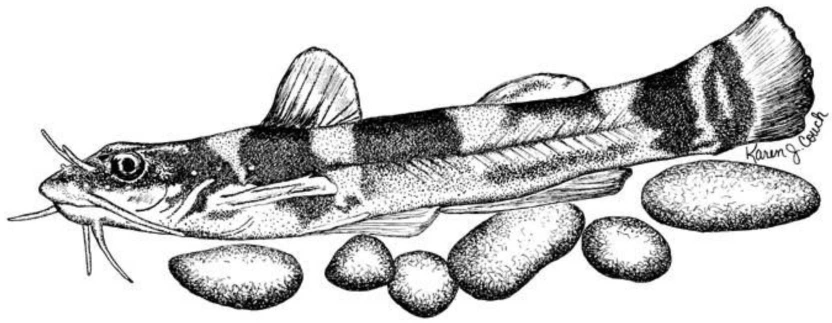
Species Status Assessment Report
for the
Carolina Madtom (*Noturus furiosus*)
Version 1.1



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U.S. Fish and Wildlife Service
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Suggested reference:

U.S. Fish and Wildlife Service. 2018. Species status assessment report for the Carolina Madtom (*Noturus furiosus*). Version 1.1. November, 2018. Atlanta, GA.

Summary of Version Updates

The change from version 1.0 (April 2017) and 1.1 (November 2018) was minor and did not change the SSA Analysis for Carolina Madtom. The change was:

1) Removed mention of SmithEnvironment Blog in Section 4.6 under Regulatory Reform in North Carolina.

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Prepared by the
U.S. Fish and Wildlife Service

EXECUTIVE SUMMARY

This species status assessment (SSA) reports the results of the comprehensive status review for the Carolina Madtom (*Noturus furiosus* (Jordan and Meek 1889)), documenting the species' historical condition and providing estimates of current and future condition under a range of different scenarios. The Carolina Madtom is a freshwater fish species endemic to the Tar-Pamlico and Neuse River drainages in North Carolina. The species occurs in riffles, runs, and pools in medium to large streams and rivers with moderate gradient in both the Piedmont and Coastal Plain physiographic regions.

The SSA process can be categorized into three sequential stages. During the first stage, we used the principles of resiliency, redundancy, and representation (together, the 3Rs) to evaluate individual madtom 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 Carolina Madtom, 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 three river basins that Carolina Madtoms have historically occupied (i.e., Tar-Pamlico, Neuse, and Trent 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 10-digit HUC (hydrologic unit code) 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 minimize the risk of extinction. A number of factors, including (but not limited to) water quality, water quantity, habitat connectivity, and instream substrate, may influence whether Carolina Madtom 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 Carolina Madtom has very limited resiliency, with the one population in moderate condition, one population in very low condition, and one in presumed extirpated condition.

Redundancy describes the ability of the species to withstand catastrophic disturbance events; for the Carolina Madtom, we considered whether the distribution of resilient populations was

sufficient for minimizing the potential loss of the species from such an event. The Carolina Madtom has an endemic range in the Tar-Pamlico River and the Neuse River (including the Trent River) basins in North Carolina, but both the abundance and distribution of madtoms 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 Carolina Madtom 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 medium streams to large rivers in two physiographic provinces, in the Piedmont and into the Coastal Plain. Much of the representation of the Carolina Madtom has been lost; physiographic variability has been lost with 86% loss in the Coastal Plain and 44% loss in the Piedmont, and those occurrences are represented by very few individuals in very few occupied localities.

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 Carolina Madtom abundance and distribution has declined considerably, with the species currently occupying approximately 26% of its historical range. 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 current 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, as well predation by the invasive Flathead Catfish. The effects of climate change have begun to be realized in current Carolina Madtom range and may have contributed to habitat degradation.

Current Viability Summary

The historical range of the Carolina Madtom included streams and rivers in the Tar, Neuse, and Trent River drainages with the documented historical distribution in 11 MUs within three former populations. The Carolina Madtom is presumed extirpated from 64% (7) of the historically occupied MUs. Of the remaining four occupied MUs, one is estimated to have high resiliency, one with moderate resiliency, one with low resiliency, and one with very low resiliency. Scaling up from the MU to the population level, one of three former populations (the Tar population) is estimated to have moderate overall resiliency, while the remaining extant population (Neuse) is characterized by very low resiliency. The Trent Population is presumed to be extirpated. 82% of watersheds that were once part of the species' range are estimated to be in low/very low condition or likely extirpated, potentially putting the Carolina Madtom at risk of extinction. Once known to occupy streams in two physiographic regions, the species has also lost substantial physiographic representation, with an estimated 44% loss in Piedmont watersheds and an estimated 86% loss in Coastal Plain watersheds.

Future Viability

To assess the future condition of the Carolina Madtom, a variety of stressors, including pollution, reduced stream flow, and continued habitat fragmentation, and their (potential) effects on population resiliency were considered. Populations with very low and 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 Carolina Madtom.

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 Carolina Madtom 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, one in moderate condition, one in low condition, and the remaining MUs would be likely extirpated. Redundancy would be reduced to two MUs in only one population. Representation would be reduced, with only one (33%) of the former three river basins occupied and with reduced variability in the Piedmont and Coastal Plain.

Given Scenario 2, the "Pessimistic" worse case option, we predicted a near complete loss of resiliency, representation, and redundancy. There is no redundancy, as only one MU within one population is predicted to persist. As such, all but one MU were predicted to be extirpated, and the remaining MU is predicted to be in low condition. All measures of representation are predicted to decline under this scenario, leaving remaining Carolina Madtom populations underrepresented in River Basin and Physiographic variability.

Given Scenario 3, the "Optimistic" better case option, we predicted only slightly higher levels of resiliency, representation, and redundancy than was estimated under the Status Quo scenario. One MU is predicted to be in high condition, one in moderate condition, one in low condition, and the remaining MUs would be likely extirpated. Despite predictions of population persistence in the Tar River Basin, this population is expected to retain only a moderate level of resiliency. Existing levels of representation are predicted to decline under this scenario with the Neuse and Trent River populations predicted to be likely extirpated.

Given Scenario 4, the "Opportunistic" moderate case option, we predicted reduced levels of resiliency, representation, and redundancy. No MUs would be in high condition, two would be in moderate condition, and nine would be likely extirpated. Redundancy would be reduced by two thirds with two of the three populations predicted to be extirpated. Under the Opportunistic Scenario, representation is predicted to be reduced with only one of three formerly occupied river basins remaining occupied and with reduced variability in the Piedmont and Coastal Plain Physiographic Regions.

Table ES-1. Summary results of the Carolina Madtom 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 pea gravels • Abundant cover • Multiple occupied management units per population	• 2 (of 3) populations known to be extant • Currently extirpated from 7 of the 11 Management Units • Population status: 1 moderate resiliency 1 very low resiliency	Projections based on future scenarios in 50 years: • Status Quo: Threats continue on current trajectory and species maintains current level of response. Two populations (9 MUs) are expected to be extirpated; remaining population has low resiliency • Pessimistic: higher level of threats and reduced species response. Two populations (10 MUs) are expected to be extirpated; remaining population has low resiliency • Optimistic: minimal level of threats and optimistic species response. Two populations expected to be likely extirpated; one population maintains moderate resiliency condition • Opportunistic: moderate level of threats and selective species response. Two populations (8 MUs) are expected to be extirpated; remaining one has 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: • 67% of river basin variability retained, however one population is in very low condition, one population is in moderate condition • Low genetic representation (due to very low abundances) in remaining populations • Limited physiographic variability in Piedmont and Coastal Plain	Projections based on future scenarios in 50 years: • Status Quo: 67% of river basin variability lost; considerable losses in physiographic variability in Piedmont (67%), substantial loss in the Coastal Plain (91%) • Pessimistic: 67% river basin variability lost; substantial losses in physiographic variability in Piedmont (89%) and Coastal Plain (95%) • Optimistic: 67% of river basin variability lost; maintain very limited physiographic variability in Coastal Plain (14%) and moderate in the Piedmont (46%) • Opportunistic: 67% of river basin variability lost; considerable losses in physiographic variability in Piedmont (56%) and substantial loss in the Coastal Plain (91%)
Redundancy (number and distribution of populations to withstand catastrophic events)	• Multiple populations in each area of representation	• Very low numbers in Neuse River population • Tar River population has three MUs currently occupied • Overall loss of 74% redundancy across range (8 out of 31 HUCs currently occupied)	Projections based on future scenarios in 50 years: • Status Quo: only one population retains redundancy; 9 of 11 MUs likely extirpated • Pessimistic: no redundancy; 10 of 11 MUs likely extirpated • Optimistic: one population retains redundancy; 8 of 11 MUs likely extirpated • Opportunistic: one population retains redundancy; 9 of 11 MUs likely extirpated

Table ES-2. Future scenario and condition category descriptions for each of four scenarios used to predict Carolina Madtom 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 Carolina Madtom population conditions under each of 4 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
Tar: Upper Tar	Low	Likely Extirpated	Likely Extirpated	Low	Likely Extirpated
Tar: Middle Tar	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Tar: Lower Tar	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Tar: Fishing Ck	Moderate	Low	Likely Extirpated	Moderate	Moderate
Tar: Sandy-Swift	High	Moderate	Low	High	Moderate
Neuse: Upper Neuse	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Neuse: Middle Neuse	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Neuse: Lower Neuse	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Neuse: Little River	Very Low	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Neuse: Contentnea	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Trent	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated

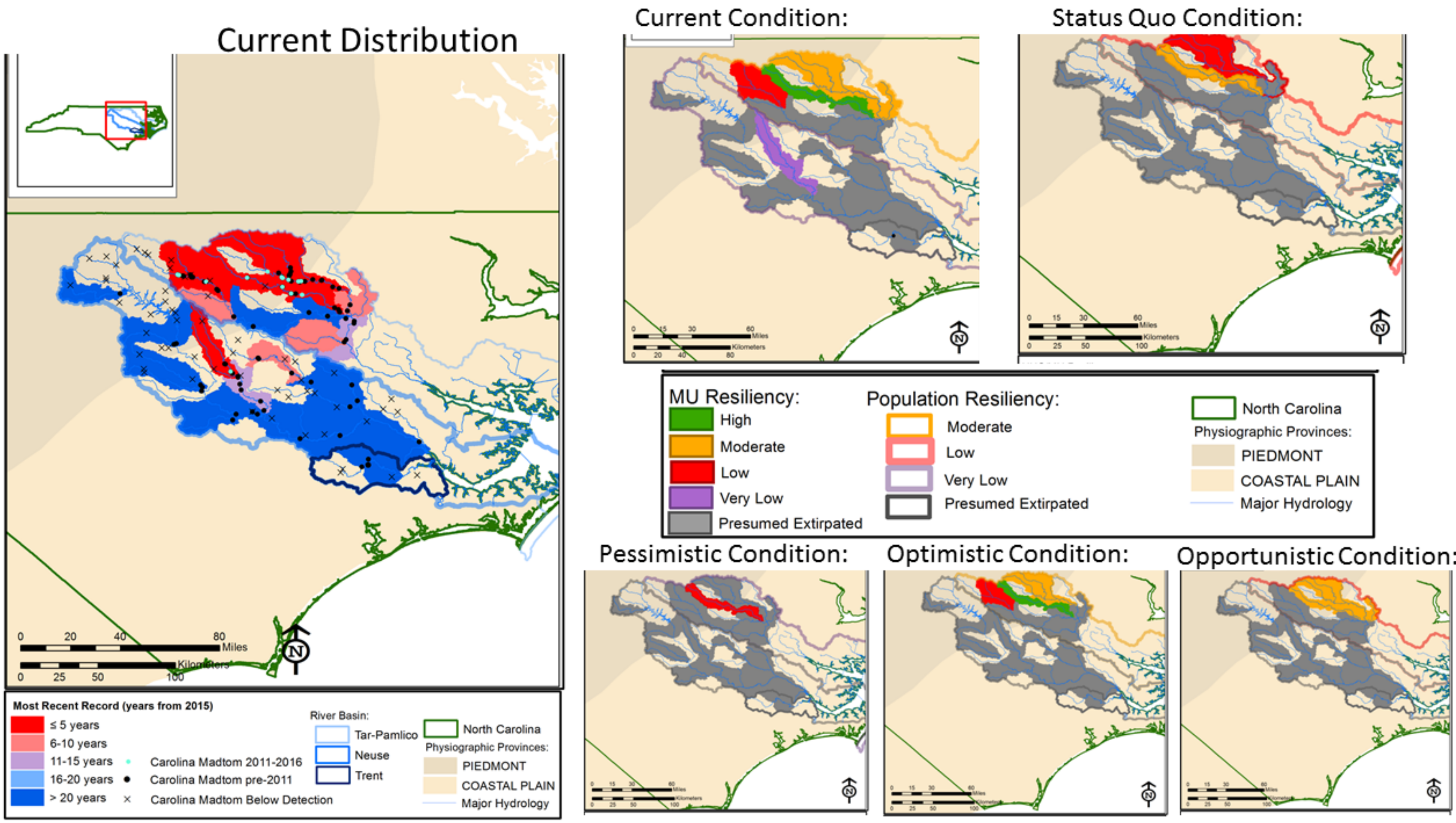

Figure ES-1 Maps of current distribution, current condition, and predicted Carolina Madtom population conditions under each scenario (see Table ES-3)

Overall Summary

Estimates of current and future resiliency for Carolina Madtom are low, as are estimates for representation and redundancy. The Carolina Madtom faces a variety of threats from declines in water quality, loss of stream flow, riparian and instream fragmentation, deterioration of instream habitats, and expansion of the invasive predator Flathead Catfish. 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 Carolina Madtom. 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 Carolina Madtom habitat conditions and population factors suggest possible extirpation of one of two currently extant populations. The one population (Tar) predicted to remain extant is expected to be characterized by low occupancy and abundance.

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CHAPTER 1 - INTRODUCTION

The Carolina Madtom is a freshwater fish that is endemic to the Atlantic Slope drainages of the Tar-Pamlico and Neuse River basins in North Carolina. 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.743).

The Species Status Assessment (SSA) framework (USFWS 2016, entire) is intended to be an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA Report to be easily updated as new information becomes available and to support all functions of the 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 Carolina Madtom 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, whether to and where to propose designating critical habitat. Importantly, the SSA Report is not a decisional document by the Service, rather; it provides a review of available information strictly related to the biological status of the Carolina Madtom. 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 2016, 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.

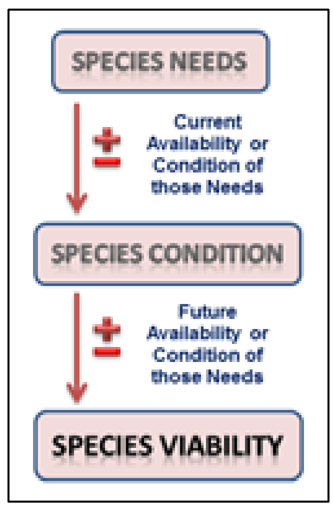


Figure 1-1 Species Status Assessment Framework

- 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 Carolina Madtom, 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 demographic risks, threats, and limiting factors in the context of determining viability and extinction risk for the species.

This SSA Report includes: (1) a description of Carolina Madtom resource needs at both individual and population levels (Chapter 2); (2) a characterization of the historic and current distribution of 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); (4) a synopsis of the factors characterized in earlier chapters as a means of examining the future biological status of the species (Chapter 5); and a Summary (Chapter 6). This document is a compilation of the best available scientific and commercial information (and associated uncertainties regarding that information) used to assess the viability of the Carolina Madtom.

CHAPTER 2 - INDIVIDUAL NEEDS: LIFE HISTORY AND BIOLOGY

In this section, we provide basic biological information about the Carolina Madtom, including its taxonomic history and morphological description, and life history traits such as reproduction and nesting, diet, age, growth, population structure, and habitat. 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 Carolina Madtom, refer to Burr et al. (1989).

2.1 Taxonomy

The type specimen (USNM 39932) of the Carolina Madtom (*Noturus furiosus*) was collected by Professors Jenkins and Meek from the Neuse River at Millburnie, near Raleigh, North Carolina in 1888. The species was formally described by Jordan and Meek in 1889 (Jordan 1889, p.351-2). The Carolina Madtom is in the subgenus *Rabida*, and while Jordan originally aligned *N. furiosus* with *N. miurus* (Brindled Madtom) and *N. eleutherus* (Mountain Madtom), it is currently a member of the *furiosus* species group which includes *N. placidus* (Neosho Madtom), *N. stigmosus* (Northern Madtom), and *N. munitus* (Frecklebelly Madtom) (Taylor 1969, p.167) and the more recently described *N. gladiator* (Piebald Madtom) (Thomas and Burr 2004).

In the early 1980s there was some question of the taxonomic status of *N. furiosus* (e.g., LeGrande (1981) did not include *N. furiosus* in an analysis of the chromosomal evolution of the genus *Noturus* and Taylor (as noted in Burr et al. 1989, p.58) suggested that *N. furiosus* might be a geographic subspecific population of *N. stigmosus* (as noted in Burr et al. 1989, p.58)). However Grady analyzed allozymes of all extant members of *Noturus* and found that the species *N. furiosus* has several fixed alleles and can be distinguished electrophoretically from other members of the *furiosus* group (Grady and LeGrande 1992, p.747-777).

The currently accepted classification is (Integrated Taxonomic Information System 2016):

Phylum: Chordata
Class: Actinopterygii
Order: Siluriformes
Family: Ictaluridae
Genus: *Noturus*
Species: *Noturus furiosus*

2.2 Description

Characteristic of all madtoms, the Carolina Madtom has its adipose fin fused to the caudal fin. It has a short, chunky body with well-developed dentations on both anterior and posterior edges of pectoral spines. *Furiosus* means "mad" or "raging", as the Carolina Madtom is the most strongly armed of the North American catfishes with poison in the tips of the serrae that is more potent than that of any other species (Jordan 1889, p.352). The moderate-sized fish reaches a maximum length of nearly five inches, and has a distinct color pattern including three dark saddles (the adipose fin has a dark blotch that does not quite reach the fin's edge, giving the impression of a fourth saddle) along its back and a wide black stripe along its side, extending from its snout to the base of its tail (Figure 2-1). In between the saddles are yellow/tan blotches, and the belly is not speckled. The tail has crescent-shaped brown bands near the edge and center. As in other species of the genus *Noturus*, there is no marked sexual dimorphism outside the breeding season.

