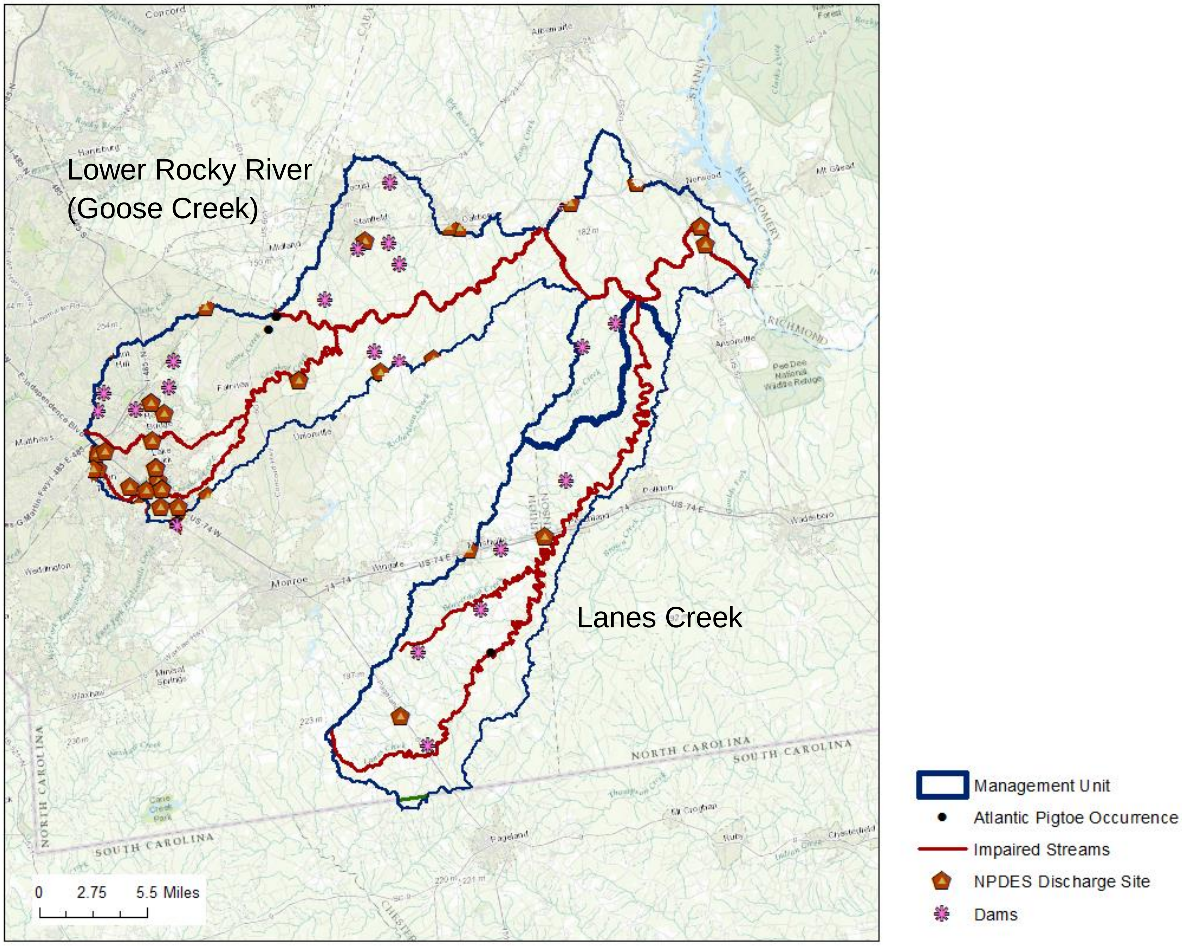





Areal Statistics for Eury Dam-Little River Subbasin
Watershed % Imp Surface
1.4
Watershed % Developed
6.8
Watershed % Agriculture
11
Watershed % Forest
73.2
ARA % Imp Surface
0.6
ARA % Developed
3.5
ARA % Agriculture
8
ARA % Forest
79.2
0
20
40
60
80
100
USGS 10 Digit HUC 0 304010403


Areal Statistics for Little River Subbasin
Watershed % Imp Surface
0.2
Watershed % Developed
3
Watershed % Agriculture
9
Watershed % Forest
79
ARA % Imp Surface
0.1
ARA % Developed
1.9
ARA % Agriculture
9.7
ARA % Forest
75
0
20
40
60
80
100
USGS 10 Digit HUC 0 304010404

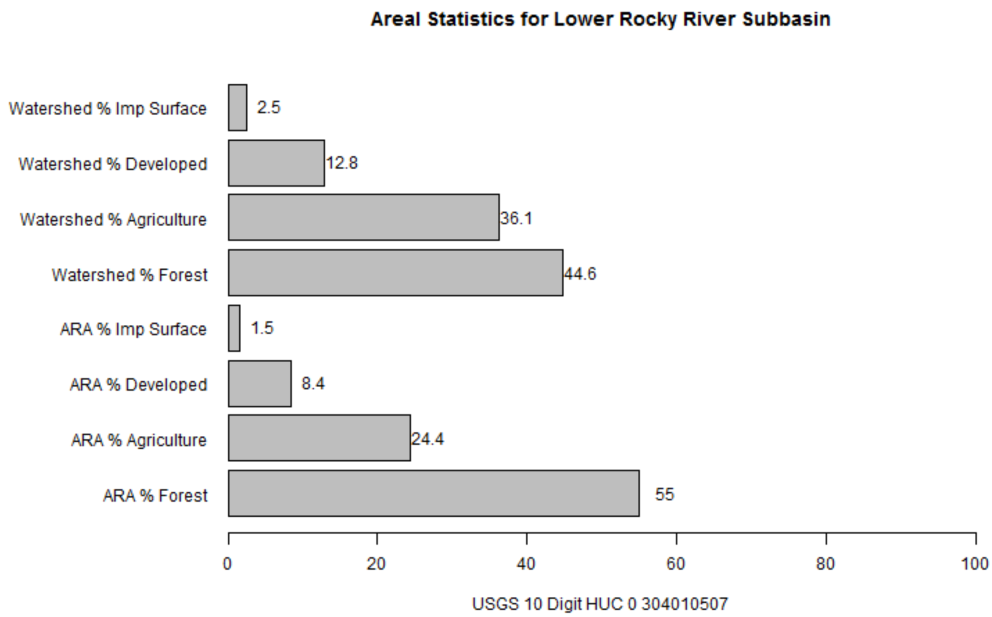
Goose/Lanes creeks Management Unit

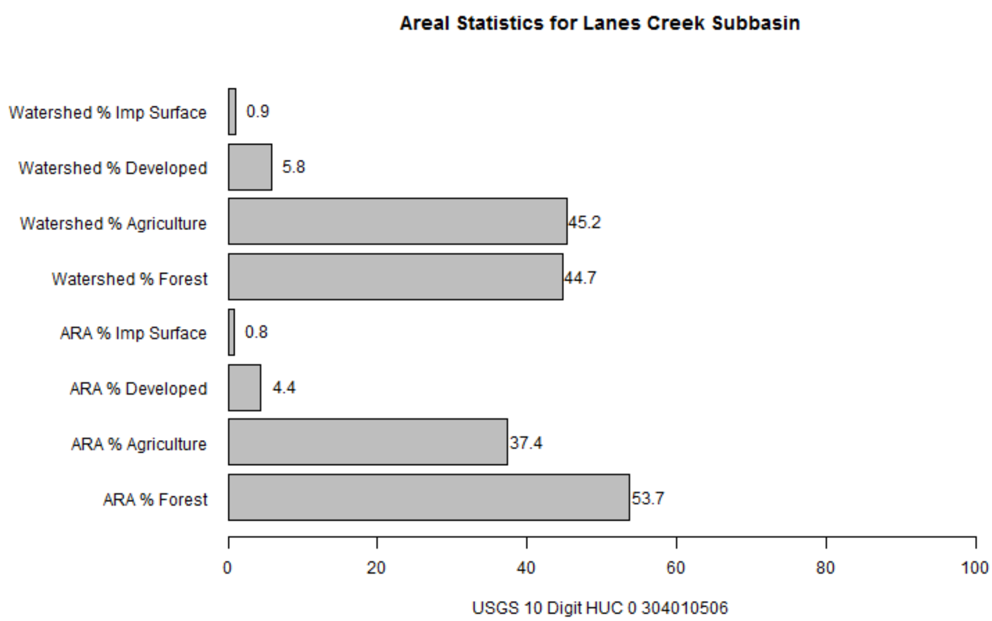


Survey Summary: Two surveys in the mid to late 1990s documented two individuals in Goose Creek, and only shell material has been observed in Lanes Creek (2002). NCWRC staff took photographs of two museum specimens from "Bissels Pond" in Mecklenburg County (Harvard MCZ 293242).

Water Quality Summary: Based on 2014 data, there are 11 impaired stream reaches totaling ~169 miles in this MU. Causes are due to low benthic-macroinvertebrate assessment scores, fair fish community, low DO, and copper. There are 37 non-major and one major (Crooked Creek WWTP) NPDES discharges in this MU.