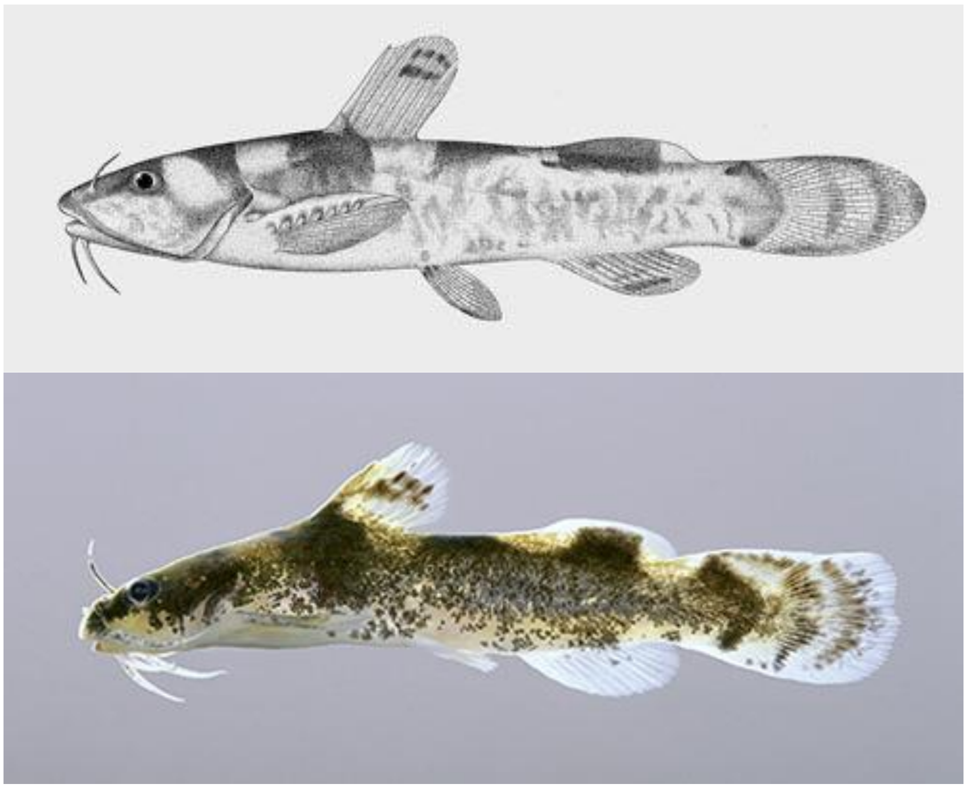


Figure 2-1 Carolina Madtom; top drawing by Jordan (1888); bottom image by R.Bryant & W.C.Starnes (1999)

2.3 Reproduction and Nesting

Burr noted that female Carolina Madtoms reached reproductive maturity by 2 years, although the vast majority of gravid females observed were 3-year-olds (Burr et al. 1989, p.72). Age at first spawning for males is unknown, however males have been found guarding nests or nest sites at age 2-4 years, or longer than 2.5 inches. Females produce 80-300 eggs per breeding season (NCWRC 2009, p.2).

Reproductively mature males have enlarged epaxial (dorsal) muscles, swollen lips, and swollen genital papillae. The swollen heads of males are presumed to help with nest guarding and possibly in nest preparation (Burr et al. 1989, p.72). Reproductively mature females have distended abdomens and swollen genital papillae.

The nesting season extends from about mid-May to late July (Burr et al. 1989, p.75). Nest sites are often found under or in relic freshwater mussel shells (Figure 2-2), under large pieces of water-logged tree bark, or in discarded beverage bottles and cans partially buried on the stream bottom. Most nest sites are in runs above riffles or in pools with current (Burr et al. 1989, p.76). All nests with embryos or larvae are guarded by solitary males, 2 to 4 years old. Embryos adhere to one another in a mass but not to other surfaces, and clutch sizes average 152 larvae (Burr et al. 1989, p.76-77). Hatchlings exhibit tightly cohesive schooling behavior (Burr et al. 1989, p.78).

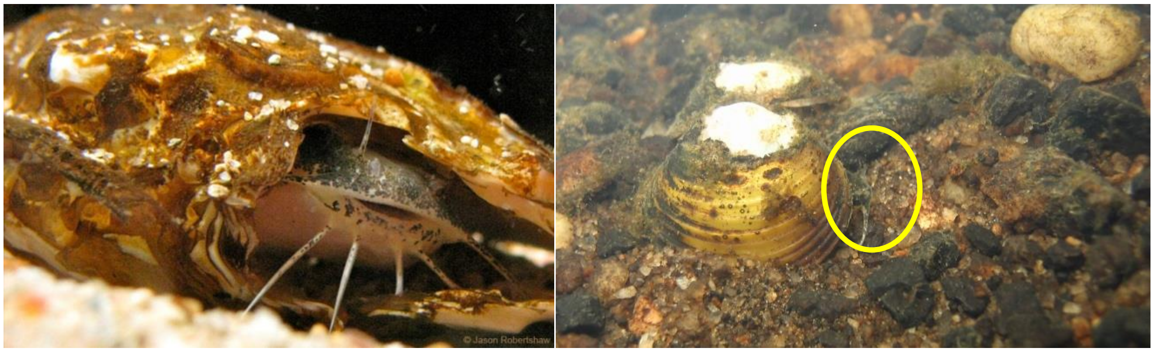


Figure 2-2 Left: Adult Carolina Madtom in a relic freshwater mussel shell (credit: Jason Robertshaw); Right: Juvenile Carolina Madtom in relic Asian clam shell (credit: C.Wood)

2.4 Diet

The Carolina Madtom is a benthic insectivore that feeds primarily during the night, with peaks at dawn and dusk (Burr et al. 1989, p.79). Burr observed that more than 95% of the food organisms in the Carolina Madtom stomachs were larval midges, mayflies, caddisflies, dragonflies and beetle larvae (Burr et al. 1989, p.78).

2.5 Age, Growth, Population Size Structure

The largest observed specimens were approximately 4 inches in length, and aged from pectoral spines to be 4 years old (Burr et al. 1989, p.72). In May 1985, Burr noted that, as expected in a healthy population experiencing normal recruitment, populations seemed skewed towards younger age classes (Burr et al. 1989, p.72). Burr also noted that the large number of individuals collected in May that were under 1.5 inches indicated that growth was slow in the winter and early spring. There was no significant deviation from a 1:1 sex ratio (Burr et al. 1989, p.75).

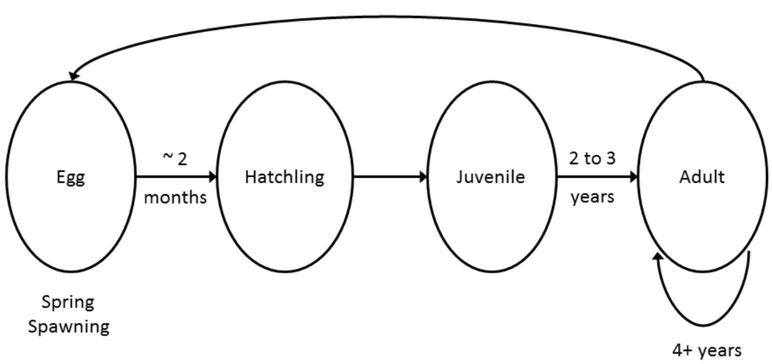


Figure 2-3 Life Cycle of the Carolina Madtom

2.6 Habitat

The Carolina Madtom is endemic to medium to large flowing streams of moderate gradient in both the Piedmont and Coastal Plain physiographic regions in the Neuse and Tar River basins (see Figure 3-1 below). Suitable instream habitats have been described as riffles, runs, and pools with current, and during the warm months the madtoms are found in or near swift current at depths of 1 to 3 feet (Burr et al. 1989, p.63). Juveniles inhabit slower currents, but some overlap with adults does occur. Stream bottom substrate composition is important for the benthic Carolina Madtom; leaf litter, sand, gravel, and small cobble are all common substrates associated with the species, although the species is most often found over sand mixed with pea-sized gravel and leaf litter (Burr et al. 1989, p.63; Midway et al. 2010, p.326; Figure 2-2). During the breeding season (May thru July), the Carolina Madtoms shift to areas of moderate to slow flow with abundant cover used for nesting (Burr et al. 1989, p.63).

Table 2.1 Life history and resource needs of the Carolina Madtom.

Life Stage	Resources and/or circumstances needed for INDIVIDUALS to complete each life stage	Resource Function (BFSD*)	Information Source
Egg/Embryo - May-July	• Clear, flowing water • Sexually mature males and females • Appropriate spawning temperatures • Nest sites (rocks, bottles, shells, cobble) • Adequate flow for oxygenation	B	- Burr et al. 1989, p.75
Hatchling - late summer	• Clear, flowing water • Cohesive schooling behavior to avoid predation	B, S	- Burr et al. 1989, p.78
Juveniles - 2 to 3 years; >2.5 inches long	• Clear, flowing water • Adequate food availability (midges, caddisflies, mayflies, etc.) • Cover (shells, bottles, cans, tires, woody debris, etc.)	F, S	- Burr et al. 1989, p.78
Adults - 3+ years - >4 inches long	• Clear, flowing water 1 to 3 feet deep • Appropriate substrate (leaf litter, sand, gravel, cobble) • Adequate food availability (midges, caddisflies, mayflies, etc.) • Cover (shells, bottles, cans, tires, woody debris, etc.)	F, S, D	- Burr et al. 1989, p.63 - Midway et al. 2010, p.326

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

CHAPTER 3 – POPULATION AND SPECIES NEEDS AND CURRENT CONDITION

In this chapter we consider the Carolina Madtom's historical distribution, its current distribution, and the factors that contribute 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 Carolina Madtom resiliency, representation, and redundancy. Through the lens of the 3Rs, we then estimate the current condition of Carolina Madtom populations.

3.1 Historical Range and Distribution

The Carolina Madtom is endemic to the Tar-Pamlico and Neuse River basins in North Carolina. Its historical distribution includes two physiographic provinces (Piedmont and Coastal Plain) comprising all major tributary systems of the Tar and Neuse (Burr and Lee 1985, p.1). Because of salt water influence, the habitats in the Trent River system are isolated from the Neuse River and its tributaries; therefore, we consider the Trent River system as a separate basin (i.e., population), even though it is technically part of the larger Neuse River Basin.

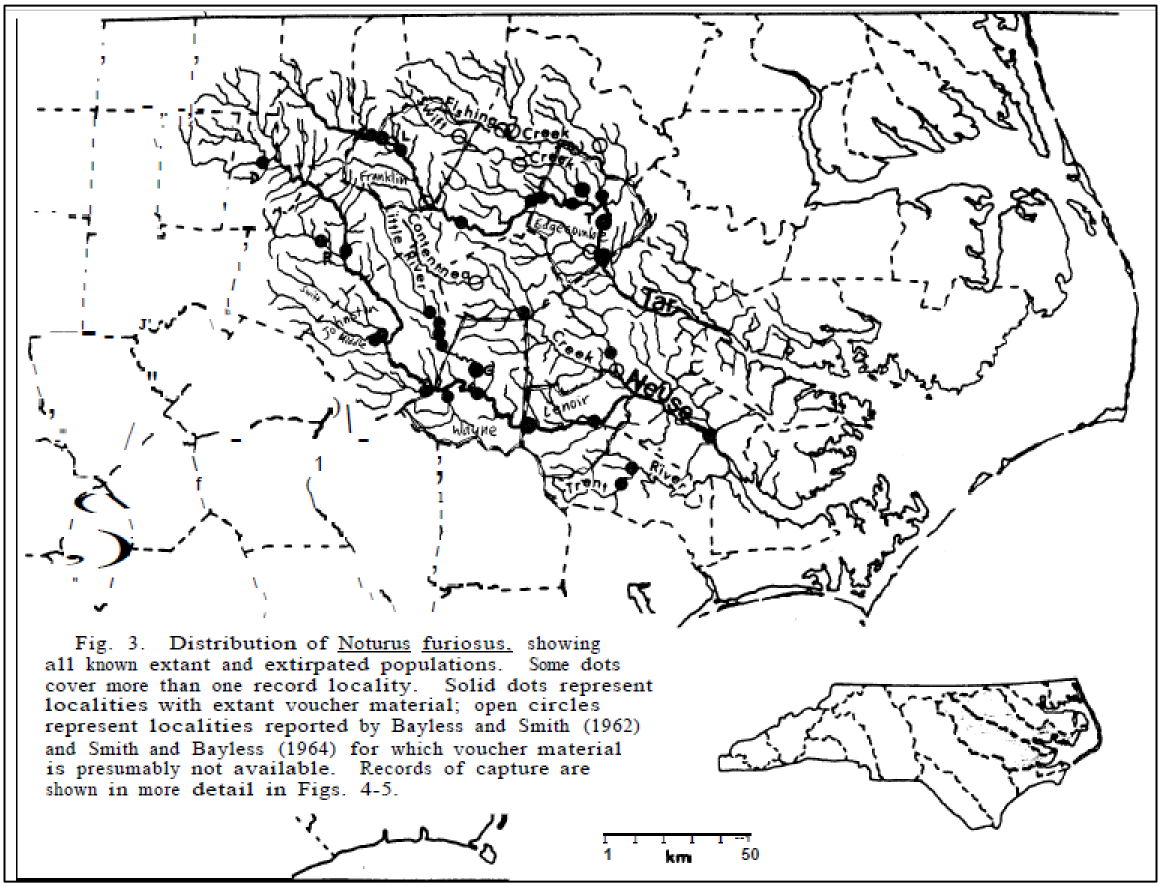
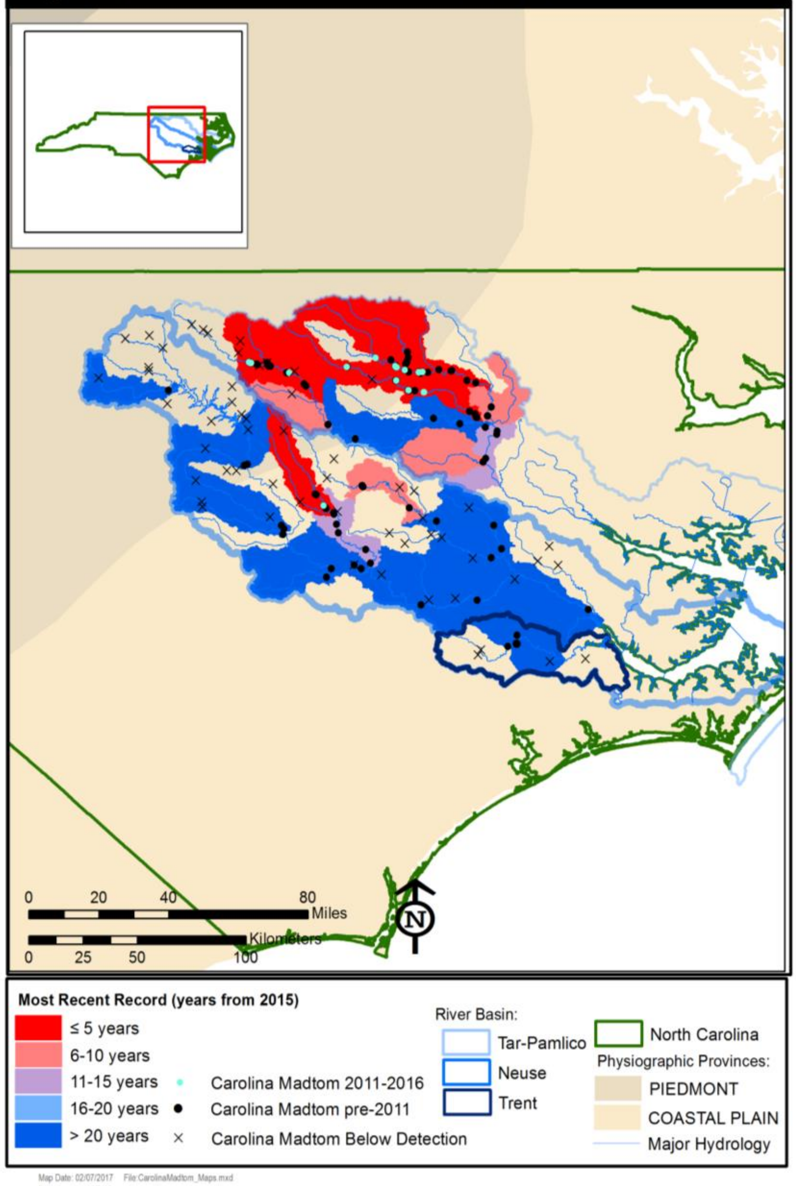


Figure 3-1 Historical distribution of Carolina Madtom (from Burr and Lee 1985, p.6).

3.2 Current Range and Distribution

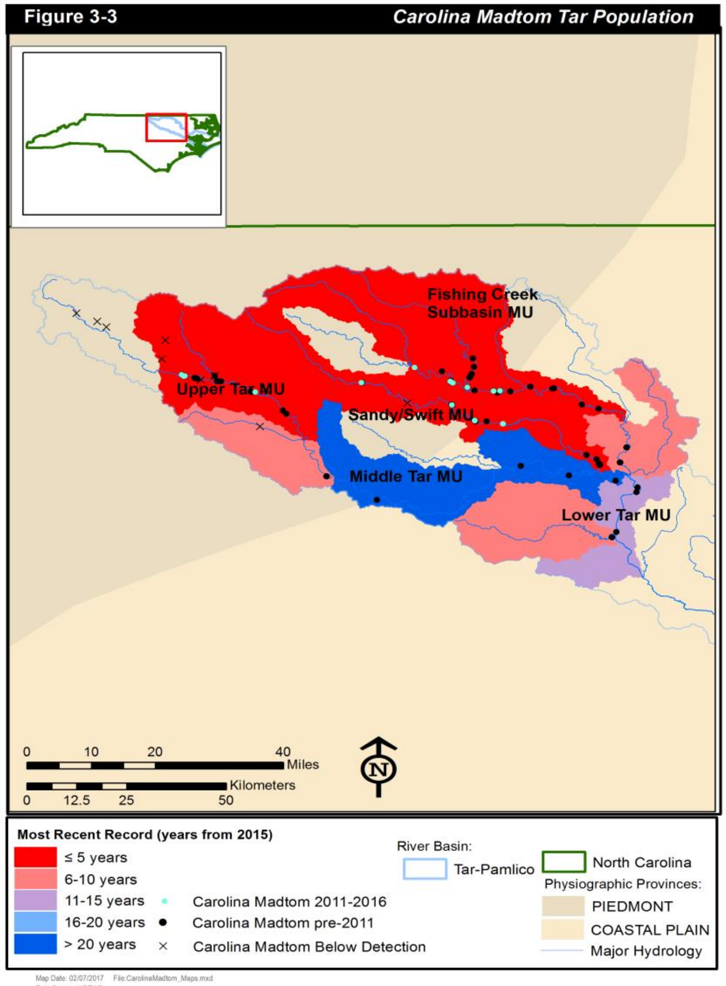
For the purposes of this assessment, populations were delineated using the river basins that Carolina Madtoms have historically occupied. This includes the Tar, the Neuse, and the Trent River basins, and from here forward, we will use these terms to refer to populations (e.g., the Tar Population). Of the three historical Carolina Madtom populations, only two have observations in the last 5 years; the Carolina Madtom is presumed extirpated from the southern portion of the range in the Trent River basin. 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 2016; 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 (Figure 3-2). Documented species occurrences are included to show distribution within HUC10s and the NC Division of Water Resources has documented sites where the Carolina Madtom is below detection ("X" in Figure 3-2), based on their most recent basin-wide fish surveys (NCDWR 2012 & 2015). Throughout this section, heat maps are used to characterize the historical and current distribution of Carolina Madtom among MUs for each of the three populations.

Figure 3-2 Carolina Madtom Current Distribution



3.2.1 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 (NCDEQ 2016d). 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 (NCDEQ 2016d). 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 (NCDEQ 2016d).

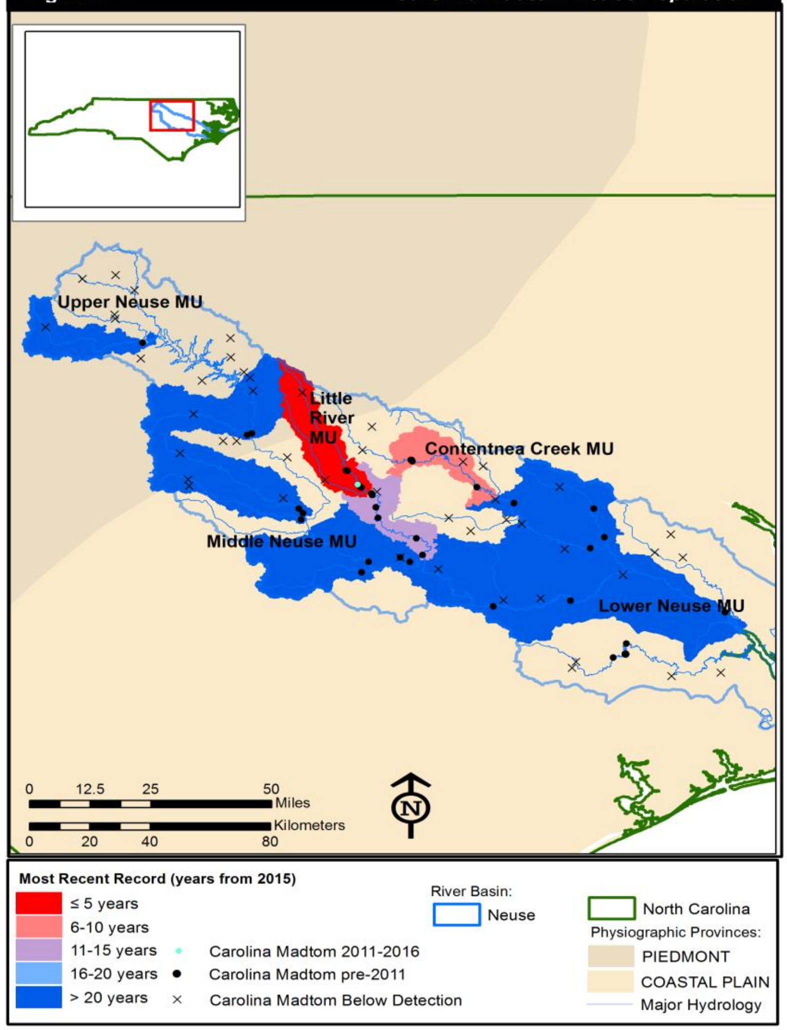


The Tar population consists of five MUs, herafter referred to as the Upper Tar MU, Middle Tar MU, Lower Tar MU, Fishing Creek Subbasin MU, and Sandy-Swift Creek MU. Many survey efforts have documented the presence of Carolina Madtom over the years; the species was first seen in Fishing Creek in 1963, and it has been documented as recently as 2016 in Fishing Creek, Swift Creek, and the Tar River. Species-specific snorkel surveys in the mid-2000s documented as many as 50 individuals in Fishing Creek; most other surveys have documented between one and 20 individuals, and most recent surveys (2015-2016) have observed four individuals. In Swift Creek, species-specific snorkel surveys in the mid-2000s documented as many as 12 individuals at any one site, and most recent surveys in 2016 documented a total of 17 individuals.

3.2.2 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 (NCDEQ 2016c). 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 Creeks and the Eno, Little, and Trent Rivers (although the Trent River is considered a separate population – see below). 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 (NCDEQ 2016c). In addition, more than 400 permitted point source sites discharge wastewater into streams and rivers in the basin (NCDEQ 2016c). 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 (NCDEQ 2016c), and increased development pressure has increased stormwater runoff, contributing to the basin's pollution and flow issues.

Figure 3-4 Carolina Madtom Neuse Population

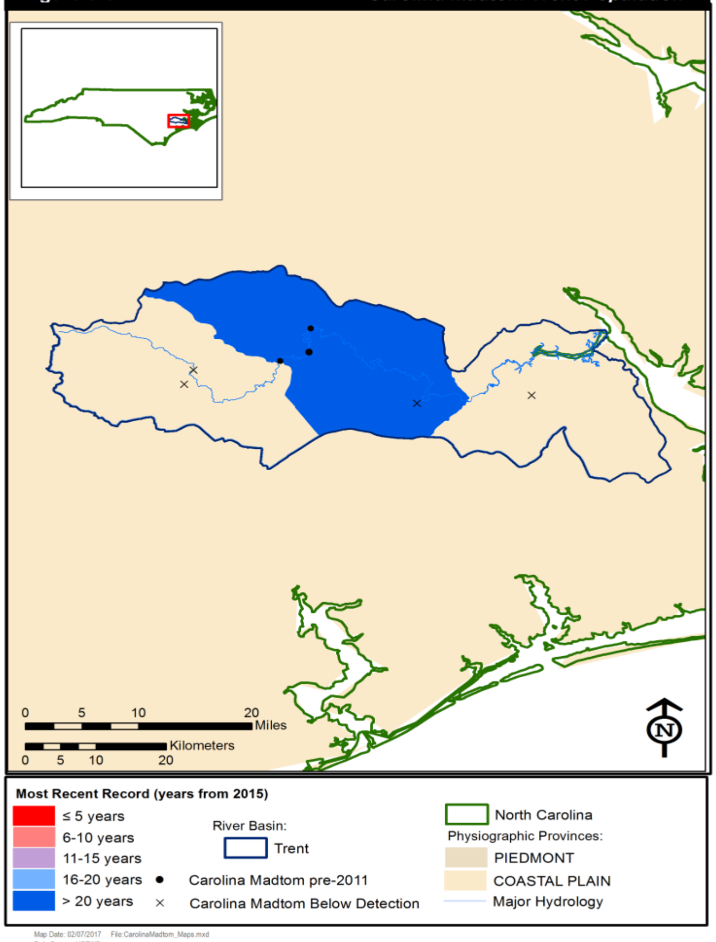


The Neuse population consists of five MUs, hereafter referred to as the Upper Neuse MU, Middle Neuse MU, Lower Neuse MU, Little River MU, and Contentnea Creek MU. Several survey efforts have documented the Carolina Madtoms over the years; the species was first seen and described from the Neuse River in 1888, and it has been documented as recently as 2016 in the Little River. Surveys have never documented high numbers of Carolina Madtoms; the most that have been observed during any targeted effort was 13 during a 2007 survey in Contentnea Creek, however recent targeted efforts have failed to find madtoms in Contentnaea Creek. Recent mussel surveys (2015 and 2016) have incidentally observed individuals in the Little River.

3.2.3 Trent River Population

Basin Overview: Technically the Trent River basin is within the greater Neuse River basin, but for our analyses it is considered a separate basin because of saltwater influence on habitats preventing madtoms in the Trent River to interact with those in the greater Neuse River Basin. The Trent River basin is contained completely within the state of North Carolina and has a drainage area of approximately 540mi^2 with over 1,400 miles of rivers and streams. The headwaters of the Trent River originate in the Coastal Plain of eastern North Carolina in Lenoir and Jones counties, and then the river flows southeast until it reaches confluence with the Neuse River and the tidal waters near New Bern where it empties into the Pamlico Sound. A major tributary is Tuckahoe Swamp. Like the Tar River basin, the Neuse River basin (including the Trent 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 (NCDEQ 2016c). In addition, 12 permitted point source sites discharge wastewater into streams and rivers in the basin. Based on the 2011 National Land Cover Data, the Trent River basin's has approximately 6% developed area, 20% agriculture, 35% wetlands, 5% grassland, and 34% forest. The watershed is mostly rural, and the Croatan National Forest covers a large portion of the lower watershed. Development and population growth are centered around New Bern.

Figure 3-5 Carolina Madtom Trent Population



The Trent Population was designated as a separate population from the Neuse River Population because of the separation of the Trent River by salt water influence at the confluence with the Neuse River. The Trent Population consists of one Management Unit, hereafter referred to as the Trent River MU. The species was first observed in 1960, and there are a few historical records of Carolina Madtom in this MU from 1985-1986. Follow-up surveys in 2007 and 2015 were unable to observe any individuals (B.Tracy (NCDWR) email to S.McRae (USFWS) on 2/1/2016). A total of 16 live individuals have been observed over time in this MU.

3.3 Needs of the Carolina Madtom

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. 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 3-6). Using various time frames and the current and projected levels of the 3Rs, we thereby describe the species' level of viability over time.

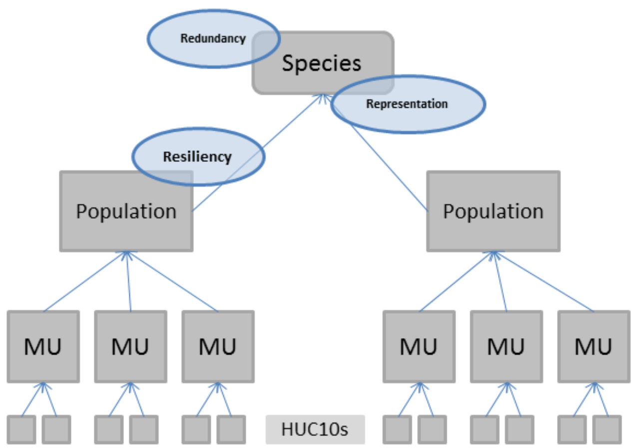


Figure 3-6 Resiliency is measured at the population level, representation is measured at the species and, possibly, population level, and redundancy is measured at the species level (after Fig 4, USFWS 2016). MU=Management Unit; HUC10 = Hydrologic Unit

3.3.1 Carolina Madtom MU Resiliency

As previously described, Carolina Madtom 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 3.2 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 assess this metric. Given the hierarchical nature of the relationship between MUs, populations, and species (Figure 3-6), 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 Carolina Madtom to be viable, some proportion of MUs must be resilient enough to withstand stochastic events. Stochastic events that have the potential to affect fish 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 madtom habitat requisites (see Figure 3-7).

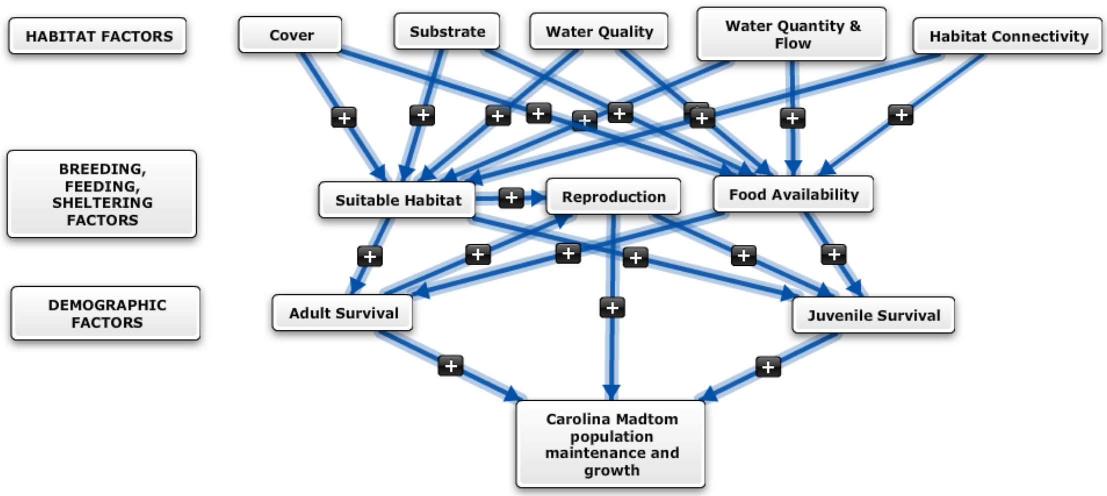


Figure 3-7 Carolina Madtom Ecology: Influence diagram illustrating how habitat factors influence breeding, feeding, and sheltering factors, which in turn affect demographic factors that ultimately drive madtom population growth and maintenance. Diagram was developed by a group of madtom experts and substantiated from literature.

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. Carolina Madtom presence was compiled from survey data made available by state agency databases. Those surveys involved electrofishing, visual (snorkel), or bait-trap by-cath methods to detect madtoms. Most surveys involved timed searches where species were identified, counted, measured, and, in some cases, fin clipped for genetic information. Fish were returned to the river post-identification.

Approximate Abundance – During stream surveys, fish abundance was recorded as either a qualitative approximation or a quantitative number of fish observed during a survey of a specific reach of stream. This is usually a result of the type of survey done – some surveys are targeted to specifically look for fish, or the Carolina Madtom in particular; other surveys, such as freshwater mussel surveys, might have incidental observations of the Carolina Madtom. Of the data available for Carolina Madtom, quantitative measures of densities are not provided for most current occurrences, and qualitative approximations (e.g., "common", "rare") are sporadically documented. More often, quantitative data are available for the number of live individuals observed at a location at a specific moment in time. Thus, we used the cumulative record of the total number of live individuals observed within a MU to provide an approximate estimate of abundance within MUs. We considered MUs with recent (≤ 5 years) documentation of high approximate abundance to be resilient. High approximate abundance is defined as cumulative counts of over 100 individuals observed over time, or more than 10 live individuals observed over the past 5 years. Since abundance estimates did not account for detection probability, the approximate abundances should be considered conservative (Wood and Nichols 2011, p.295). That is, Carolina Madtoms 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 - For this analysis, data used to indicate reproduction/recruitment were either specifically documented as "Yes" for recruitment in the WRC database or the size of the madtom was <40mm, which is the young-of-year cutoff used in NCDEQ's SOP for fish Index of Biotic Integrity (IBI) calculations (NCDWR 2013, entire). 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 instream habitat quality and quantity, which, in turn, influence the condition and abundance of species using that habitat. In the case of the Carolina Madtom, breeding, feeding, and sheltering needs such as appropriate nest sites, adequate food sources, and suitable stable habitat are all needs influenced by water quality, water quantity, and suitable in-stream (substrate) habitat and habitat connectivity (Figure 3-7). See Chapter 4 for further discussion about the many factors that influence the condition of these habitat elements.

Water Quality - Clean, non-polluted water is essential to the survival of the Carolina Madtom. Streams that have non-altered thermal regimes, average pH, low salinity, and negligible chemical pollution provide suitable habitat for the persistence of madtom populations. As required by section 303(d) of the Clean Water Act, all waters that do not meet standards for the designated use of the particular waterbody (e.g., to support/protect aquatic life) are placed on the Impaired Streams List. Note that not all streams throughout every river basin are monitored, therefore it is possible that there are more miles of impaired streams than actually reported. 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. As with many fish, the Carolina Madtom is sensitive to changes in water quality parameters such as DO, pH, and pollutants (see Chapter 2 for more information). For this assessment, the number and miles of impaired stream reaches (as designated by the NC Division of Water Resources), as well as the number of National Pollutant Discharge Elimination System (NPDES) point discharges were used to characterize water quality within a given MU.

Water Quantity – Optimal habitats for Carolina Madtoms are perennial streams with continuous, year-round flow. Because a lotic environment is a critical need for the Carolina Madtom, perturbations that disrupt natural discharge regimes have a potential negative influence on Carolina Madtom resilience metrics. Carolina Madtom habitat must have adequate flow to deliver oxygen, provide optimal water temperatures, enable fish movement, and deliver prey items, as well as to carry away waste materials and remove fine sediments from the bottom substrate. 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).

Figure 3-8 Fish kill due to low flows and lack of oxygen for fish in the Neuse River (credit: T.Graves)

While fish 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, fish can become stressed during the low flow times of year, either because they have to tolerate less than ideal conditions where water remains, or they are unable to find refuge and ultimately die (Figure 3-8). 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.

To understand whether Carolina Madtom 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 fish were exposed to consecutive droughts (Figure 3-9).