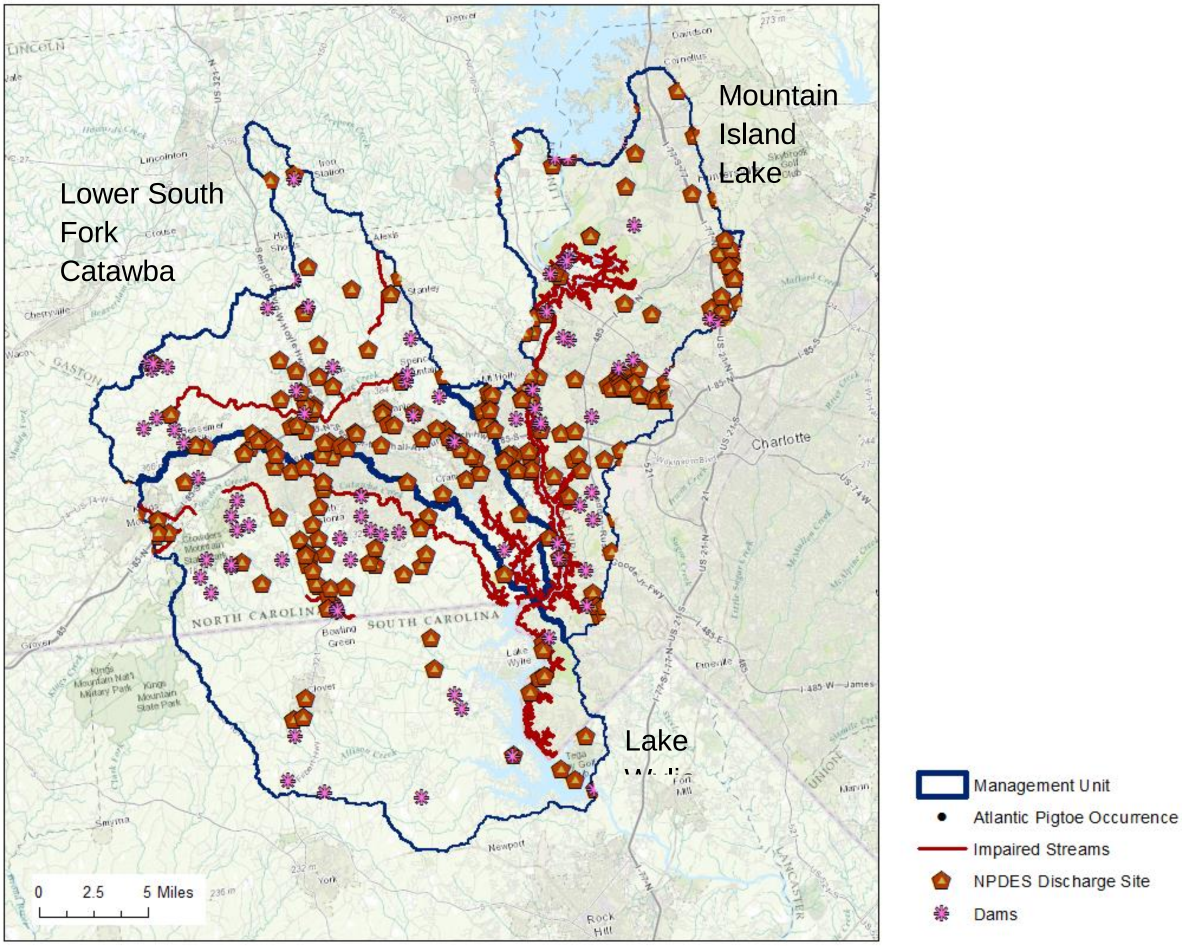
Land Use Land Cover Summary:





Catawba River Population (*Presumed extirpated*)
Consists of one MU: Catawba

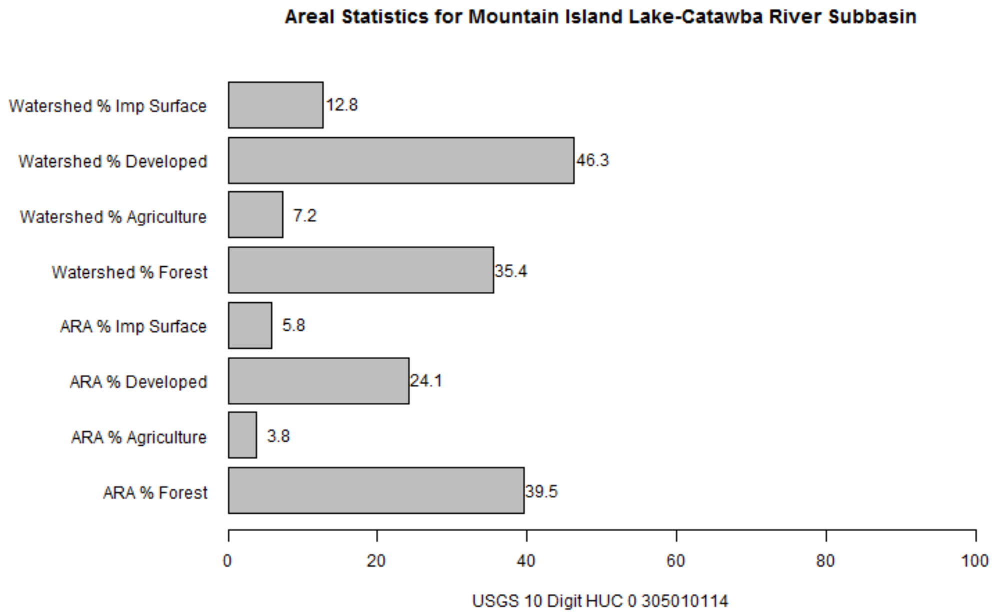
Catawba Management Unit

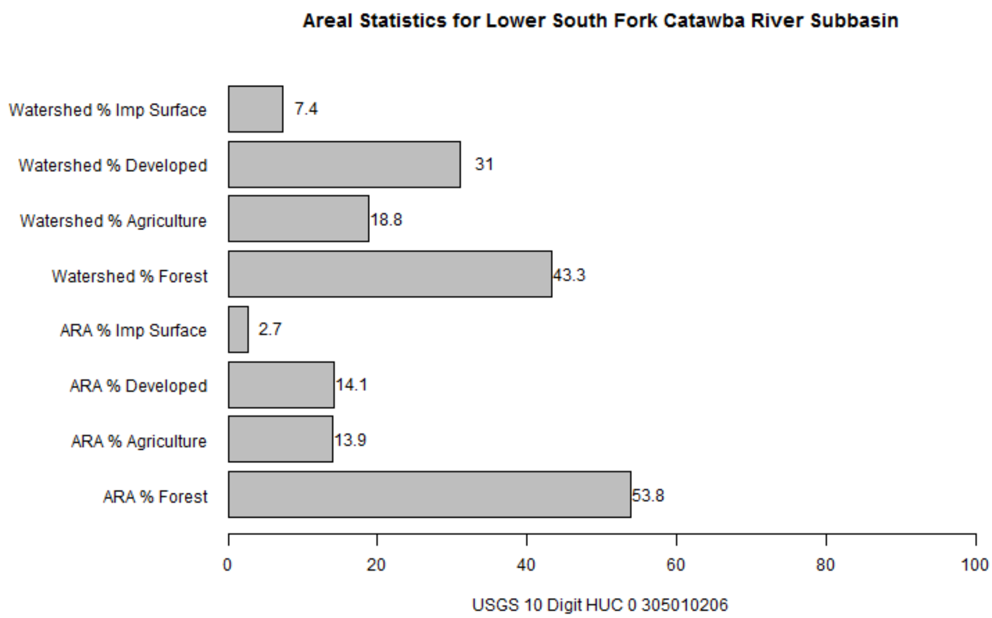


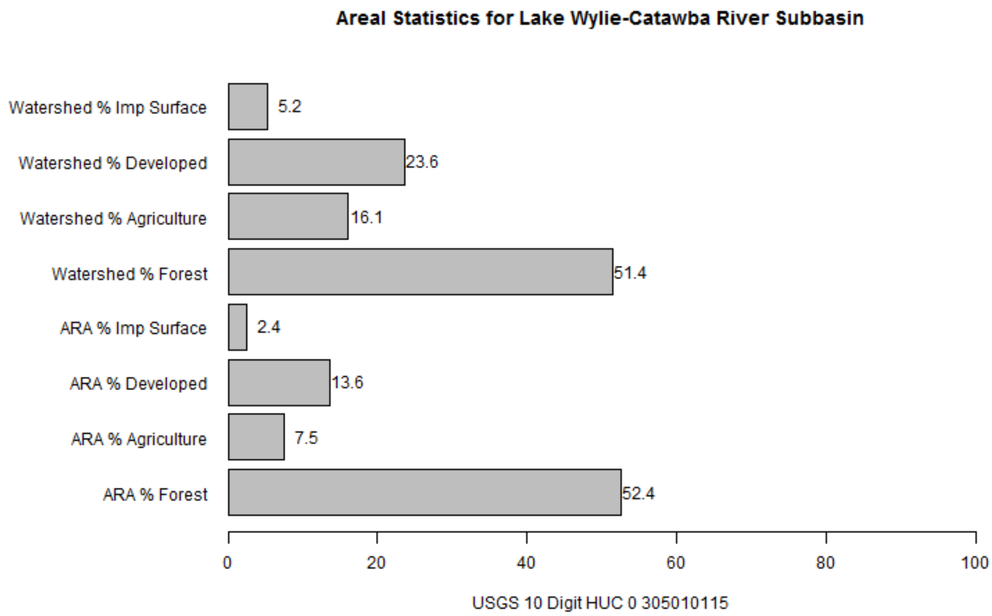
Survey Summary: One shell has been observed in the Catawba River in the 1800s (Alderman and Alderman 2014, p.19). NCWRC staff took photographs of a museum specimen from Long Creek in Gaston Co (Harvard MCZ 288358).

Water Quality Summary: Based on 2014 data, there are 12 impaired stream reaches totaling ~48 miles in this MU. Causes are due to low benthic-macroinvertebrate assessment scores, poor fish community, and PCBs. There are 267 non-major and 13 major (Plant Allen Steam Station, Lithium Division Plant, Riverbend Steam Station, Pharr Yarns Inc., Eagle Road WWTP, Crowder’s Creek WWTP, Long Creek WWTP, McDowell Creek WWTP, Mount Holly East, Mouth Holly WWTP, Belmont Water Pollution Control Facility, Duke Power Catawba Nuclear Station, and Former Yorkshire Americas Site) NPDES discharges in this MU.

Land Use Land Cover Summary:

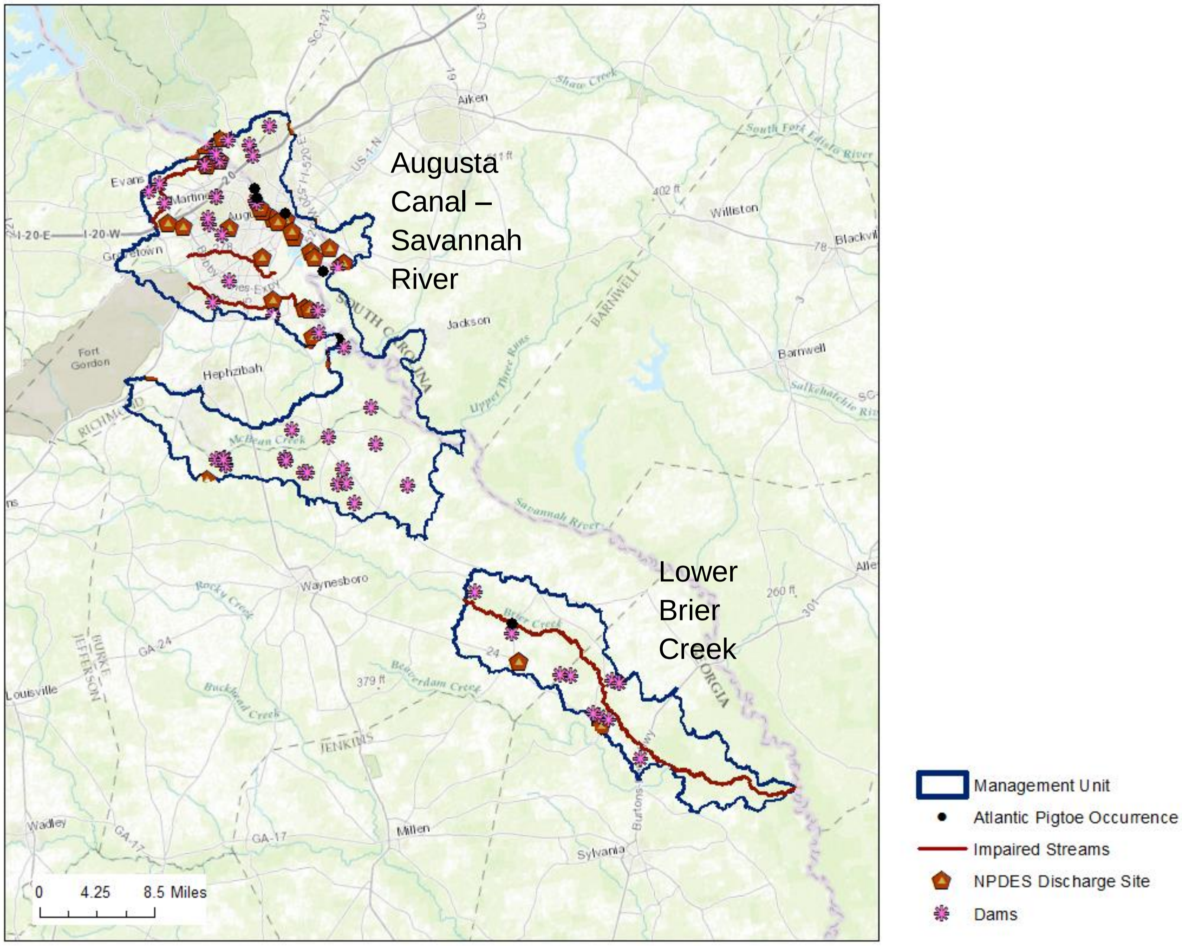





Areal Statistics for Lake Wylie-Catawba River Subbasin
Watershed % Imp Surface
5.2
Watershed % Developed
23.6
Watershed % Agriculture
16.1
Watershed % Forest
51.4
ARA % Imp Surface
2.4
ARA % Developed
13.6
ARA % Agriculture
7.5
ARA % Forest
52.4
0
20
40
60
80
100
USGS 10 Digit HUC 0 305010115

Savannah River Population (*Presumed extirpated*)
Consists of one MU: Savannah River