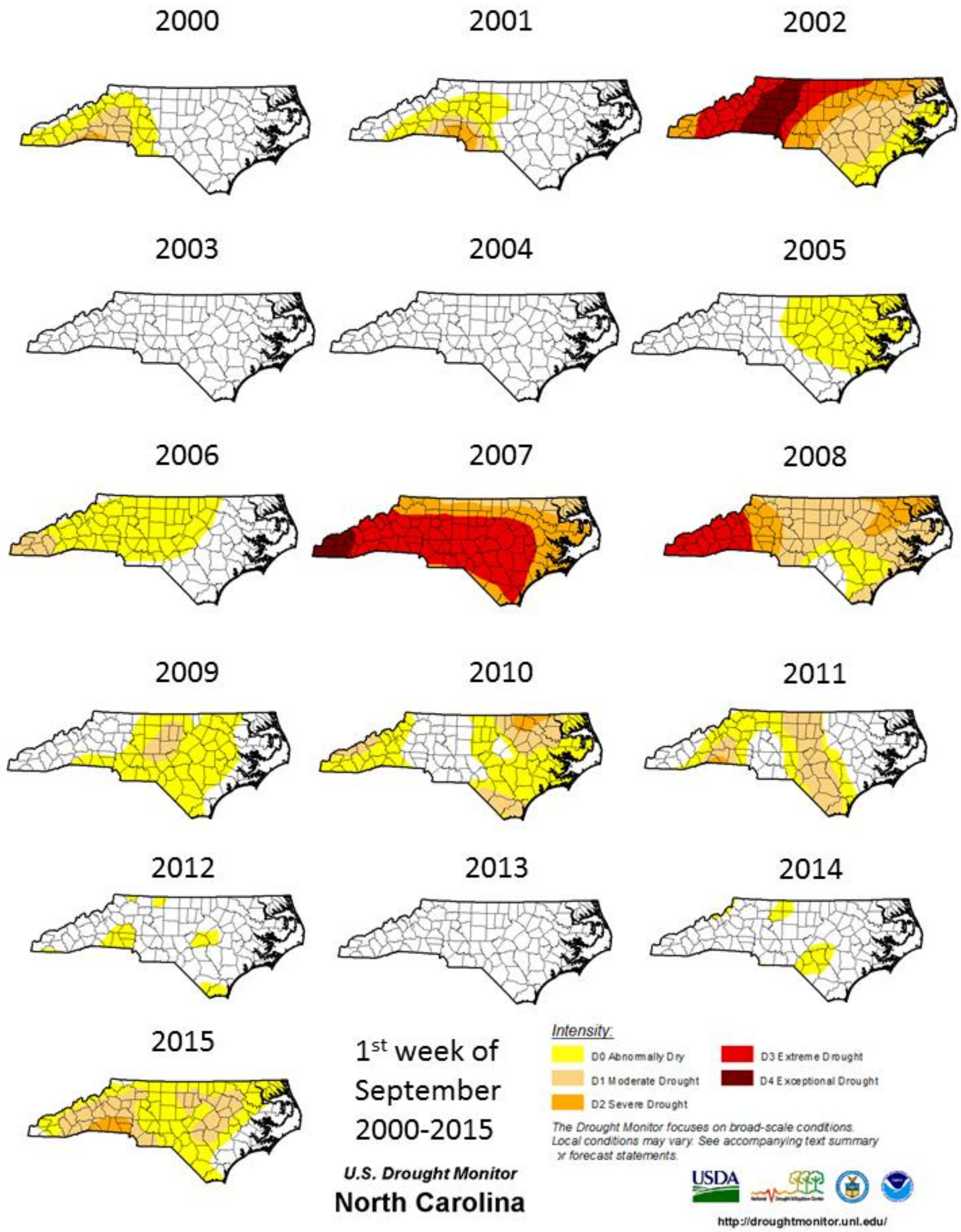


Figure 3-9 North Carolina Drought Monitor annual images for 1st week in September

Substrate and Cover – For breeding and sheltering, the Carolina Madtom requires cover for nest sites – this cover can be from cans, bottles, mussel shells, boards, flat rocks, logs, and even tires. Midway et al. (2010, entire) documented prevalent cover habitat in both the Neuse and Tar River basins, thus cover habitat for breeding is not likely a limiting factor for madtoms. In addition, optimal substrate for the Carolina Madtom is predominantly silt-free, stable, gravel and cobble bottom habitat. Riparian condition strongly influences the composition and stability of substrates that fish 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 fish 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 et al. 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, and the construction of Falls Lake dam in the upper Neuse is an example of habitat fragmentation that isolated Carolina Madtoms in the upper basin from the middle Neuse basin. 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 madtoms, fragmentation can result in loss of access to quality habitat for one or more life stages, such as preventing resident fish from moving among habitats, thus potentially impacting overall distributions. Barriers to movement can cause isolated or patchy distributions of fish which may limit both genetic exchange and recolonization (e.g., after a high flow, scouring event barriers can limit upstream repopulation). To assess the influence of factors affecting Carolina Madtom habitat connectivity, 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 Carolina Madtom habitat (see Section 4.1 below).

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 Carolina Madtom can be described in terms of River Basin Variability and Physiographic Variability. Below we examine these aspects of the historic and current distribution of the Carolina Madtom and identify potential causal effects for changes in representation over time.

River Basin Variability – As a narrow endemic species, the Carolina Madtom has a very restricted range, historically occurring in 3rd and 4th order perennial streams in the Tar and Neuse (including the Trent) River basins. The species has experienced loss in the Neuse basin, including presumed extirpation from the Trent River system. Current occurrences of the madtom are centered primarily in the upper Tar River basin (inclusive of the Upper Tar River, Sandy-Swift Creek, and Fishing Creek subbasin, see Figure 3-2) as well as the upper Little River in the Neuse River basin. While the species maintains presence in two river basins, distribution variability is significantly reduced in the Neuse basin with four of the five MUs likely extirpated, Table 3-1); the species has lost nearly 67% of its River Basin Variability. It should be noted that this is a relatively conservative estimate of loss as variability for each population is largely represented by just one HUC per MU (Table 3-2 below).

Table 3-1 Carolina Madtom Basin Variability. "Current" is defined by observations during surveys in the past 5 years (2011-2016).

Population/ Management Unit	# of Historically Occupied MUs	# of Currently Occupied MUs	% Decline
Tar	5	3	40
Neuse	5	1	80
Trent	1	0	100

Physiographic Variability – The Carolina Madtom is found in two physiographic provinces – the eastern Piedmont and Coastal Plain; the majority of extant Carolina Madtom occurrences are clustered around the Fall Line (see Figure 3-2), with most in the Coastal Plain portions of the basins. Monitoring data indicate precipitous declines in occurrence in both physiographic regions. A 86% decline in occurrence was estimated in the Coastal Plain Province, and 44% decline in the Piedmont (Figure 3-9). The species has been almost completely eliminated from its once much larger presence in the Coastal Plain. There are no remaining Piedmont occurrences of the species in the Neuse River basin.

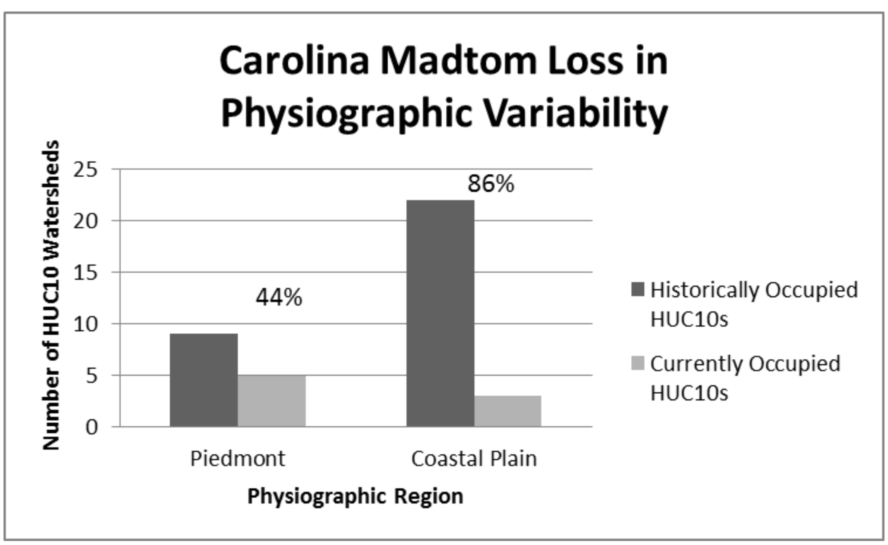


Figure 3 9 Change in physiographic variability for Carolina Madtom. Percentages are the proportion lost from historically occupied HUC10s to currently occupied HUC10s.

Summary
As evaluated through the lens of river basin and physiographic province, the contemporary distribution of Carolina Madtom reflects a considerable loss in historical 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 Carolina Madtom 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 Carolina Madtom populations were once much more broadly distributed throughout their historical range (Figure 3-1). However, several factors, including impoundments (e.g., Falls Reservoir, Milburnie Dam, and Buckhorn Reservoir), unsuitable water quality (e.g., the Neuse River downstream from the City of Raleigh's wastewater treatment plant discharge), and expansion of invasive Flathead Catfish have resulted in population fragmentation (see Chapter 4), making repopulation of extirpated locations unlikely without human intervention.

We assessed Carolina Madtom 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 level. This assessment revealed that of the 31 HUC10s historically occupied by Carolina Madtom, only 8 (26%) are currently occupied (Table 3-2). Note that current occupancy was defined as the observation of at least one Carolina Madtom during surveys conducted from 2011 to 2016. Of those 8 HUC10s that were counted as occupied, only seven had more than one observation during that 5-year sample period (Table 3-2). At the level of MUs, seven are likely extirpated, two have experienced an estimated 25-50% decline, and two have experienced no decline (Table 3-2).

Table 3-2 Carolina Madtom occupancy changes over time. Historical occupancy represents detections that occurred from 1960 to 2010, while current occupancy represents a sample period from 2011 to 2016. 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
Tar	**13**	**7**	**46**
Upper Tar*	2	2	0
Middle Tar	3	0	100
Lower Tar	2	0	100
Fishing Ck Subbasin*	4	3	25
Sandy-Swift*	2	2	0
Neuse	**16**	**1**	**94**
Upper Neuse	1	0	100
Middle Neuse	6	0	100
Lower Neuse	4	0	100
Little River	2	1	50
Contentnea	3	0	100
Trent	**2**	**0**	**100**
* MUs with more than one observation in last 5 years			

3.4 Current Conditions

The results of surveys conducted from 2011 to 2016 suggest that the currently occupied range of the Carolina Madtom includes four MUs from two populations in the Tar and Neuse River basins in North Carolina, however only one population (Tar) has multiple documented occurrences within the past 5 years. The species has been extirpated from the southern portion of its range, including a large portion of the Neuse River basin and the entire Trent River basin. For context, Table 3-3 shows the current species status as tracked by national and state entities that track conservation status of species:

Table 3-3 Current species status/ranks by other entities who track conservation status of Carolina Madtom

Entity	**Status/Rank**	Notes	Reference
NatureServe	G2N2 (Imperiled)		NatureServe 2015
IUCN	NT (Near Threatened)	Trend over the past 10 years or three generations is uncertain, but distribution and abundance probably are slowly declining.	IUCN 2001
American Fisheries Society (AFS)	T (Threatened)	Status declined since 1989	AFS 2008, p.394
North Carolina	Threatened/S2 (Imperiled)		NC Scientific Council on Fishes 2010; NCNHP 2014

3.4.1 Current MU/Population Resiliency

Methodology

To summarize the overall current conditions of Carolina Madtom MUs, we sorted them into five categories (high, moderate, low, very low, and null (ø)) based on the population factors and habitat elements discussed in Section 3.3.1 above (Table 3-4). Included in this summary are areas where the species is presumed to be extirpated to show the entire 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 Reproduction) 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 Fishing Creek Subbasin MU, given the categorical scale of: High – Moderate – Low – Very Low – ø (see Table 3-4), the overall Current Population Condition is estimated to be *Moderate* (Figure 3-10); the *High* MU Occupancy Condition combined with the *Low* Approximate Abundance Condition is *Moderate* and when that is combined with the *Low* Reproduction condition, the overall ranking becomes *Moderate*:

Population/ Management Unit	MU Occupancy Condition		Approx Abundance Condition		Reproduction Condition	**Current Condition - Population Factors**
Tar/Fishing Creek Subbasin	**H**	**+**	**L**		**L**	
		M		+	L	
			M			**Moderate**

Figure 3-10 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 Upper Tar MU, the overall Current Habitat Condition was determined by first combining the *High* Instream Habitat Condition with the *Low* Water Quantity Condition to get *Moderate*; when this *Moderate* was then combined with the *Moderate* Connectivity Condition and the *Moderate* Water Quality Condition, the three *Moderate* ranks combine to get an overall Current Habitat Condition of *Moderate* (Figure 3-11):

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

Figure 3-11 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 Carolina Madtom 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 3-6 displays the presumed ranges of probabilities of persistence of a population with a given current condition category over 10 years (about 3 generations of the Carolina Madtom). These ranges were not calculated; instead they serve to communicate what the experts mean when describing the current condition of a population. Because the "high" condition category does not represent a reference condition (i.e., a condition that implies the absence of significant human disturbance or alteration), the probability of persistence for "high" condition was determined to be 40-70% (Table 3-6).

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/Flowing Water	Habitat Elements: Streamside Condition (in-stream substrate condition)	Habitat Elements: Habitat Connectivity
High	<30% decline	Cumulative numbers at high end of known range (over 100 individuals observed over time); and large numbers (10+) of individuals seen during recent (past 5-years) targeted surveys	More than 50% of sites with recent (past 5 years) documentation of reproduction (gravidity) or presence of small (<40mm) individuals	Very few (if any) known impairment or contaminant problems (<15 miles impaired streams; no major discharges, <25 non-major discharges)	Optimal flowing water conditions to remove fine sediments, sustain prey items, and allow optimal movement; no known flow issues; fewer than two consecutive drought years	Predominantly natural (>60% 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	51 to 100 individuals observed over time; large numbers (10+) of individuals seen during recent (past 5-years) targeted surveys	25-50% of sites with recent documentation of reproduction or presence of small (<40mm) individuals	Impairment or contaminants known to be an issue, but not at a level to put population at risk of being eliminated (15-50 miles impaired streams; 1-3 major discharges; 25-100 non-major discharges)	Water flow not sufficent to consistently remove fine sediments, drying conditions which could impact both prey base and successful movement; moderate flow issues; no more than two consecutive drought years	30-60% 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	Small numbers (10-50) seen during recent (past 5-years) targeted surveys; or less than 10 individuals observed over time	Fewer than 25% of sites with recent documentation of reproduction or presence of small (<40mm) individuals	Impairment or contaminants at levels high enough to put the population at risk of being eliminated (>50 miles impaired streams; >4 major discharges; 100+ non-major discharges)	Water not flowing - either inundated or dry; severe flow and drought issues; three or more consecutive drought years	<30% 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 5 years	Reproduction data are older than 10 years; or no evidence or known information about reproduction	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	None observed over time	Population is extirpated	N/A	N/A	N/A	N/A

Table 3-5 Resiliency of Carolina Madtom populations. See Table 3-4 for condition categories. Data for categorization are found in Appendix C.

	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**
Tar				Moderate					Moderate	Moderate
Upper Tar	High	Low	Low	Low	Moderate	Low	Moderate	High	Moderate	Low
Middle Tar	Ø	Low	Ø	Ø	Low	Moderate	Moderate	Moderate	Moderate	Ø
Lower Tar	Ø	Low	Ø	Ø	Moderate	Moderate	High	Low	Moderate	Ø
Fishing Ck Subbasin	High	Low	Low	Moderate	Moderate	Low	High	Moderate	Moderate	Moderate
Sandy-Swift	High	Moderate	Moderate	High	High	Moderate	Moderate	Moderate	Moderate	High
Neuse				Very Low					Low	Very Low
Upper Neuse	Ø	Very Low	Ø	Ø	Low	Low	Moderate	Moderate	Low	Ø
Middle Neuse	Ø	Very Low	Ø	Ø	Low	Low	Low	Low	Low	Ø
Lower Neuse	Ø	Very Low	Ø	Ø	Low	Moderate	Moderate	Low	Low	Ø
Little River	Low	Low	Very Low	Low	Moderate	Low	Moderate	Moderate	Moderate	Low
Contentnea	Ø	Low	Low	Ø	Low	Low	High	Low	Low	Ø
Trent				Ø					Moderate	Ø
Trent	Ø	Very Low	Ø	Ø	High	Moderate	High	Moderate	Moderate	Ø

Table 3-6 Presumed probability of persistence for current condition categories.

Likelihood of Persistence:	**High**	**Moderate**	**Low**	**Very Low**	**Ø**
Range of Presumed Probability of **Persistence** over 10 years (~3 generations)	40-70%	10-40%	<10%	<10%	0%
* Generation time for CMT is ~3years					

Combined habitat elements, representing overall habitat condition, were moderate in seven MUs, and low in four MUs (Table 3-4). Combined population factors, representing a combination of occupancy, approximate abundance, and reproduction, was estimated to be high for one MU, moderate for one MU, low for two MUs, and likely extirpated for seven MUs (Table 3-4). As noted in Section 3.3.1, both approximate abundances and reproduction should be considered conservative estimates.

At the population level, the overall current condition (= resiliency) was estimated to be moderate for the Tar Population, very low for the Neuse population, and likely extirpated for the Trent Population (Table 3-4; Figure 3-12).

3.4.2 Current Species Representation

We estimated that the Carolina Madtom currently has low adaptive potential due to limited representation in two river basins and two physiographic regions (Figure 3-12). The species retains 33% of its known River Basin variability, considering greatly reduced variability observed in the Neuse River population. In addition, compared to historical occupancy, the species currently retains very limited Physiographic Variability in the Coastal Plain (14%) and moderate variability in the Piedmont (56%).