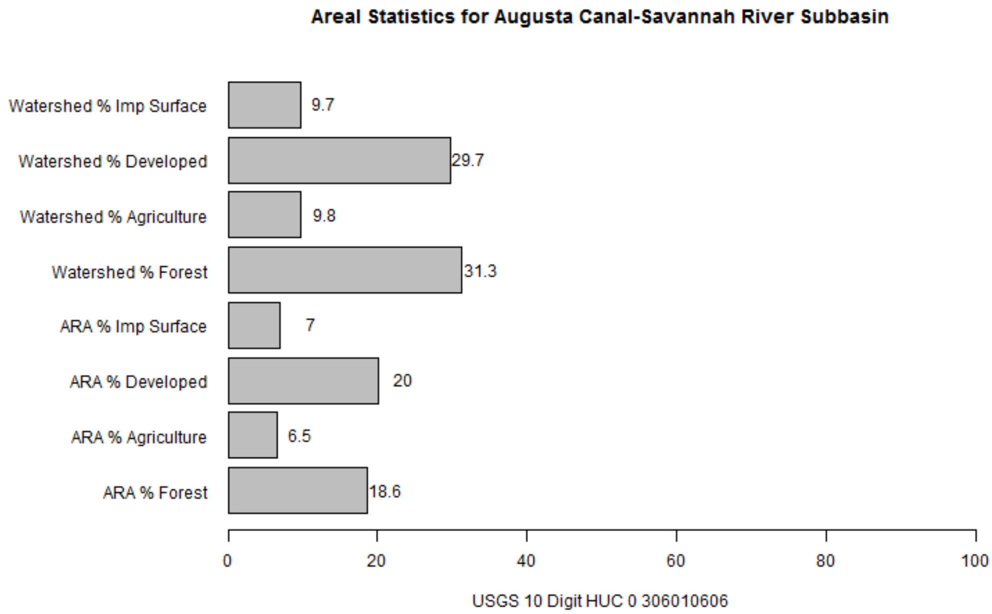
Savannah River Management Unit

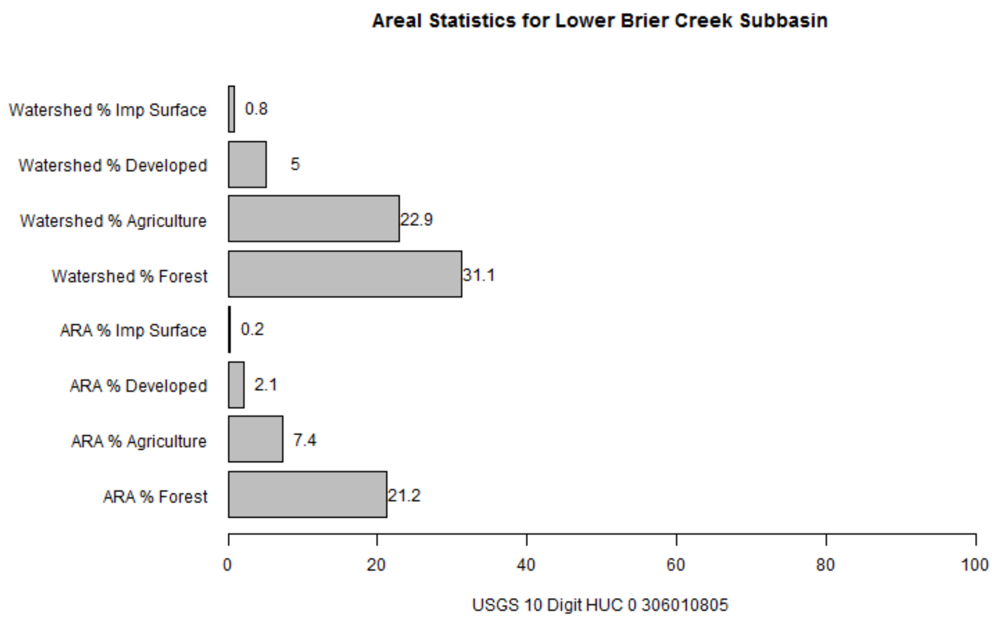


Survey Summary: In 1834, the type specimen was collected from the Savannah River near Augusta, GA. Dive surveys in 2006 documented four live and one shell, although the true species identification of these specimens was determined to be *Elliptios*, not Atlantic Pigtoes (J.Alderman (AES) email to S.McRae (USFWS) on 9/24/2016). Recent surveys have not been able to document the species, and it is presumed extirpated from this MU (J.Wisniewski (GADNR) email to S.McRae (USFWS) on 12/7/2016).

Water Quality Summary: Based on 2012 data, there are six impaired stream reaches totaling ~54 miles in this MU. Causes are due to low benthic-macroinvertebrate assessment scores and fecal coliform. There are 30 non-major and six major (PCS Nitrogen Fertilizer, Columbia County WPCP, DSM Chemicals, Kimberly Clark Corp., SC Gas & Electric Urquhart Generation Station, and Augusta WWTP) NPDES discharges in this MU.

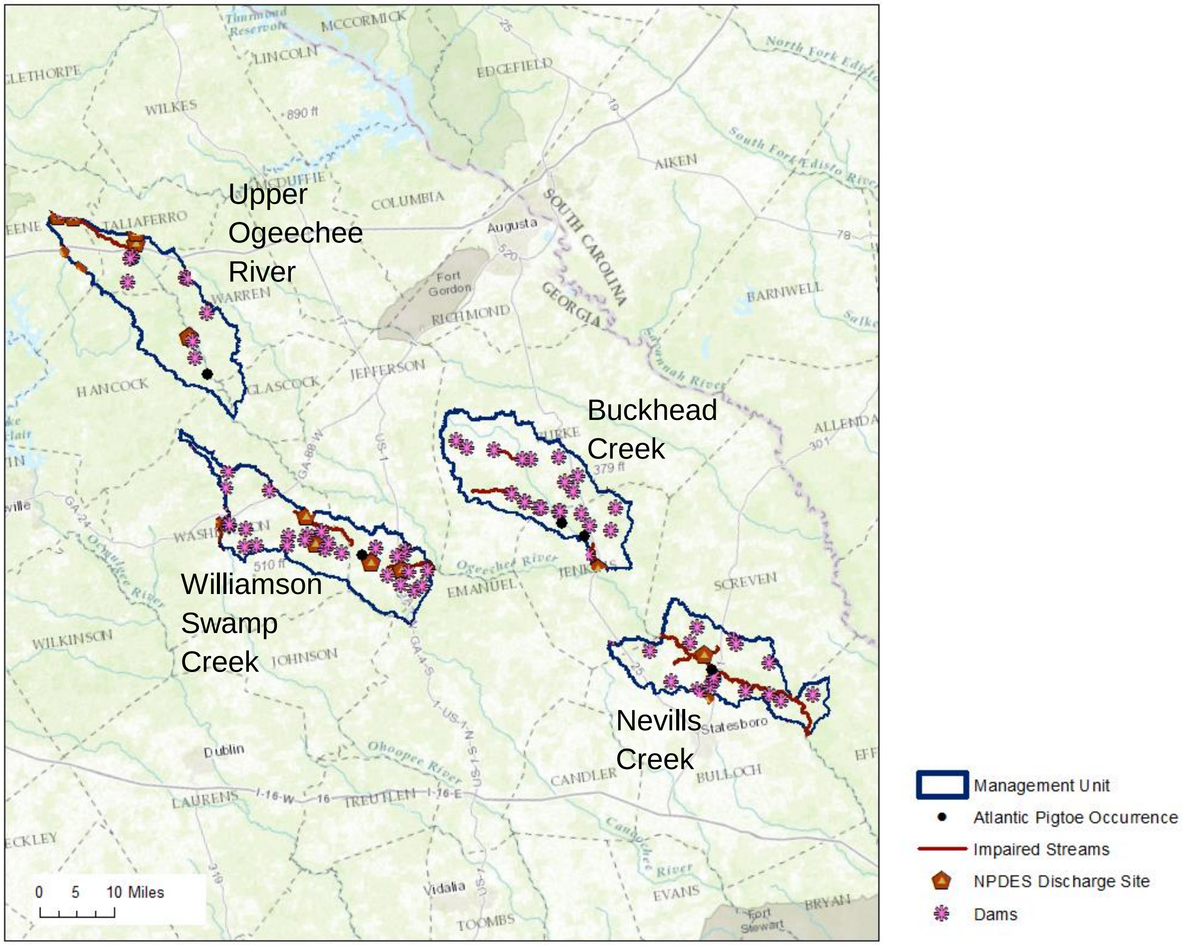
Land Use Land Cover Summary:





Ogeechee River Population (*Presumed extirpated*)
Consists of one MU: Ogeechee River

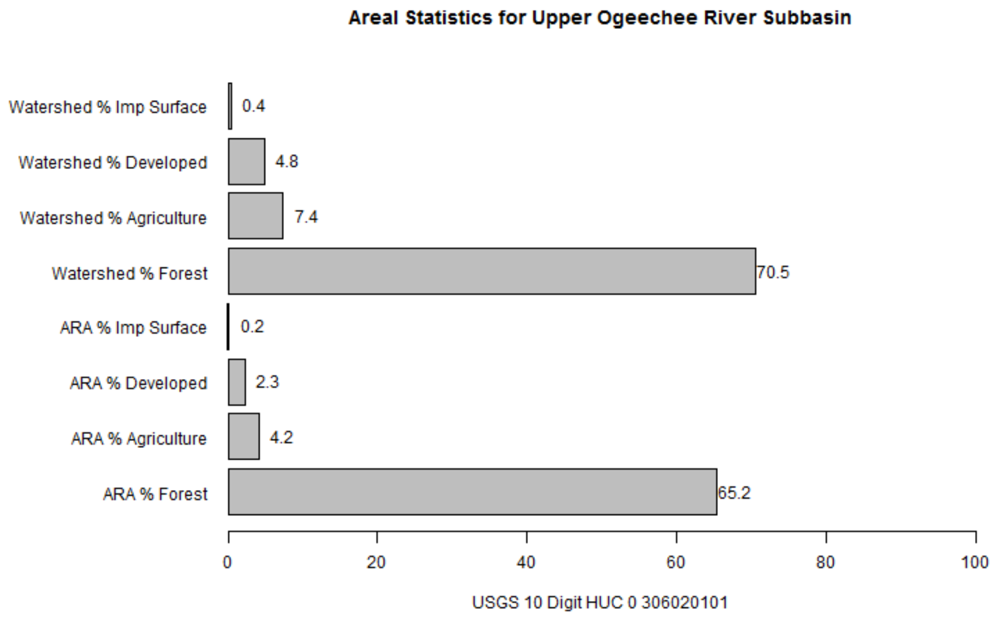
Ogeechee River Management Unit

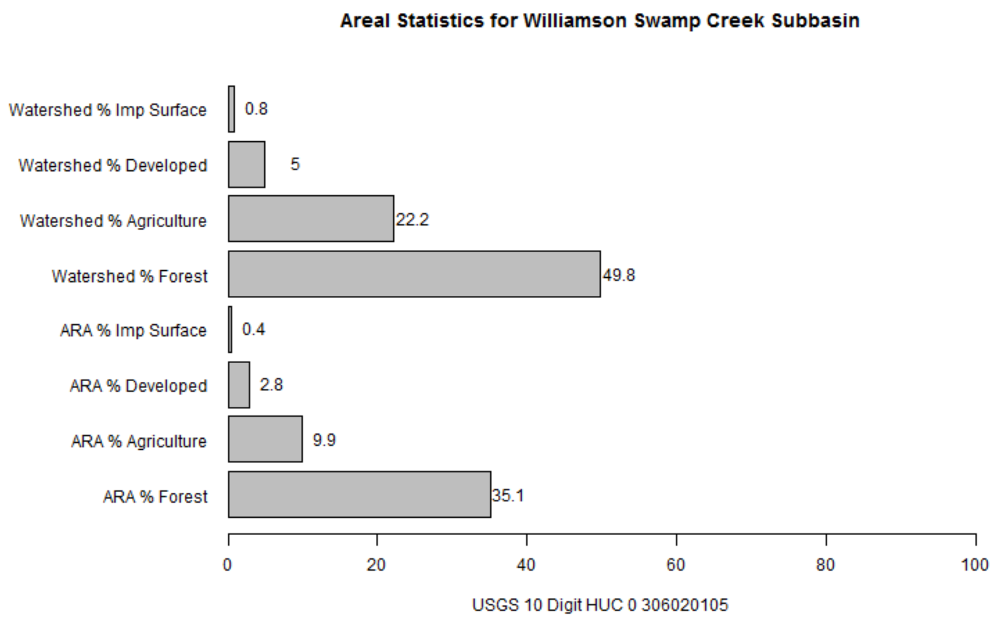


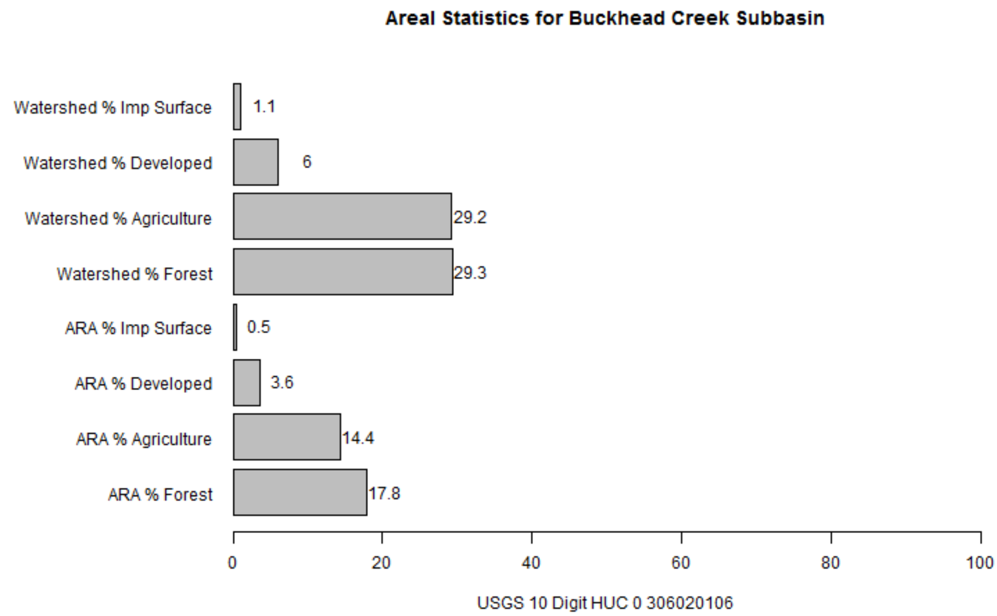
Survey Summary: The species was first observed in this MU in the 1970s, and the most recent observation of a live individual was in the early 1990s (four live individuals were collected from Williamson Swamp Creek). Several surveys in the mid-2000s failed to document the species, thus it is presumed extirpated from this MU.

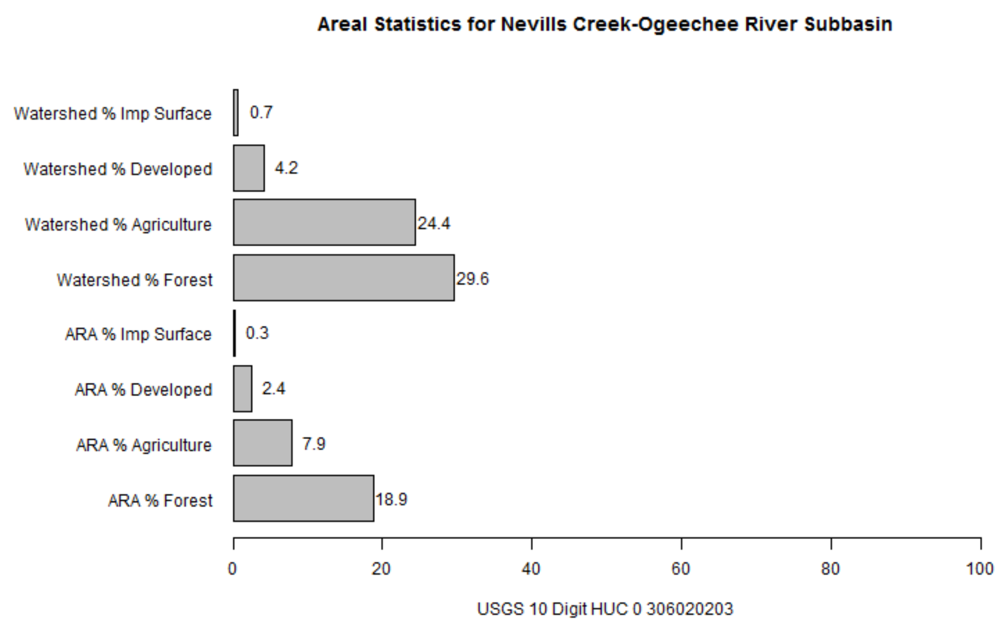
Water Quality Summary: Based on 2012 data, there are seven impaired stream reaches totaling ~44 miles in this MU, not including the 98-mile segment of the Ogeechee River which is impaired for mercury. Causes are low benthic-macroinvertebrate assessment scores and fecal coliform. There are 25 non-major (primarily water pollution control plants) NPDES discharges in this MU.

Land Use Land Cover Summary:



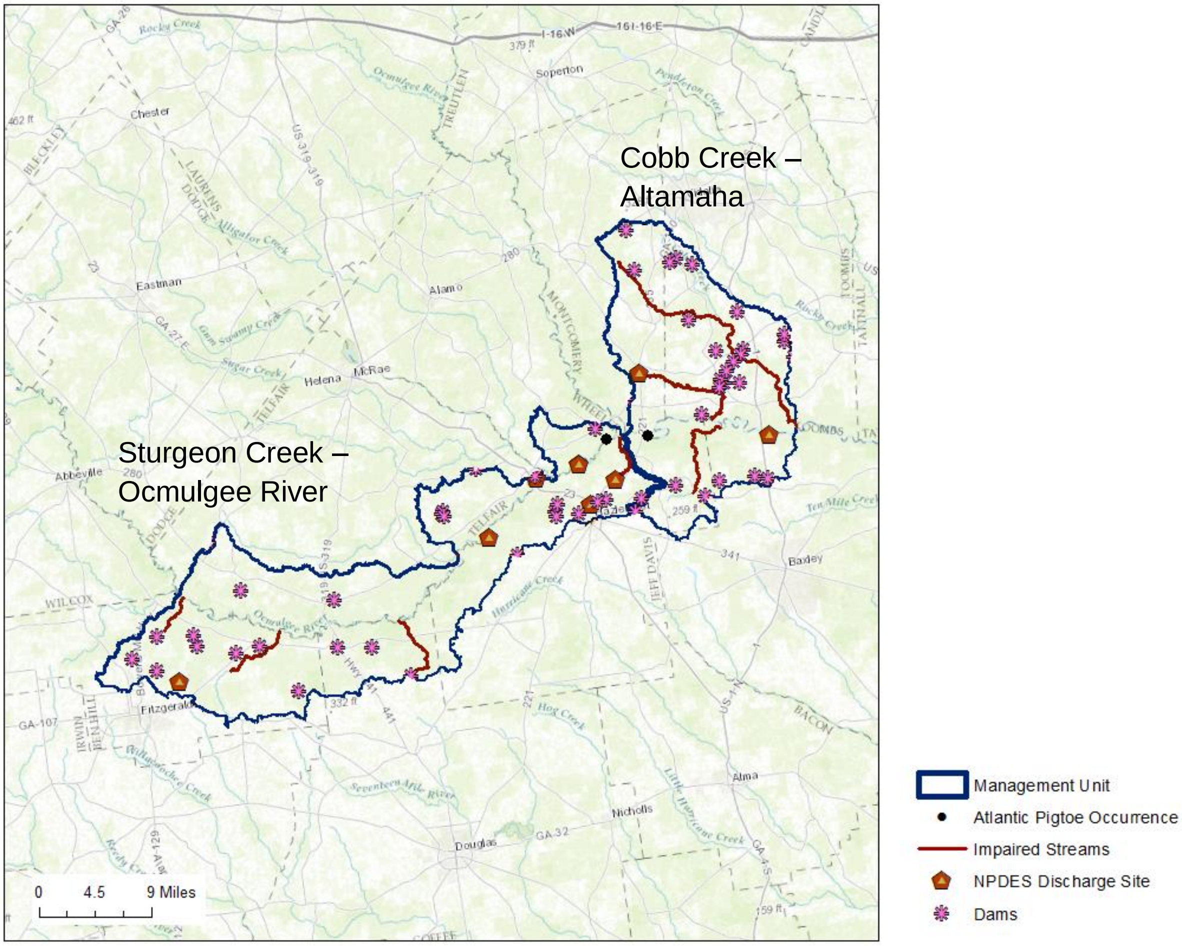



Areal Statistics for Buckhead Creek Subbasin
Watershed % Imp Surface
1.1
Watershed % Developed
6
Watershed % Agriculture
29.2
Watershed % Forest
29.3
ARA % Imp Surface
0.5
ARA % Developed
3.6
ARA % Agriculture
14.4
ARA % Forest
17.8
0
20
40
60
80
100
USGS 10 Digit HUC 0 306020106