3.4.3 Current Species Redundancy

The range of the Carolina Madtom has always been very narrow – limited to the Tar and Neuse River drainages (with the Trent River Subbasin considered functionally a separate drainage). Within the identified representation areas, the species retains redundancy within the Tar River population (3 MUs currently extant), however it has no redundancy (only 1 MU extant in the Neuse River population and no redundancy (extirpated) in the Trent River population. Overall, the species has lost 64% of its redundancy across its narrow, endemic range.

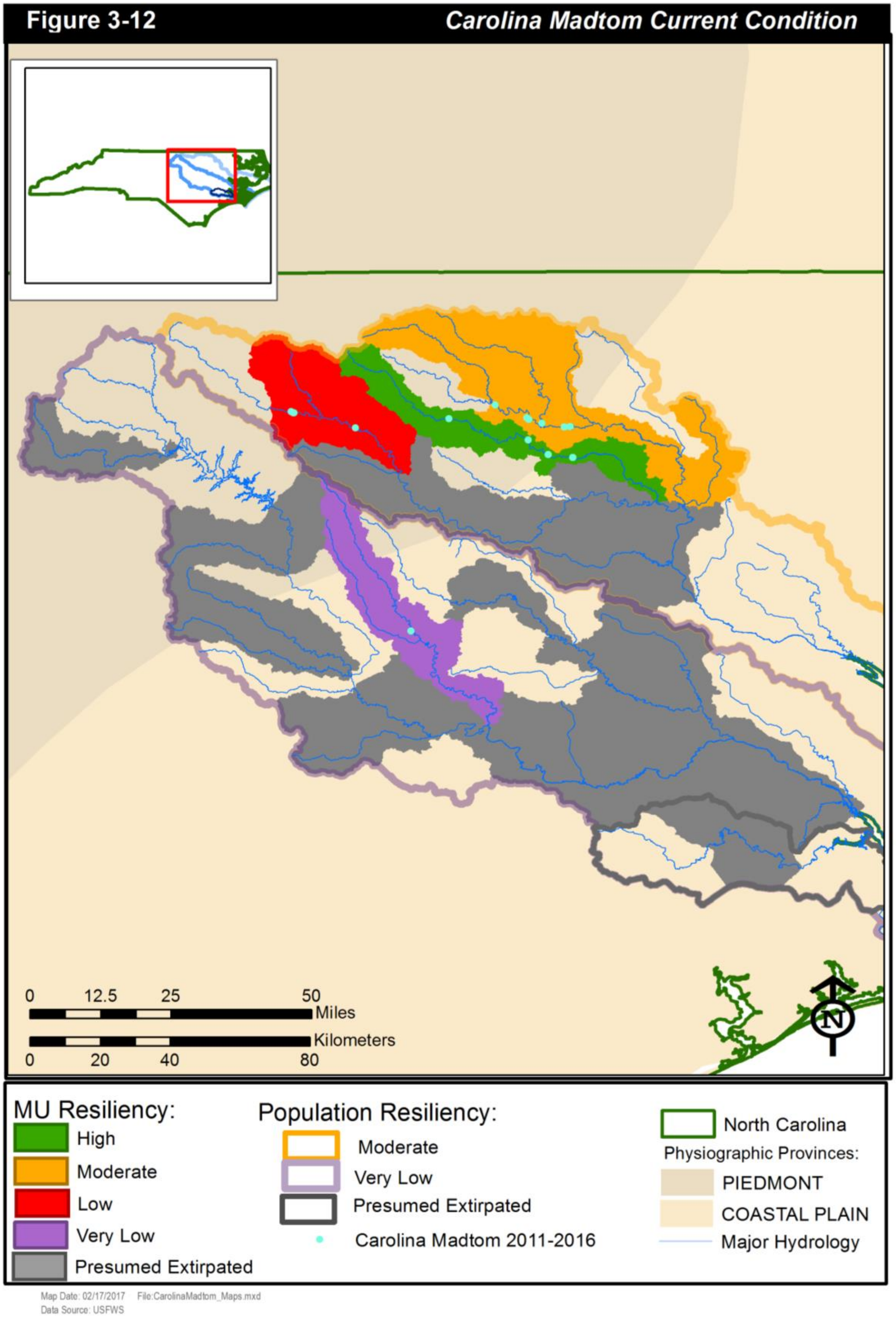


Figure 3-12
Carolina Madtom Current Condition
0
12.5
25
50
Miles
Kilometers
0
20
40
80
N
MU Resiliency:
High
Moderate
Low
Very Low
Presumed Extirpated
Population Resiliency:
Moderate
Very Low
Presumed Extirpated
Carolina Madtom 2011-2016
North Carolina
Physiographic Provinces:
PIEDMONT
COASTAL PLAIN
Major Hydrology
Map Date: 02/17/2017 File:CarolinaMadtom_Maps.mxd
Data Source: USFWS

CHAPTER 4 - FACTORS INFLUENCING VIABILITY

In this chapter, we evaluate the past, current, and future factors that are affecting what the Carolina Madtom needs for long term viability. Aquatic systems face a multitude of natural and anthropogenic threats and stressors (Neves et al. 1997, p.44). The North Carolina State Wildlife Action Plan has identified several factors that have impacts on habitats (NCWRC 2015; Table 4-1). Generally, the factors can be categorized as either environmental stressors (e.g., development, agriculture practices, or forest conversion/management) or systematic changes (e.g., climate change, invasive species, barriers, regulatory frameworks), or conservation management practices (Figure 4-1).

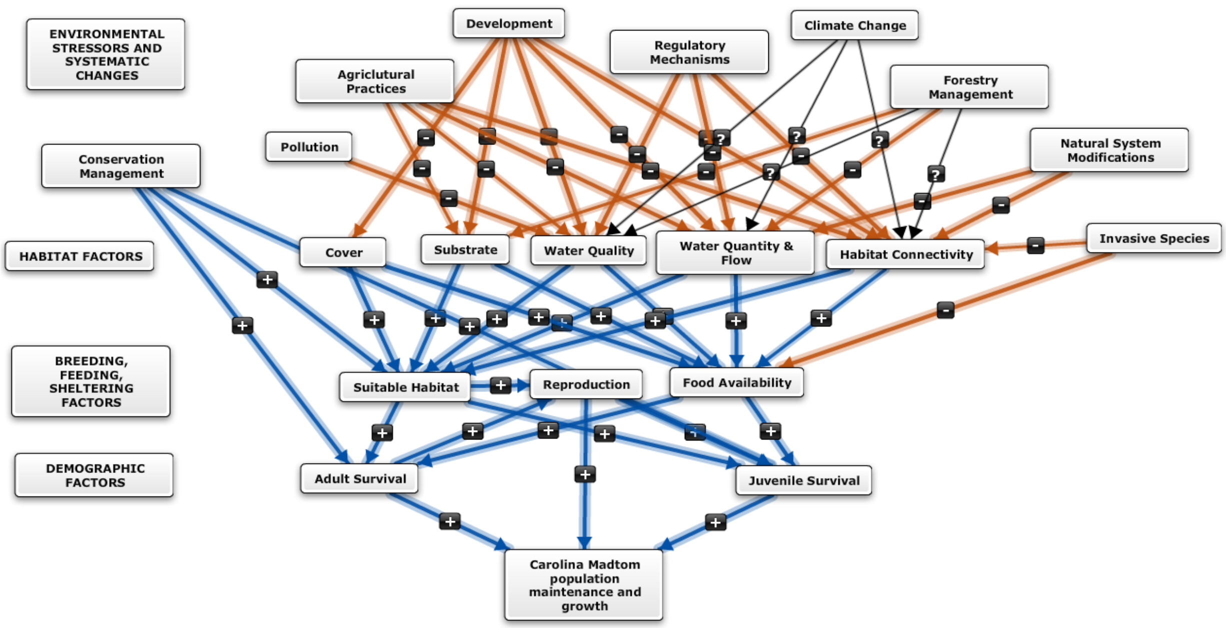


Figure 4-1 Influence diagram illustrating how environmental stressors and systematic changes influence habitat factors which in turn influence breeding, feeding, and sheltering needs of the species; in turn, these affect demographic factors which ultimately influence madtom population growth and maintenance.

Current and potential future effects, along with current expected distribution and abundance, determine present viability and, therefore, vulnerability to extinction. Detailed information is provided for those factors that ranked as “high” or “very high” as Wildlife Action Plan Conservation Concerns for the Carolina Madtom, with the addition of information about regulatory frameworks and climate change. Those factors that are not known to have effects on Carolina Madtom populations, such as overutilization for commercial and scientific purposes and disease, are not discussed in this SSA report.

Table 4-1 Threats to Carolina Madtom as listed in the North Carolina State Wildlife Action Plan (SWAP), including Conservation Concern Score and Scope and Severity categorizations for each threat (NCWRC 2015, Chapter 5).

SWAP Metric:	**Conservation Concern Score**	Scope*	Severity**
Development	VERY HIGH	PERVASIVE	EXTREME
Agriculture & Forestry	HIGH	LARGE to PERVASIVE	SERIOUS to EXTREME
Energy & Mining	LOW	UNKNOWN to LARGE	UNKNOWN to SERIOUS
Transportation	LOW	RESTRICTED	MODERATE
Biological Resource Use	LOW	UNKNOWN to SMALL	UNKNOWN to SLIGHT
Human Intrusions & Disturbance	LOW	UNKNOWN to SMALL	UNKNOWN to SLIGHT
Natural System Modifications	VERY HIGH	PERVASIVE	EXTREME
Invasives	HIGH	LARGE to PERVASIVE	EXTREME
Pollution	HIGH	LARGE to PERVASIVE	SERIOUS to EXTREME
Climate Change	LOW	UNKNOWN to LARGE	UNKNOWN to MODERATE
Disease & Pathogens	UNKNOWN	UNKNOWN	UNKNOWN

***SCOPE**
(a) Pervasive   Affects all or most (71-100%) of the total population or occurrences
(b) Large   Affects much (31-70%) of the total population or occurrences
(c) Restricted   Affects some (11-30%) of the total population or occurrences
(d) Small   Affects a small (1-10%) proportion of the total population or occurrences
(e) Unknown   There is insufficient information to determine the scope of threats
(f) None
****SEVERITY**
(a) Extreme   Likely to destroy or eliminate occurrences, or reduce the population 71-100%
(b) Serious   Likely to seriously degrade/reduce affected occurrences or habitat or reduce the population 31-70%
(c) Moderate   Likely to moderately degrade/reduce affected occurrences or habitat or reduce the population 11-30%
(d) Slight   Likely to only slightly degrade/reduce affected occurrences or habitat, or reduce the population 1-10%
(e) Unknown   There is insufficient information to determine the severity of threats
(f) None

4.1 Development & Pollution

We use the term "development" to refer to urbanization of the landscape, including (but not necessarily limited to) land conversion for urban and commercial development, infrastructure (roads, bridges, utilities) development, and urban water uses (water supply reservoirs, wastewater treatment, etc.). The effects of urbanization 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 slow seepage into streams (Brabec et al. 2002, p.499; NHEP 2007, p.2). Instead, the rain water accumulates and flows rapidly into storm drains which drain as runoff to local streams (Figure 4-2).

Impervious results in degradation of stream habitats 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 during storm events.
3. Water Temperature: During warm weather, rain that falls on impervious surfaces becomes superheated and can stress or kill freshwater species when it enters streams.

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 20013, p.1). The resulting stormwater runoff affects water quality parameters such as temperature, pH, dissolved oxygen, salinity, and turbidity which in turn alters the water chemistry potentially making it inhospitable for aquatic biota (Figure 4-3.).

Figure 4-2 Rain becomes stormwater runoff to local streams (Credit: NCDENR)

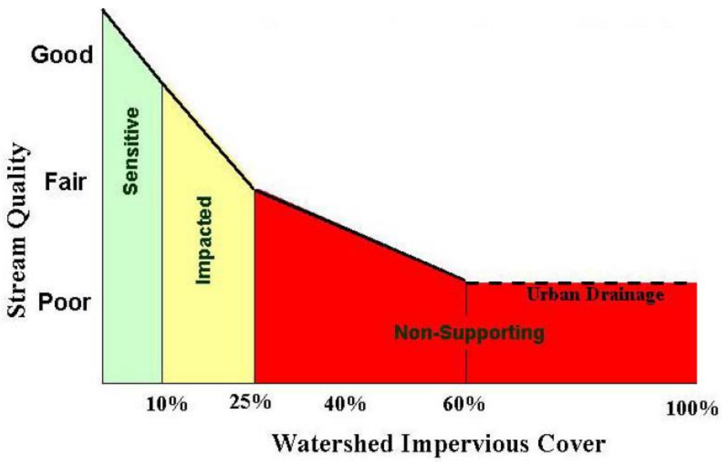


Figure 4-3. Stream Quality is adversely impacted by increased impervious surfaces (from CWP 2003, p.2)

Madtoms prefer clean water with permanent flow and are not tolerant of siltation and turbidity (Midway 2008, p.4). Benthic fish such as the madtom have disproportionate rates of imperilment and extirpation because stream bottoms are often the first habitats affected by pollution (Midway et al. 2010, p.325). Furthermore, the Carolina Madtom is classified as an "intolerant" species according to the NC Division of Water Resources, meaning the species is most affected by environmental perturbations (NCDWR 2013, p.19).

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). 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 ultimately reduces feeding, spawning, and living spaces of the Carolina Madtom and other aquatic biota living in the streams (Giddings et al. 2009, p.1).

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).

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

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

A major component 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). These changes affect stream-dwelling organisms such as the Carolina Madtom by displacing them from once preferred, but now polluted habitats, as well as increasing exposure and assimilation of pollutants that can result in growth defects, decreased immune response, and even death. 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 such as Carolina Madtoms cannot pass through them.

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 NC, including significant Carolina Madtom habitats in the Tar and Neuse 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 vehicles from the ROW (which destroy instream habitat).

All three of the river basins within the range of the Carolina Madtom are affected by development, from an average of 7 percent in the Tar River Basin to an average of 13 percent in the Neuse River Basin (based on the 2011 National Land Cover Data). The Neuse River Basin contains one-sixth of the entire State's population, indicating heavy development pressure on the watershed. Furthermore, the Middle Neuse MU contains 182 impaired stream miles, 9 major discharges, 272 minor discharges, and nearly 4,000 road crossings, affecting the quality of the habitat for the species. The Middle Neuse is also 31% developed, with nearly 8 percent impervious surface, changing natural streamflow, reducing appropriate stream habitat, and decreasing water quality throughout the population. For complete data on all of the populations, refer to Appendices A and C.

4.2 Agricultural Practices

Nutrient and Chemical Pollution

Farming operations can contribute to nutrient pollution when not properly managed (EPA 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 in the proper amount, 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 or groundwater. 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. For fish like the Carolina Madtom, excess ammonia can cause a number of problems, from alteration of metabolism to injury to gill tissue to reduced growth rates and extreme levels can cause death (Oram 2014, p.2)

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, thus potentially resulting in dewatering of channels and displacement of fish.

Agriculture Exemptions from Permit Requirements

Normal farming, silviculture, and ranching activities are exempt from the CWA 404 permitting process (USEPA 2017, p.1). 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 US ACE 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 (E.Wells (USFWS) email to S.McRae (USFWS) on 5/13/2016).

Confined Animal Feeding Operations

Confined Animal Feeding Operations (CAFOs) and feedlots can cause degradation of aquatic ecosystems, primarily because of manure management issues (Burkholder et al. 2007, p.308). CAFOs hold tens of thousands of animals and produce a large amount of waste which enters the environment either by being discharged directly into streams or constructed ditches, stored in open lagoons, or applied to fields in wet or dry form (as referenced by Buckner et al. 2002, Mallin and Cahoon 2003, and Orlando 2004 in CBD 2010, p.18). CAFO wastes contain nutrients, pharmaceuticals, and hormones, and cause eutrophication of waterways, toxic blooms of algae and dinoflagellates, and endocrine disruption in downstream wildlife (Mallin and Cahoon 2003, p.369; Orlando et al. 2004, p.353).

The number of CAFOs in the southeast has increased drastically since 1990 as livestock production has undergone extensive industrialization (Mallin and Cahoon 2003, p.371). As shown in Figure 4-7, poultry CAFOs are also abundant in North Carolina, and there are many swine CAFOs in the Coastal Plain; North Carolina is now the nation's second largest pork producer (as referenced in CBD 2010, p.18).

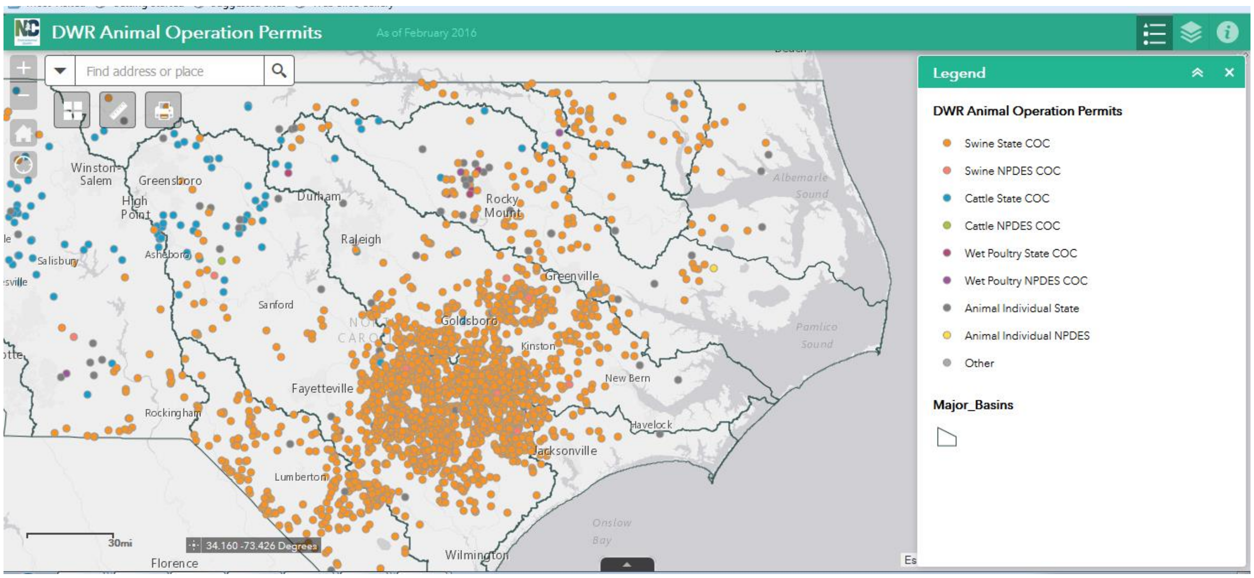


Figure 4-7 CAFO locations in eastern North Carolina from the NC Division of Water Resources website (accessed: 11/22/2016)

According to the 2011 National Land Cover Data, all of the watersheds within the range of the Carolina Madtom are affected by agricultural land uses, with the Lower Tar, Lower Neuse, Little River and Contentnea Creek MUs having around 40 percent or more of the watershed converted for agricultural use.