Areal Statistics for Nevills Creek-Ogeechee River Subbasin
Watershed % Imp Surface
0.7
Watershed % Developed
4.2
Watershed % Agriculture
24.4
Watershed % Forest
29.6
ARA % Imp Surface
0.3
ARA % Developed
2.4
ARA % Agriculture
7.9
ARA % Forest
18.9
0
20
40
60
80
100
USGS 10 Digit HUC 0 306020203

Altamaha River Population (*Presumed extirpated*)
Consists of one MU: Altamaha River

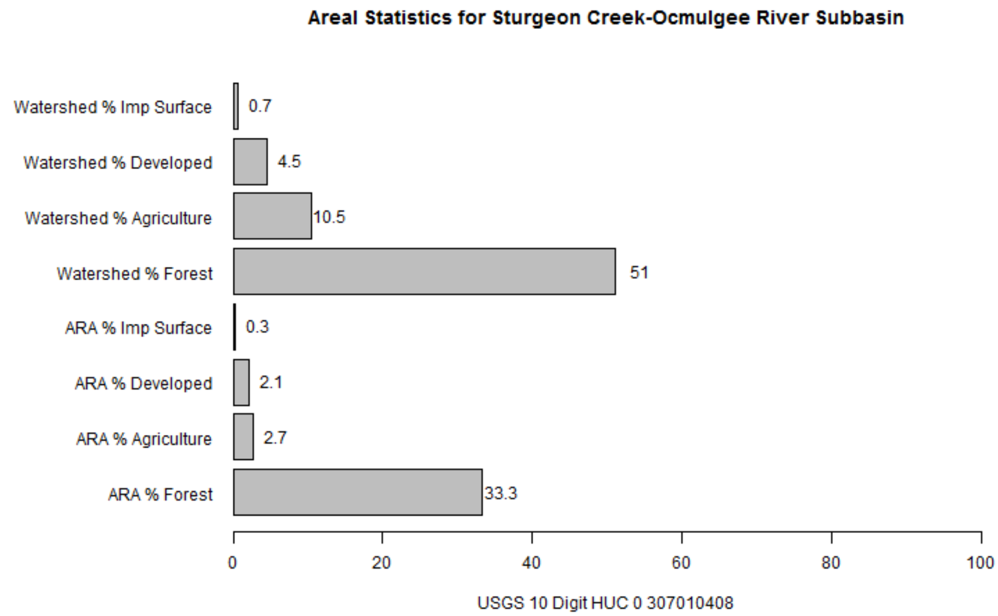
Altamaha River Management Unit

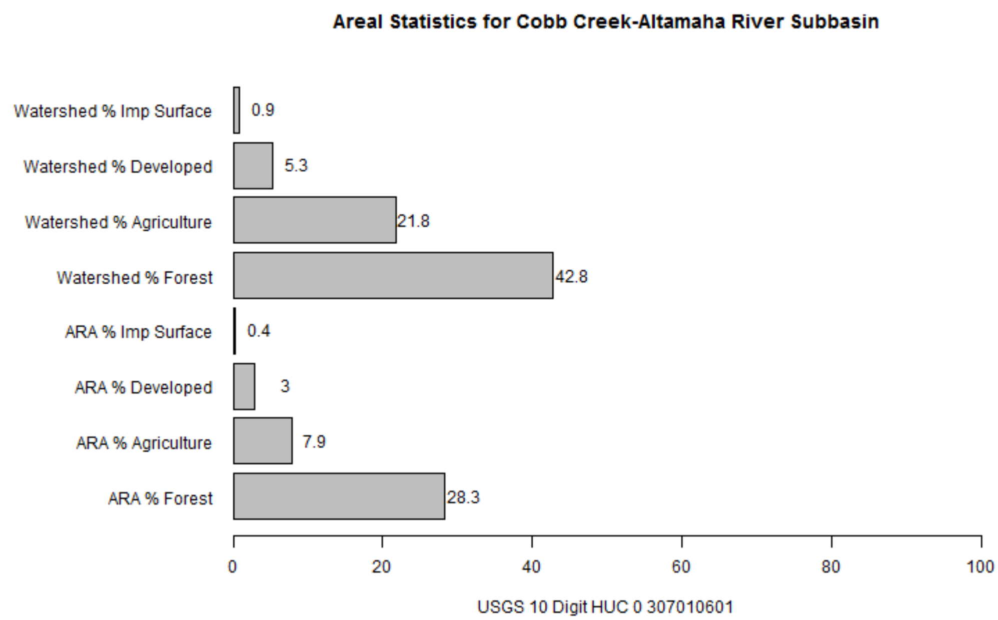


Survey Summary: Two shells from the 1800s have documented the historical occurrence of the Atlantic Pigtoe in the Altamaha River Basin (Alderman and Alderman 2014, p.19).

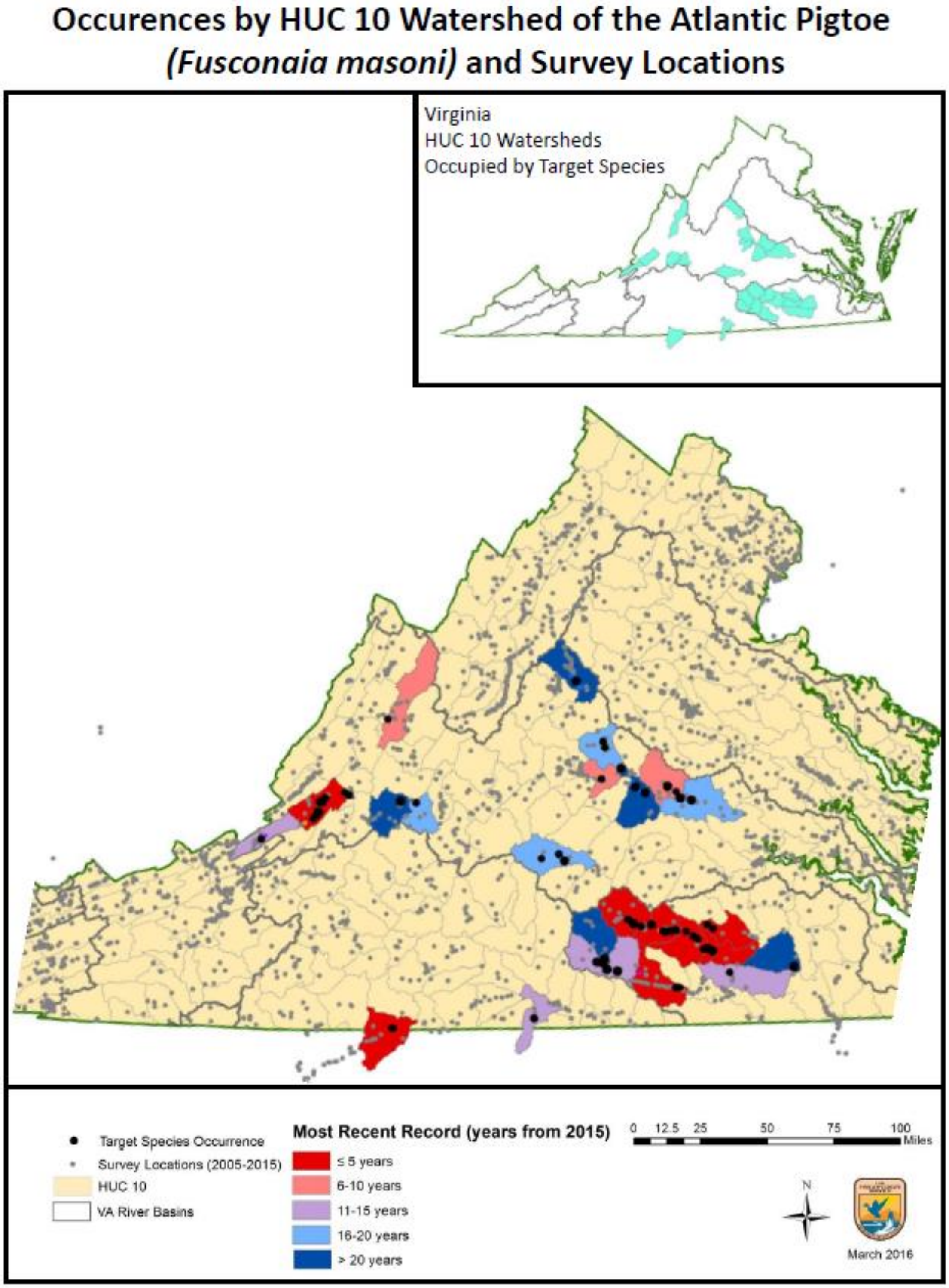
Water Quality Summary: Based on 2012 data, there are eight impaired stream reaches totaling ~64 miles in this MU. Causes are low benthic-macroinvertebrate assessment scores, low DO, and fecal coliform. There are nine non-major and one major (Hazlehurst WPCP) NPDES discharges in this MU.

Land Use Land Cover Summary:

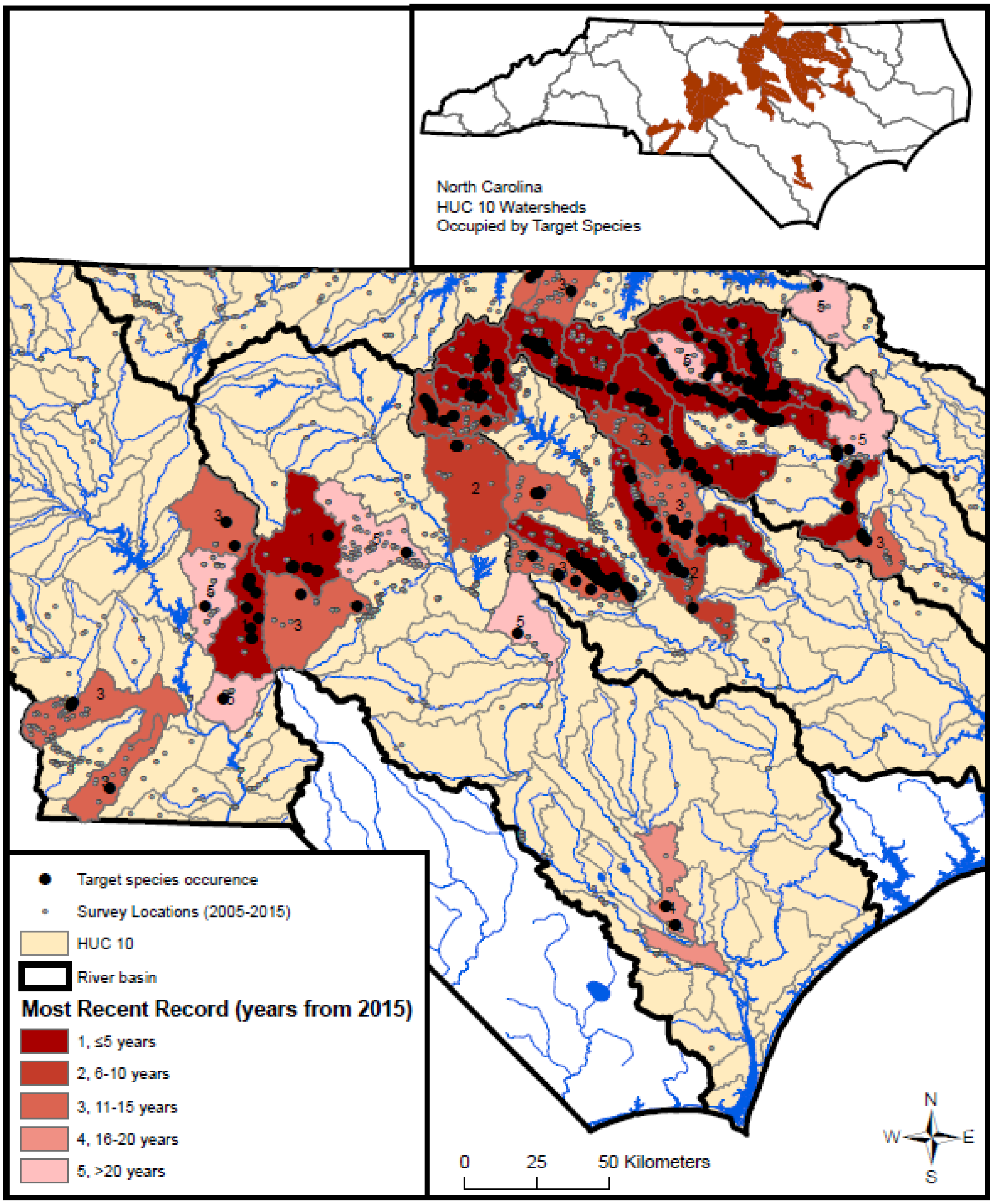




APPENDIX B – Atlantic Pigtoe Heat Maps (Virginia, North Carolina, and Georgia)

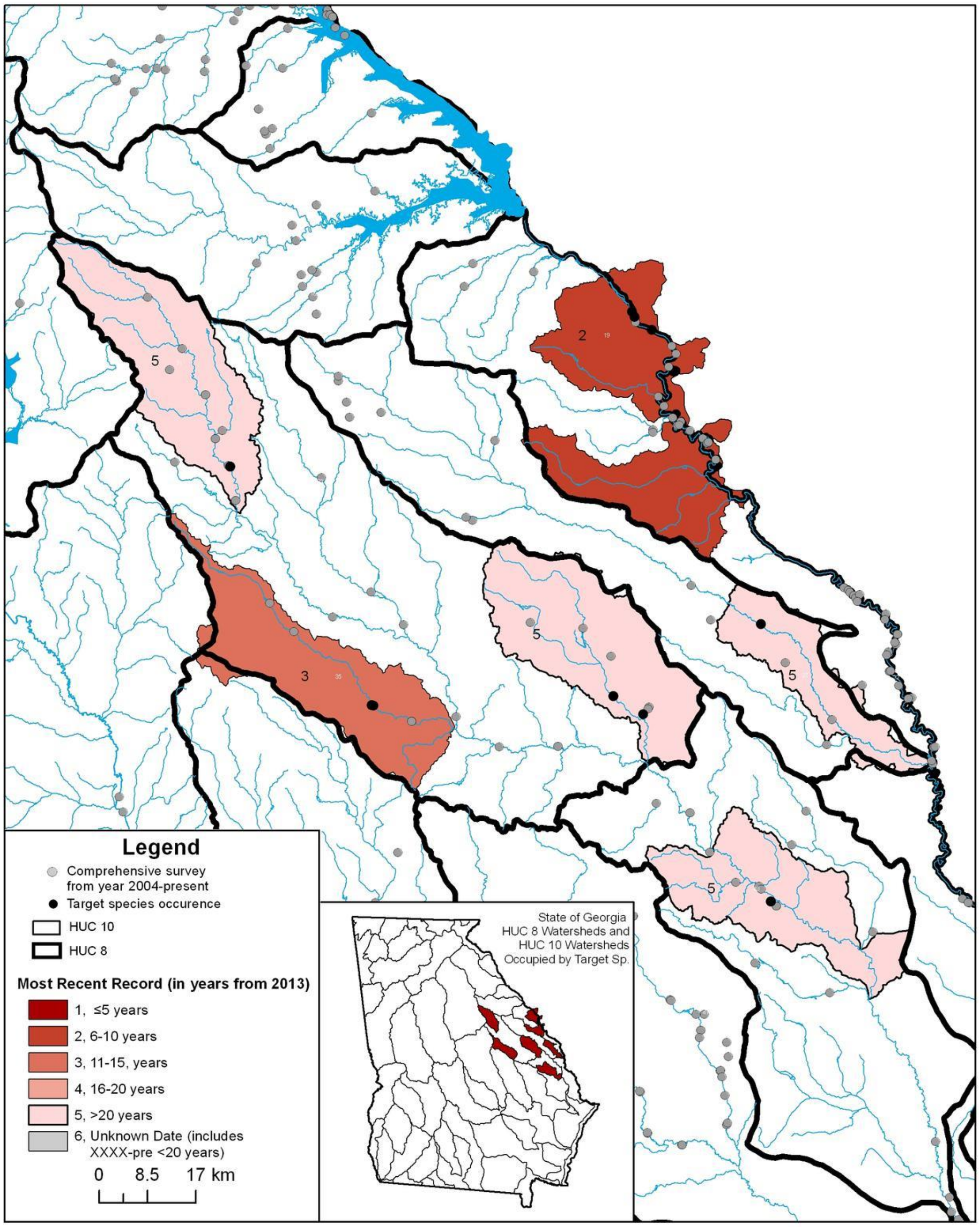


Occurrences by HUC 10 Watershed of the Atlantic Pigtoe (*Fusconaia masoni*) and Survey Locations



Map created by: Tyler Black, Ph.D., 1/6/2016
Data sources: NC Wildlife Resources Commission and NC Museum of Natural Sciences

Occurrences by HUC 10 Watershed of the Atlantic Pigtoe
(Fusconaia masoni) and Recent Aquatic Survey Locations



Map created by: Catherine Reuter, 2014-01-28
Data sources: Georgia DNR Nongame Conservation Section, 2014-01-28

Georgia Department of Natural Resources
Wildlife Resources Division
Nongame Conservation Section

*Note: this map was made in 2014, before the identification of specimens from the Savannah drainage were confirmed to be *Elliptios*.