4.3 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.

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;
- 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).

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

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

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, p.107). 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).

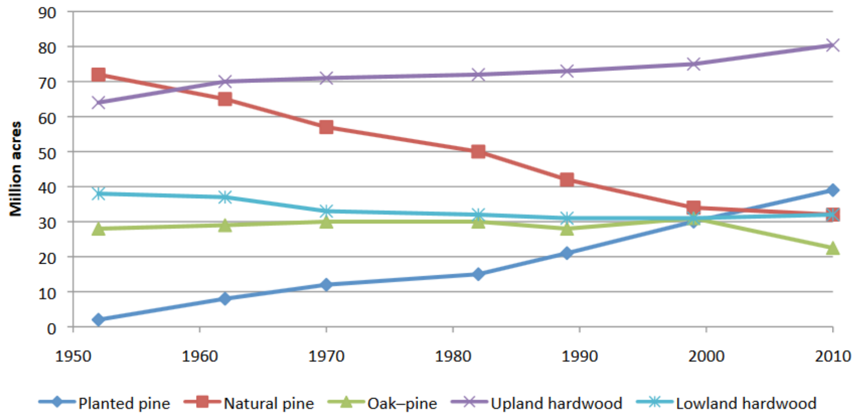


Figure 4-8 Historical trends in forest area by broad management type, showing an increase in planted pine over the past half-century (from Wear and Greis 2012, p.13)

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 (Kishi et al. 2004, p.283; Couceiro et al. 2007, p.272; 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.

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)

	Range of Implementation Rates in SE States		Average Implementation Rate
BMP Category	SGSF (2012)[1]	NASF (2015)[2]	(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).

4.4 Invasive Species

The South Atlantic seaboard has many native species that are declining and nonnative nuisance species are one of the major causes for these declines. 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 North Carolina 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.

The Flathead Catfish is an invasive species that likely has a significant impact on Carolina Madtom distribution, especially in the Neuse River Basin. The Flathead Catfish is an obligate piscivore and apex predator, known to influence native fish populations, including predation on bullheads and madtoms (Pine et al. 2005, p.901; NCANSMPC 2015, p.75; Figure 4-9), and it occurs in both the Neuse and Tar River basins. The Flathead Catfish has been intentionally introduced into several river basins in NC, including the Neuse River Basin in the early 1980s (USFWS 2014, pp.1-2). The Flathead Catfish became the dominant predator in the Cape Fear drainage, just south of the Neuse River Basin, within 15 years of the introduction and a severe decline in native fish species, particularly native bullhead species, was observed in the Cape Fear River within 15 years of the first Flathead Catfish introduction (as referenced in USFWS 2014, p.7).

Figure 4-9 Flathead catfish eating another catfish (credit: J.Raabe)

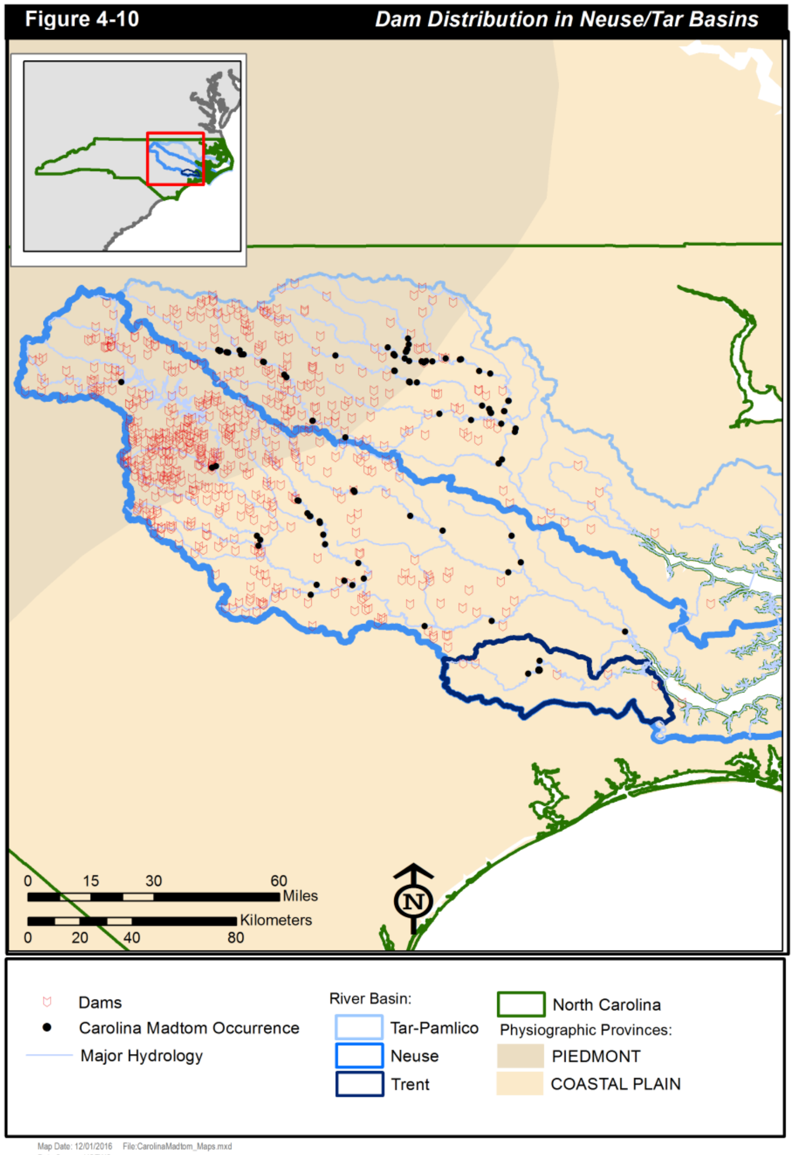
Hydrilla is an aquatic plant that alters stream habitat, decreases flows, and contributes to sediment buildup in streams (NCANSMPC 2015, p.57). High sedimentation can cause suffocation and reduce stream flow necessary for madtom survival. Hydrilla occurs in several watersheds where the Carolina Madtoms occur, including recent documentation from the Neuse system and the Tar River. The dense growth is altering the flow in these systems and causing sediment buildup, which alters the habitat for the Carolina Madtom. While data are lacking on Hydrilla currently having population-level effects on the madtom, the spread of this invasive plant is expected to increase in the future.

4.5 Dams and Barriers (Natural System Modifications)

Extinction/extirpation of some North American freshwater fish 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 fish and their overall reproductive success.

- Downstream of dams – fluctuations in flow regimes, minimal releases and scouring flows, seasonal dissolved oxygen depletion, reduced water temperatures, and changes in fish assemblages.



Dams have also been identified as causing genetic segregation/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. Figure 4-10 shows the distribution of dams across the known range of the Carolina Madtom.

Interestingly, recent studies have shown that some mussel and fish 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 toxins, 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 segregation of the aquatic species inhabiting the streams.

4.6 Regulatory Mechanisms

State Endangered Species Law

North Carolina has state-level legislation modeled after the federal Endangered Species Act: the North Carolina Endangered Species Act was enacted in 1987. Animal species that are protected by the state laws are regulated by the state wildlife agency, the North Carolina Wildlife Resources Commission. The state endangered species protection law allow the state wildlife agency to identify, document, and protect any animal species that is considered rare or in danger of extinction. Illegal activities include taking, transporting, exporting, 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 where recommendations, not requirements, can be made for lands to be protected or acquired (Pellerito 2002, Snape and George 2010, p.346).

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 sediment and pollution from rain water runoff before it enters rivers, streams, wetlands, and marshes. North Carolina had buffer requirements in specific watersheds (1997-2015), including the Tar-Pamlico and Neuse, 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 2016a, entire)).

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/water features are issued by the U.S. 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 as what is 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, Carolina Madtoms may be more susceptible to some pollutants than the test organisms commonly used in bioassays. Despite existing authorities such as the Clean Water Act, pollutants continue to impair the water quality throughout the current range of the Carolina Madtom. 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 species' 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 important habitats for species like the Carolina Madtom. In the past six years (since 2010), there have been several changes to state regulations, known as "Regulatory Reform" and in 2016, the changes are described in legislation titled: "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 review. 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 2016b, 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 and Tar-Pamlico river basins (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 CWA 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 Carolina Madtom, 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.

4.7 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.

Droughts have impacted all river basins within the range of the madtom, from an "abnormally dry" ranking for North Carolina in 2001 on the Southeast Drought Monitor scale to the highest ranking of "exceptionally dry" for the entire range of the species in 2002 and 2007. The 2015 drought data indicated a range of "abnormally dry" to "moderate drought" (Figure 3-9). These data are from the first week in September, indicating a sensitive time for drought to be affecting the species. The Middle Neuse tributaries of the Neuse River basin had consecutive drought years from 2005-2012, indicating sustained stress on the species over a long period of time. The madtoms have limited refugia from disturbances such as droughts and floods, and they are completely dependent on specific water temperatures to complete their physiological requirements. Changes in water temperature lead to stress, increased mortality, and also increase the likelihood of extinction for the species (Poff et al. 2002, pp. ii-v).

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 in North Carolina. Land Trusts are targeting key parcels for acquisition, federal, state, and University biologists are surveying and monitoring species occurrences, and recently there has been increased interest in efforts to consider captive propagation and species population restoration via augmentation, expansion, and reintroduction efforts.

4.9 Summary

Of the past, current, and future influences on what the Carolina Madtom needs for long term viability, the largest factors affecting the future viability of the species relate to habitat degradation from stressors influencing water quality, water quantity, instream habitat, and habitat connectivity (Table 4-4). 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 Carolina Madtom 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 Carolina Madtom MUs and populations, and the viability of the species overall.

Table 4-4 Summary of Factors affecting Carolina Madtom viability and whether they influence Habitat Elements ("x" indicates an influence of a factor on the habitat element)

		Habitat Element			
		Water Quality	Water Quantity	Connectivity	Substrate & Cover
Factor	Development	x	x	x	x
	Agricultural Practices	x	x	x	x
	Forest Conversion/Management	x	x	x	x
	Invasive Species	x		x	x
	Dams and Barriers	x	x	x	x
	Regulatory Mechanisms	x	x	x	x
	Climate Change	x	x	x	x
	Conservation Measures	x	x	x	x

CHAPTER 5 – FUTURE CONDITIONS

Thus far, we have considered Carolina Madtom 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 Carolina Madtom.

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 Carolina Madtom 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 Carolina Madtom populations.

To forecast future urbanization, we developed future scenarios that incorporate the SLEUTH (<u>S</u>lope, <u>L</u>and use, <u>E</u>xcluded area, <u>U</u>rban area, <u>T</u>ransportation, <u>H</u>illside 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), and as mentioned above, is in line with the Southeast being the fastest growing region in the country.

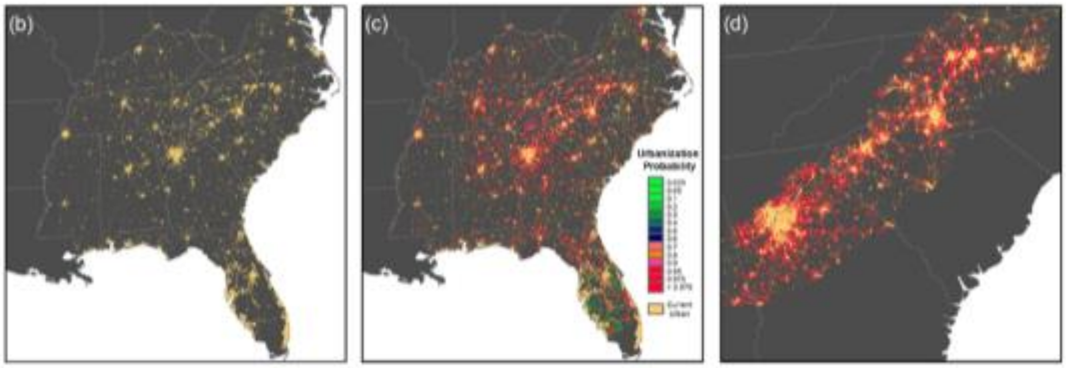


Figure 5-1 "Business-as-usual" urbanization scenario for the Southeast US from Terando et al. 2014, p.3. Red areas are the urban extent as classified by their methodology. (b) is the initial urban land cover in 2009; (c) is the projected urban land cover in 2060; and (d) is the projected urban land cover 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 Carolina Madtom. Consequently, water quality and quantity will likely decline, habitat connectivity will become more fragmented, and instream substrate habitat may become less suitable for the species to survive. As such, urban sprawl will, almost certainly, influence the ability of the 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).

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).

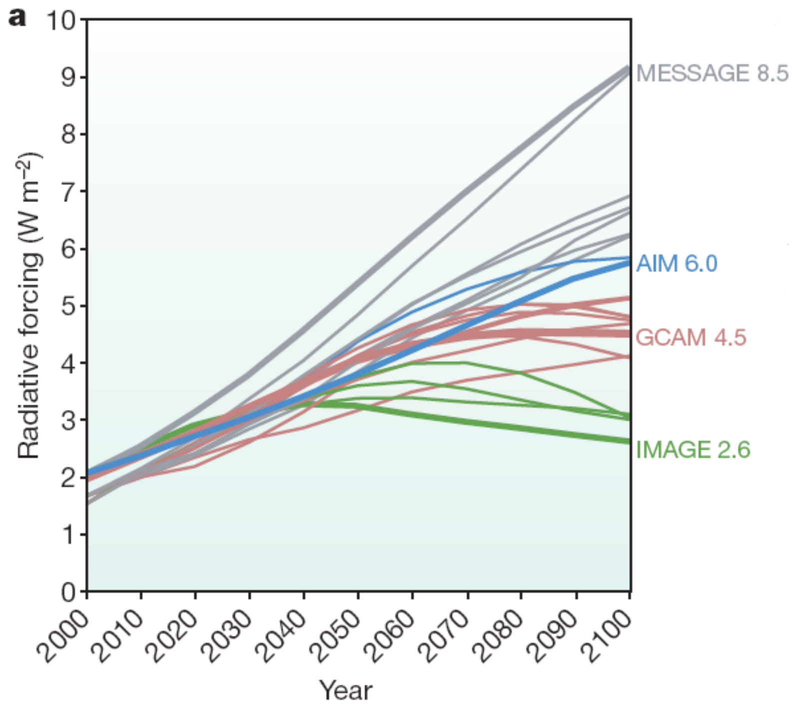


Figure 5-2 Changes in radiative forcing relative to pre-industrial conditions. Bold colored lines show the four RCPs; thin lines show individual scenarios from approximately 30 candidate RCP scenarios that provide information on all key factors affecting radiative forcing (from Moss et al., 2010).

RCP2.6, the low trajectory pathway, 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, the high trajectory pathway, 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, the intermediate pathways, 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 biotic assemblages by altering the abiotic conditions 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 Carolina Madtom.

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; Table 4-1), climate change is seen as a "low" threat to the Carolina Madtom, with Unknown to Large Scope (affecting up to 70% of the total population or occurrences) and Unknown to Moderate Severity (likely to only slightly degrade/reduce affected occurrences or habitat, or reduce the population by up to 30%). 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 Carolina Madtom 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 RCP8.5 and RCP2.6 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, Figure 5-3)
- Increased heavy precipitation events (e.g., flooding)
- More intense storms (e.g., frequency of major hurricanes increases)
- Rising sea level and accompanying storm surge

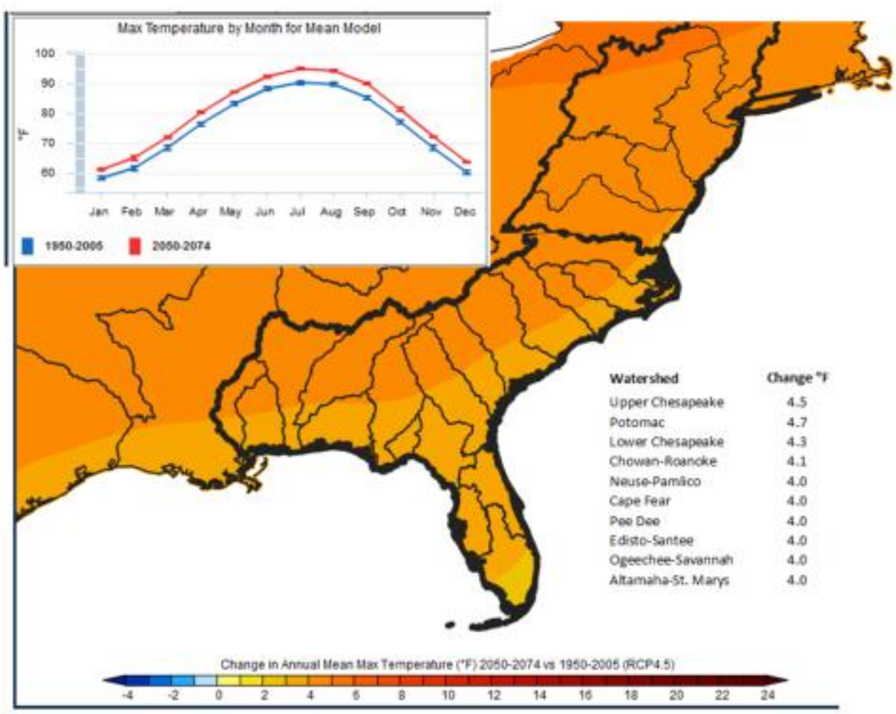


Figure 5-3 Predicted change in annual mean maximum air temperature under RCP4.5 (NCCV 2016)

5.1.1 The Scenarios

The Carolina Madtom has declined precipitously in overall distribution and abundance (see Chapter 3). The species currently occupies approximately 55% of its historical range with most remaining populations being small and fragmented, occupying sporadic reaches compared to previous historical occurrences, 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 Carolina Madtom occurs (Figure 5-4), 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 for habitat loss.

Figure 5-4 The Tar River during drought conditions in September 2008. During this period the discharge (<100 ft3/s) was lower than ever recorded (records exist back to 1931). (Credit: C. Moore, ECU)

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 Carolina Madtom, 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 the species response to changes across the landscape, we have forecasted what the Carolina Madtom 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 Carolina Madtom. 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 Carolina Madtom 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 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 that may occur. MUs in moderate condition were defined as having lower resiliency than those in high condition but are still expected to persist beyond 50 years. Populations in moderate condition have lower abundances and reduced reproductive potential than those in high condition. Finally, those MUs in low or very low condition were defined as having low/very low resiliency and may not be able to withstand stochastic events. As a result, low/very low condition MUs were predicted to be much less likely to persist 50 years into the future.

Table 5-1 Future Scenario Summary

			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 Carolina Madtom 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). This scenario also assumed that current conservation efforts would remain in place but that no new actions would be taken. Described below are how factors affecting populations, such as water quality, flow, and riparian cover are expected to change under the Status Quo scenario. Given predicted habitat conditions and current population factors (i.e., initial conditions) we then forecast Carolina Madtom viability using the 3R framework.

- Tar – Continued climate induced changes that reduce flows (NCILT 2012, p.27) are predicted to affect habitat in the Upper Tar MU, causing likely extirpation of the species; continuation of reduced water quality through utilization of basic effluent treatment technologies and reduced riparian habitat protections (see Section 4.2; Table 5-2) are predicted to result in low habitat conditions throughout the Middle Tar MU, thus species will likely remain extirpated in this MU. The Fishing Creek Subbasin is predicted to be in low condition, and the Sandy-Swift Creek MU will likely maintain moderate habitat conditions in the Status Quo scenario, but lower numbers currently seen in the Fishing Creek watershed are predicted to continue while moderate population conditions in Sandy-Swift are projected to continue into the future. The Lower Tar MU is likely to remain extirpated under the Status Quo scenario.
- Neuse – Urbanization in the Upper and Middle portions of the basin is predicted to result in continued declines in water quality from runoff (see Section 4-1) and wastewater effluent issues. Additionally, this scenario predicts declines in water quantity as the area continues to withdraw water to support continued population growth and declines in habitat connectivity by maintaining existing dam infrastructure and population-growth resulting in more road crossings. All of these factors contribute to declining instream habitat for the species. Furthermore, Flathead Catfish expansion throughout the Neuse River basin will likely continue. These factors are likely to contribute to a precipitous overall decline in conditions for the species, thus we predicted the species will be likely extirpated in this basin under the Status Quo scenario (Table 5-2).
- Trent – 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 Carolina Madtom reproduction and survival. Only the Sandy-Swift MU is predicted to remain moderately resilient, while the Fishing Creek Subbasin MU was predicted to have low resiliency at the end of the predictive time horizon (Table 5-2). All other MUs were predicted to become extirpated.

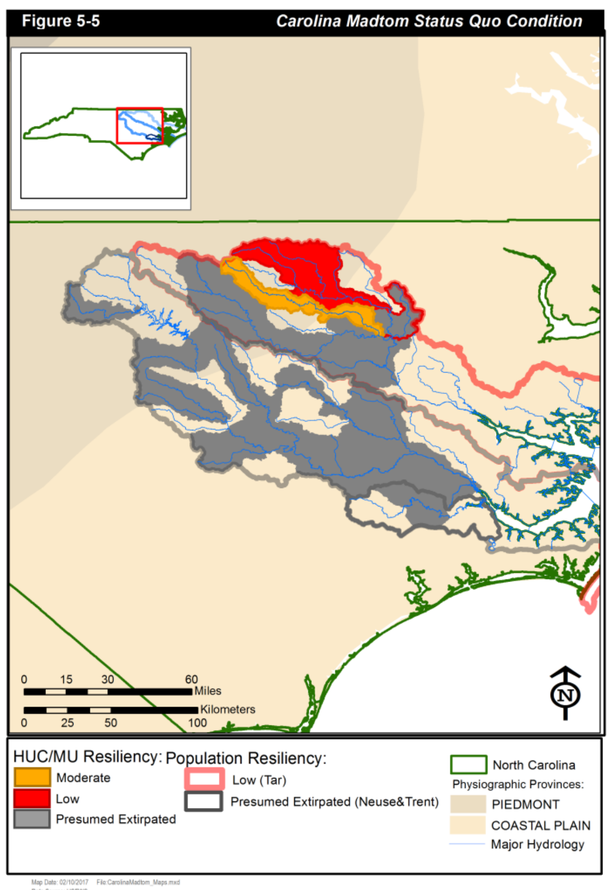
Scaling up to the population level, only one population (Tar) is expected to have low resiliency under the Status Quo scenario. All other populations (two of the three currently extant populations) of Carolina Madtom are predicted to become extirpated in 50 years under the Status Quo scenario.

Table 5-2 Carolina Madtom 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**
Tar										**Low**
Upper Tar	Ø	Ø	Ø	Ø	Moderate	Low	Moderate	Moderate	Moderate	Ø
Middle Tar	Ø	Ø	Ø	Ø	Low	Moderate	Low	Low	Low	Ø
Lower Tar	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Low	Low	Ø
Fishing Ck Subbasin	Low	Moderate	Low	Low	Moderate	Low	Moderate	Moderate	Moderate	Low
Sandy-Swift	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Neuse										**Ø**
Upper Neuse	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Middle Neuse	Ø	Ø	Ø	Ø	VLow	Low	Low	Low	Low	Ø
Lower Neuse	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Low	Low	Ø
Little River	Ø	Ø	Ø	Ø	Low	VLow	Moderate	Low	Low	Ø
Contentnea	Ø	Ø	Ø	Ø	Low	Low	High	Low	Low	Ø
Trent										**Ø**
Trent	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Moderate	Moderate	Ø

5.2.2 Representation

Given our measures of representation, including Physiographic and River Basin Variability, we predicted that the Carolina Madtom will have extremely limited representation at the end of the predictive time horizon (Figure 5-5). Under the Status Quo Scenario, the species is expected to lose 67% of its known River Basin Variability with only the Tar River Population remaining. Physiographic Variability is also expected to decline precipitously in both the Piedmont (67%) and in the Coastal Plain (89%).



5.2.3 Redundancy

Under the Status Quo scenario, we predicted that there will be only one low resiliency Carolina Madtom population with redundancy, and likely extirpation in nine of eleven MUs. This expected loss in both the number and distribution of resilient MUs is likely to make the species vulnerable to chatastrophic disturbance events.

5.3 Scenario 2 – Pessimistic

Factors that negatively influence Carolina Madtom populations (see Chapter 4) get worse under the Pessimistic scenario (Table 5-1). Reflecting Climate Model 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 5-6), more storms and flooding, and exacerbated drought conditions (IPCC 2013, p.7).

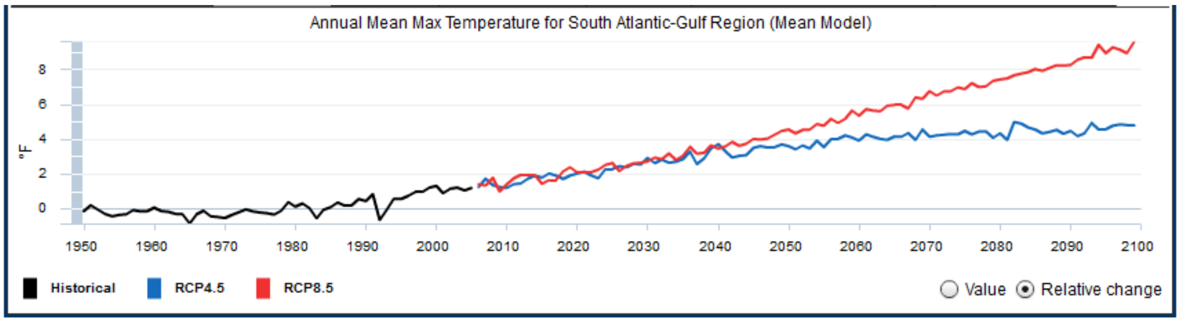


Figure 5-6 Time Series of Annual Mean Maximum Temperature under RCP8.5 (shown in red) (NCCV 2016)

Based on the results of the SLEUTH BAU model (Terando et al. 2014, entire), urbanization in Carolian Madtom 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.

- Tar – Climate change is predicted to result in an increase in the number and duration of droughts in the Tar Basin (see Section 4-7; Table 5-1). Low flows combined with basic effluent treatment in the Upper Tar basin will continue to make both the Upper and Middle Tar MUs uninhabitable for the Carolina Madtom. Habitat conditions in the Fishing Creek and Sandy-Swift Creek MUs are predicted to decline under more extreme climate and urbanization futures, thus reducing flows and water quality conditions, and the species is expected to persist at low resiliency in only the Sandy-Swift Creek MU. The lower Tar MU is predicted to remain extirpated.
- Neuse - High urbanization rates (up to 200% in 50-years, or double the current rate) is predicted to further degrade habitat conditions, especially through water quality stressors and instream habitat unsuitability (see Section 4-1), thus the species is not expected to persist in this MU under the Pessimistic scenario.
- Trent – This population is predicted to remain extirpated under the Pessimistic scenario.

5.3.1 Resiliency

The Pessimistic scenario projects the condition of the Carolina Madtom populations under a more extreme climate and urbanization future, with increased impacts to habitat conditions resulting in a reduced species response. Habitat conditions are only expected to be able to support the continued survival of one population (Tar) at very low levels (Table 5-3). We predict that no highly or moderately resilient populations will remain at the end of the predictive time horizon, thus the remaining one MU (Sandy-Swift Creek) is predicted to have low resiliency. All other MUs are predicted to either become or remain extirpated from their current/historical range. Similar to Status Quo scenario, two of three populations of Carolina Madtom are predicted to become extirpated in 50 years; however, the population conditions in the Pessimistic Scenario are expected to be much lower than those predicted for the Status Quo Scenario (Tables 5-2 and 5-3).

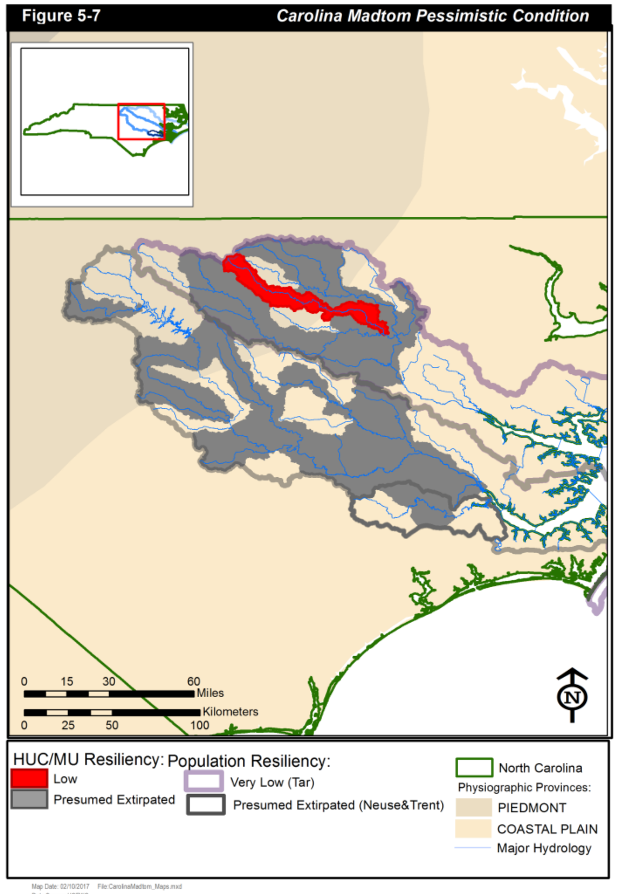
Table 5-3 Carolina Madtom Resiliency under Scenario 2 - Pessimistic

	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
Tar										**Very Low**
Upper Tar	Ø	Ø	Ø	Ø	VLow	Low	Moderate	Low	Low	Ø
Middle Tar	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Lower Tar	Ø	Ø	Ø	Ø	VLow	Moderate	Low	Low	Low	Ø
Fishing Ck Subbasin	Ø	Ø	Ø	Ø	Low	Low	Moderate	Moderate	Moderate	Ø
Sandy-Swift	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate	Moderate	Low
Neuse										**Ø**
Upper Neuse	Ø	Ø	Ø	Ø	VLow	VLow	Low	Low	VLow	Ø
Middle Neuse	Ø	Ø	Ø	Ø	VLow	Low	Low	VLow	VLow	Ø
Lower Neuse	Ø	Ø	Ø	Ø	Low	Moderate	Low	Low	Low	Ø
Little River	Ø	Ø	Ø	Ø	Low	VLow	Low	Low	Low	Ø
Contentnea	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Trent										**Ø**
Trent	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Low	Low	Ø

5.3.2 Representation

We predicted that the Carolina Madtom will have very limited representation in the form of Physiographic and River Basin variability. The species is expected to lose 67% of its known River Basin Variability, with losses in 10 of 11 MUs but retaining low condition representation in the Tar River Basin. The species is also expected to lose Physiographic Variability in the Piedmont (89%) and the Coastal Plain (95%). At the population level, one population (Tar) is expected to be extant, although in low condition in one MU, at the end of the predictive time horizon (Figure 5-7).

Figure 5-7 ***Carolina Madtom Pessimistic Condition***



5.3.3 Redundancy

Under the Pessimistic scenario, it is predicted that the Carolina Madtom will lose all redundancy, with likely extirpation in 10 of the 11 MUs, and one population (Tar) is predicted to be extant, though in very low condition, at the end of the 50 year time horizon.

5.4 Scenario 3 - Optimistic

Factors that influence population and habitat conditions of Carolina Madtom are expected to be somewhat improved given the Optimistic scenario. Reflecting Climate Model RCP2.6 (Wayne 2013, p.11), climate change effects are predicted to be minimal under this scenario, so effects of increased temperatures, storms, and droughts are not reflected in Optimistic predictions as they were in Status Quo and Pessimistic scenario predictions. Urbanization is also predicted to have less of impact in this scenario as reflected by effects that are slightly lower than the SLEUTH BAU model predictions (Table 5-1). Because water quality, flow, and habitat impacts are predicted to be less severe in this scenario as compared to others, it is expected that the species will maintain or have a slightly positive response. Capacity for species restoration and control of the invasive Flathead Catfish are potential conservation activities that could benefit the Carolina Madtom across its range, however, there is no planned or committed effort for such activities and they therefore cannot be considered as part of the Optimistic scenario.

- Tar – Given the Optimistic scenario, both urbanization and climate-induced impacts are expected to be minimal (Table 5-1). As such, habitat conditions, including water quality, flows, and instream and riparian habitat, are predicted to enable persistence at high levels in the Sandy-Swift Creek MU and at moderate levels in the Fishing Creek Subbasin MU and low levels in the Upper Tar MU.
- Neuse – Despite a moderate climate future and lower levels of urbanization, the currently low population condition and the pervasive presence of Flathead Catfish is not likely to sustain species persistence in the Neuse River basin under even an Optimistic scenario.
- Trent - This population is predicted to remain extirpated under the Optimistic scenario.

5.4.1 Resiliency

The Optimistic scenario projects the condition of the Carolina Madtom populations if the current risks will be slightly improved by the end of the predictive time horizon. Because of the more optimistic lens, more MUs are predicted to remain extant than the Status Quo or Pessimistic scenarios (Table 5-4). Specifically, the Tar River population is predicted to be moderately resilient under the Optimistic scenario with the Sandy-Swift Creek MU in high condition and the Fishing Creek MU in moderate condition. Despite a more optimistic future, we predict that the Neuse River Population will likely be extirpated.

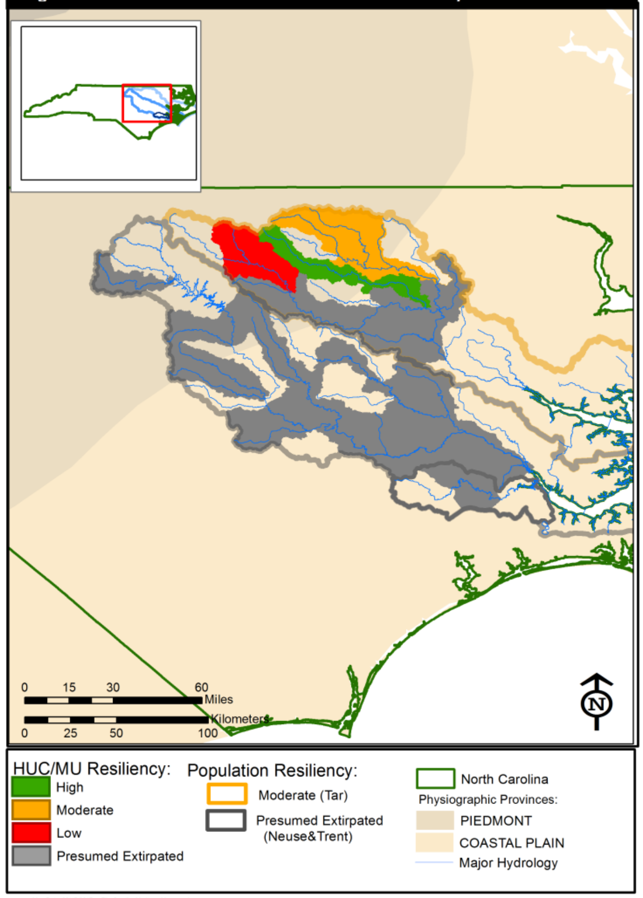
Table 5-4 Carolina Madtom Resiliency under Scenario 3 - Optimistic

	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
Tar										**Moderate**
Upper Tar	Low	Low	Low	Low	Moderate	Low	Moderate	Moderate	Moderate	Low
Middle Tar	Ø	Ø	Ø	Ø	Moderate	Moderate	Low	Moderate	Moderate	Ø
Lower Tar	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Low	Low	Ø
Fishing Ck Subbasin	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Sandy-Swift	High	High	High	High	Moderate	Moderate	Moderate	Moderate	Moderate	High
Neuse										**Ø**
Upper Neuse	Ø	Ø	Ø	Ø	Low	Low	Moderate	Low	Low	Ø
Middle Neuse	Ø	Ø	Ø	Ø	VLow	Low	Low	Low	Low	Ø
Lower Neuse	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Low	Low	Ø
Little River	Ø	Ø	Ø	Ø	Low	Moderate	Moderate	Moderate	Moderate	Ø
Contentnea	Ø	Ø	Ø	Ø	Low	Low	High	Moderate	Moderate	Ø
Trent										**Ø**
Trent	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	Ø

5.4.2 Representation

Under the Optimistic scenario, it is predicted that the Carolina Madtom will retain current levels of representation in the Tar River Basin, but will lose representation in the Neuse and Trent River basins. As such, the species will continue to retain only 33% of its known River Basin Variability (i.e., it will only remain representative in the Tar River Basin). The species is predicted to retain limited Physiographic Variability in the Coastal Plain (14%) and moderate variability in the Piedmont (56%). At the population level, only the Tar River Population is predicted to have moderate resiliency, while the remaining two populations (Neuse and Trent) are predicted to be likely extirpated (Figure 5-7).