APPENDIX C – Data for Population Factors and Habitat Elements

	Occupancy Factors				Abundance Factors				Reproduction Factors			
Population/ Management Unit	# Historically Occupied HUC10s	# Currently Occupied HUC10s	% Occupancy Decline	MU Occupancy Condition	Approx Pop Size (Abundance) or #live/#shell	Total Number of Live Individuals Observed 2005-2015	Year Last Seen	Approx Abundance Condition	Reproduction/ Recruitment	% sites with evidence of recent reproduction	Reproduction Condition	**Overall Population Condition**
James			**83**	**VL**				**L**			**L**	**L**
Craig Ck Subbasin	2	1	50	M	204/5	172	2013	M	Y	20%	L	M
Mill Ck	1	0	100	Ø	1/0	1	2005	VL	N	N	Ø	Ø
Rivanna	2	0	100	Ø	10/183	0	1998	VL	N	N	Ø	Ø
Upper James	2	0	100	Ø	0/1	0	2005	Ø	N	N	L	Ø
Middle James	4	1	75	VL	64/135	0	2012	L	N	N	Ø	VL
Appomattox	1	0	100	Ø	12/13	0	2003	L	N	N	Ø	Ø
Chowan			**45**	**M**				**M**			**L**	**M**
Nottoway	7	5	29	H	256/127	56	2012	M	Y	N	L	M
Meherrin	4	1	75	VL	18/19	2	2014	L	N	N	L	L
Roanoke			**50**	**M**				**VL**			**L**	**VL**
Dan R Subbasin	3	2	33	M	7/3	3	2014	VL	Y	N	L	L
Roanoke	1	0	100	Ø	0/2	0	1959	Ø	N	N	Ø	Ø
Tar			**27**	**H**				**M**			**H**	**H**
Upper /Middle Tar	5	5	0	H	184/96	82	2014	M	Y	60%	H	H
Lower Tar	3	1	66	L	14/38	3	2002	L	Y	33%	M	L
Fishing Ck Subbasin	5	3	40	M	608/188	532	2016	H	Y	75%	H	H
Sandy Swift Ck	2	2	0	H	475/1576	79	2016	H	Y	30%	M	H
Neuse			**46**	**M**				**M**			**M**	**M**
Upper Neuse	3	3	0	H	139/34	24	2011	M	Y	45%	M	M
Middle Neuse	10	4	60	L	398/128	241	2016	H	Y	45%	M	M
Cape Fear			**71**	**VL**				**L**			**L**	L
New Hope	1	1	0	H	25/0	24	2006	L	N	N	L	M
Deep R Subbasin	3	1	66	L	14/5	3	2010	L	Y	20%	L	L
Cape Fear Mainstem	2	0	100	Ø	10/3	0	1990	VL	N	N	Ø	Ø
Black	1	0	100	Ø	5/2	0	1990	VL	N	N	Ø	Ø
Pee Dee			**86**	**VL**				**L**			**L**	**L**
Muddy Ck	1	0	100	Ø	0/2	0	1800s	Ø	N	N	Ø	Ø
Uwharrie/Little	4	1	75	VL	15/2	10	2010	L	Y	10%	L	L
Goose/Lanes	2	0	100	Ø	3/4	0	2002	VL	N	N	Ø	Ø
Catawba			**100**	**Ø**				**Ø**			**Ø**	**Ø**
Catawba	3	0	100	Ø	0/1	0	1800s	Ø	N	N	Ø	Ø
Edisto			**100**	**Ø**				**Ø**			**Ø**	**Ø**
Edisto	1	0	100	Ø	0/5	0	1800s	Ø	N	N	Ø	Ø
Savannah			**100**	**Ø**				**VL**			**Ø**	**Ø**
Savannah	2	0	100	Ø	4/1	0	1800s	VL	N	N	Ø	Ø
Ogeechee			**100**	**Ø**				**VL**			**Ø**	**Ø**
Ogeechee	4	0	100	Ø	6/1	0	1998	VL	N	N	Ø	Ø
Altamaha			**100**	**Ø**				**Ø**			**Ø**	**Ø**
Altamaha	2	0	100	Ø	0/2	0	1800s	Ø	N	N	Ø	Ø

			Water Quality				Water Quantity			Connectivity				Substrate Condition			
Population/ Management Unit	Size of MU (km2)	Size of MU (mi2)	Impaired Stream Miles	Major NPDES	Minor NPDES	Overall Water Quality Condition	Known Flow Issues?	Consecutive Drought Years	Overall Water Quantity Condition	# of Dams	Actual # of Road Crossings per MU	Avg # Road Crossings per MU	Overall Connectivity Condition	Avg ARA % Forest	Avg Watershed % Imp Surface	Overall Instream Habitat (Substrate) Condition - combine ARA Forest + Watershed Impervious Surface	Current HABITAT Condition
James						**M**			**M**				**M**			**H**	**M**
Craig Ck Subbasin	674	260	21	0	2	M	N	2007, 2008	H	4	528	264	H	82	0.3	H	H
Mill Ck	611	236	2	0	4	H	Y	2007, 2008	M	2	385	385	M	71	0.2	H	M
Rivanna	958	370	48	1	15	M	Y	2007, 2008	L	36	532	266	L	66	1.0	M	L
Upper James	626	242	0	1	5	H	Y	2007, 2008	M	12	606	303	M	74	0.8	H	M
Middle James	1660	641	159	2	19	L	Y	2007, 2008	L	152	1300	325	L	61	2.0	M	L
Appomattox	508	196	5	1	11	M	Y	2007, 2008	M	14	226	226	M	70	0.9	M	M
Chowan						**M**			**L**				**M**			**H**	**M**
Nottoway	2777	1072	199	2	22	L	Y	2007, 2008, 2009, 2010	L	40	2504	358	L	56	0.7	M	L
Meherrin	1473	569	51	0	9	M	Y	2007, 2008, 2009, 2010	L	8	1050	263	H	78	0.5	H	M
Roanoke						**M**			**M**				**M**			**M**	**M**
Dan R Subbasin	1116	431	12	2	61	L	N	2005-2012	M	28	1634	545	L	64	1.1	M	M
Roanoke	338	131	0	3	4	M	Y	2005-2012	L	6	196	196	H	33	0.9	M	M
Tar						**M**			**M**				**H**			**M**	**M**
Upper & Middle Tar	2099	810	32	3	70	M	Y	2005-2010	L	46	1490	298	M	56	1.4	M	M
Lower Tar	1088	420	11	2	52	M	N	2005-2010	M	11	1018	339	M	20	3.4	L	M
Fishing Ck Subbasin	1855	716	14	1	22	M	Y	2005-2010	M	16	801	160	H	51	0.5	M	M
Sandy Swift Ck	705	272	5	0	21	H	Y	2005-2010	L	25	431	216	H	44	1.3	M	H
Neuse						**L**			**L**				**L**			**L**	**L**
Upper Neuse	1126	435	4	1	329	L	Y	2005-2012	L	44	1394	465	L	65	1.9	M	L
Middle Neuse	3740	1444	447	6	349	L	Y	2005-2012	L	237	5490	549	L	33	5.3	L	L
Cape Fear						**L**			**M**				**L**			**L**	**L**
New Hope	889	343	59	3	237	L	Y	2005-2011	M	62	1666	1666	L	49	7	L	L
Deep R Subbasin	2175	840	36	1	89	L	Y	2005-2011	M	68	2008	669	L	67	1.1	M	L
Cape Fear Mainstem	1006	388	39	5	60	L	Y	2005-2011	M	53	1233	617	L	36	4.8	M	L
Black	550	212	0	0	0	H	N	2005-2011	H	2	212	212	H	28	0.3	L	H
Pee Dee						**L**			**L**				**L**			**M**	**L**
Muddy Ck	662	256	33	2	173	L	Y	2001-2002, 2005-2010	L	62	1486	1486	L	39	12.3	L	L
Uwharrie/Little	1913	739	6	1	79	M	Y	2001-2002, 2005-2010	M	76	1285	321	L	74	1.1	H	M
Goose/Lanes	1040	402	169	1	37	L	Y	2001-2002, 2005-2010	L	21	1211	606	L	54	1.7	M	L
Catawba						**L**			**L**				**L**			**L**	**L**
Catawba	1478	571	48	13	267	L	Y	2001-2002, 2005-2010	L	81	1783	594	L	49	8.4	L	L
Edisto						**H**			**M**				**H**			**M**	**M**
Edisto	831	321	?	0	7	H	N	2007-2009, 2011-2012	M	0	143	143	H	22	1.4	M	M
Savannah						**L**			**L**				**L**			**L**	**L**
Savannah	1310	506	54	6	30	L	Y	2000-2002, 2006-2009, 2011-2012, 2014-2015	L	55	2576	1288	L	20	5.3	L	L
Ogeechee						**M**			**M**				**L**			**M**	**M**
Ogeechee	2828	1092	44	0	25	M	N	2006-2008, 2014-2015	M	74	1363	341	L	34	0.8	M	M
Altamaha						**M**			**M**				**L**			**M**	**M**
Altamaha	1765	681	64	1	9	M	N	2006-2008, 2014-2015	M	51	785	393	L	31	0.8	M	M