Figure 5-8 Carolina Madtom Optimistic Condition



5.4.3 Redundancy

Under the Optimistic scenario, it is predicted that the Carolina Madtom will maintain existing levels of redundancy (3 occupied MUs) in the Tar River Basin, but will likely become extirpated from the Neuse River Basin and will remain likely extirpated from the Trent River Basin. The species will have low, moderate, and high resiliency in three of eleven MUs. Scaling up to the population level, this leaves the species with one of the three (historical) populations.

5.5 Scenario 4 – Opportunistic

Under the Opportunistic Scenario, those landscape-level factors (e.g., development and climate change) that are having an influence on populations of Carolina Madtom get moderately worse, reflecting Climate Change Model RCP4.5 (Wayne 2013, p.11) and SLEUTH BAU (Terando et al. 2014; Table 5-1). Effects of climate change are expected to be moderate, resulting in some increased impacts from heat, storms, and droughts (IPCC 2013, p.7). Urbanization in this scenario reflects the moderate BAU SLEUTH levels, indicating approximately double the amount of developed area compared to current levels. Overall, it is expected that the synergistic impacts of changes in water quality, flow, and habitat connectivity will negatively affect the Carolina Madtom.

- Tar – Under the Opportunistic scenario, there will be moderate climate-induced impacts resulting in continued drought issues in the Upper Tar, resulting in predicted extirpation of the species in this MU. Habitat conditions in the Sandy-Swift Creek MU and Fishing Creek Subbasin MU are expected to enable the species to persist in moderate condition. The Lower Tar MU is predicted to remain likely extirpated.
- Neuse – Impacts from urbanization, including declining water quality from stormwater runoff and decreased flows from consumptive use, along with minimal development restrictions will continue to degrade habitat condition under the Opportunistic scenario. Flathead Catfish are also likely to persist throughout the watershed. The species is predicted to be likely extirpated from this river basin under the Opportunistic scenario.
- Trent - This population is predicted to remain extirpated under the Opportunistic scenario.

5.5.1 Resiliency

The Opportunistic scenario projects the condition of the Carolina Madtom 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 populations are expected to have high resiliency under this scenario. Only the Fishing Creek and Sandy-Swift Creek MUs retain moderate resiliency, whereas the Middle Tar MU is not predicted to persist. At the population level, only one population (Tar) retains overall low resiliency. Under this scenario, it is predicted that two of the three populations (i.e., the Neuse and Trent) of Carolina Madtom will remain/become extirpated in 50 years.

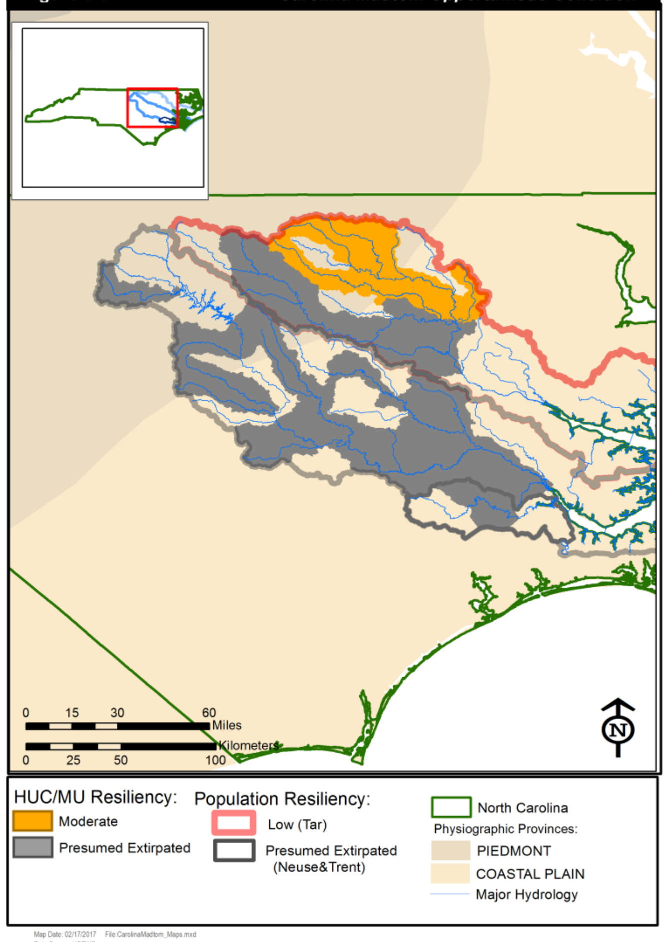
Table 5-5 Carolina Madtom Resiliency under Scenario 4 - Opportunistic

Population/ Management Unit	MU Occupancy	Abundance	Reproduction	Combined Population Factors	Water Quality	Water Quantity	Connectivity	Instream Habitat (Substrate)	Combined Habitat Elements	Overall
Tar										**Low**
Upper Tar	Ø	Ø	Ø	Ø	Low	Low	Moderate	Moderate	Low	Ø
Middle Tar	Ø	Ø	Ø	Ø	VLow	Moderate	Low	Low	Low	Ø
Lower Tar	Ø	Ø	Ø	Ø	Low	Moderate	Low	Low	Low	Ø
Fishing Ck Subbasin	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Sandy-Swift	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Neuse										**Ø**
Upper Neuse	Ø	Ø	Ø	Ø	Low	Low	Low	Low	Low	Ø
Middle Neuse	Ø	Ø	Ø	Ø	VLow	Low	VLow	Low	Low	Ø
Lower Neuse	Ø	Ø	Ø	Ø	Low	Moderate	Low	Low	Low	Ø
Little River	Ø	Ø	Ø	Ø	Low	VLow	Low	Low	Low	Ø
Contentnea	Ø	Ø	Ø	Ø	Low	Low	Moderate	Low	Low	Ø
Trent										**Ø**
Trent	Ø	Ø	Ø	Ø	Moderate	Moderate	Moderate	Moderate	Moderate	Ø

5.5.2 Representation

Under the Opportunistic scenario, it is predicted that the Carolina Madtom will have reduced representation. The species will only retain 33% of its known River Basin variability, remaining in the Tar River Basin. The species also retains limited Physiographic variability in the Coastal Plain (14%) and moderate variability in the Piedmont (46%). At the population level, the Tar population retains low condition representation (Figure 5-9).

Figure 5-9 Carolina Madtom Opportunistic Condition



5.5.3 Redundancy

Under the Opportunistic scenario, it is predicted that the Carolina Madtom will have reduced levels of redundancy, with likely extirpation in nine of the eleven MUs, and persisting in only one (Tar) of three populations.

CHAPTER 6 – STATUS ASSESSMENT SUMMARY

Current Viability Summary

The historical range of the Carolina Madtom included 3rd and 4th order streams and rivers in the Tar, Neuse, and Trent drainages, with documented historical distribution in 11 MUs within three former populations, the Tar, Neuse, and Trent. The Carolina Madtom is presumed extirpated from 64% (7) of the historically occupied MUs. Of the remaining four occupied MUs, one is estimated to have high resiliency, one with moderate resiliency, one with low resiliency, and one with very low resiliency. Scaling up from the MU to the population level, one of three former populations (the Tar Population) is estimated to have moderate resiliency, while the remaining extant population (Neuse) is characterized by very low resiliency. The Trent Population is presumed to be extirpated. 82% of streams that were once part of the species' range are estimated to be in low condition or likely extirpated, potentially putting the Carolina Madtom at risk of extinction. Once known to occupy streams in two physiographic regions, the species has also lost substantial physiographic representation with an estimated 44% loss in Piedmont watersheds and an estimated 86% loss in Coastal Plain watersheds.

Future Viability Summary

The goal of this assessment was to describe the viability of the Carolina Madtom in terms of resiliency, representation, and redundancy (the 3Rs) 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 Carolina Madtom. The results of the predictive analysis describe a range of possible conditions in terms of the number and distribution of Carolina Madtom populations (Table 6-1). While the future projections were made using a 50-year predictive time horizon, after the analysis the experts noted that that not all scenario outcomes have the same likelihood of occurrence at any one time step. To account for this, a discretized range of probabilities (Table 6-2) was used to describe the likelihood of scenario outcome at 10, 25, and 50 year time-steps (Table 6-3). (Note: the range of likelihoods in Table 6-2 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 6-1 Summary of Current and Future Scenario Outcomes

POPULATIONS: Management Units	Current	#1 Status Quo	#2 Pessimistic	#3 Optimistic	#4 Opportunistic
		Future Scenarios of Population Conditions			
Tar: Upper Tar	Low	Likely Extirpated	Likely Extirpated	Low	Likely Extirpated
Tar: Middle Tar	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Tar: Lower Tar	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Tar: Fishing Ck	Moderate	Low	Likely Extirpated	Moderate	Moderate
Tar: Sandy-Swift	High	Moderate	Low	High	Moderate
Neuse: Upper Neuse	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Neuse: Middle Neuse	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Neuse: Lower Neuse	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Neuse: Little River	Very Low	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Neuse: Contentnea	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated
Trent	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated	Likely Extirpated

Table 6-2 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 the outcome of this scenario will occur.
Likely	We are **70-90% sure** that the outcome of this scenario will occur.
As Likely As Not	We are **40-70% sure** that the outcome of this scenario will occur.
Unlikely	We are **10-40% sure** that the outcome of this scenario will occur.
Very unlikely	We are **less than 10% sure** that the outcome of this scenario will occur.

Table 6-3 Likelihood of Scenario occurrence at 10, 25, and 50 years

Likelihood of Scenario Occurring at:	Status Quo	Pessimistic	Optimistic	Opportunistic
10 Years	Very Likely	As Likely As Not	Unlikely	Likely
25 Years	As Likely As Not	Likely	Unlikely	As Likely As Not
50 Years	As Likely As Not	Likely	Unlikely	Unlikely

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 all currently extant Carolina Madtom populations would experience negative changes to these important habitat requisites. Predicted viability varied among scenarios and is summarized below and in Table 6-1.

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, one in moderate condition, one in low condition, and the remaining nine MUs would be likely extirpated. Redundancy would be reduced to two MUs in the Tar population. Representation would be reduced, with only 33% of the former river basins occupied and with reduced variability in the Piedmont and Coastal Plain. This scenario is very likely at the 10 year time-step, and as likely as not at the 25 and 50 year time-steps, respectively (Tables 6-2 and 6-3).

Given Scenario 2, the "Pessimistic" option, we predicted a near complete loss of resiliency, representation, and redundancy. Redundancy would be lost with one population (Tar) remaining, and the resiliency of that population is expected to be very low. Nearly all MUs were predicted to be extirpated, and the remaining MU (Sandy-Swift Creek MU) would be in low condition. All measures of representation are predicted to decline precipitously under this scenario, leaving the remaining Carolina Madtom population underrepresented in River Basin and Physiographic variability. This scenario is as likely as not and likely at the 10 year time-step, and likely at the 25 and 50 year time-steps, respectively (Tables 6-2, 6-3).

Given Scenario 3, the "Optimistic" option, we predicted slightly higher levels of resiliency, representation, and redundancy than was estimated under the Status Quo or Pessimistic options. One MU would be in high condition, one in moderate condition, one in low condition, and the remaining eight MUs would be likely extirpated. Despite predictions of population persistence in the Tar River Basin, this population is expected to retain only a moderate level of resiliency. Existing levels of representation are predicted to decline under this scenario. This scenario is unlikely at each time-step (Tables 6-2 and 6-3), primarily because there is a lot of uncertainty in the success of management actions affecting the future condition of the species, as well as uncertainty about species response.

Given Scenario 4, the "Opportunistic" option, we predicted reduced levels of resiliency, representation, and redundancy. No MUs would be in high condition, two would be in moderate condition, and nine would be likely extirpated. Redundancy would be reduced with only two MUs remaining in the Tar Population. Under the Opportunistic Scenario, representation is predicted to be reduced with only 33% of formerly occupied river basins remaining occupied and with reduced variability in the Piedmont and Coastal Plain Physiographic Regions. This scenario is likely at the 10 year time-step, as likely as not at the 25 year time-step, and unlikely at the 50 year time-step (Tables 6-2, 6-3).

Overall Summary

Estimates of current and future resiliency for Carolina Madtom are low, as are estimates for representation and redundancy. The Carolina Madtom faces a variety of risks from declines in water quality, loss of stream flow, riparian and instream fragmentation, deterioration of instream habitats, and predation from the invasive Flathead Catfish. These risks, which are expected to be exacerbated by urbanization and climate change, were important factors in our assessment of the future viability of the Carolina Madtom. Given losses of resiliency, populations become more vulnerable to extirpation, in turn, resulting in concurrent losses in representation and redundancy. Predictions of Carolina Madtom habitat conditions and population factors suggest possible extirpation in one of two currently extant populations. The one population predicted to remain extant (Tar) is expected to be characterized by low occupancy and abundance.

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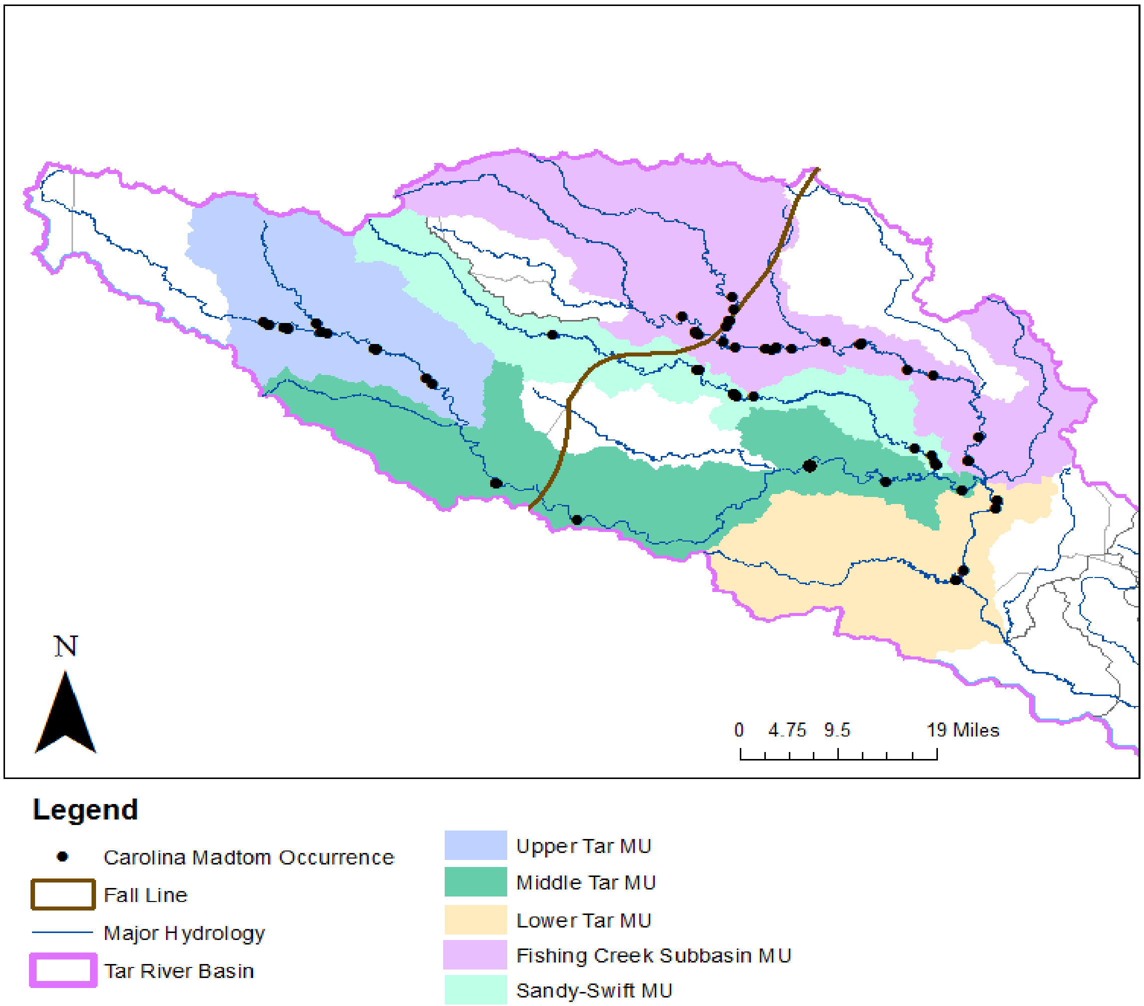
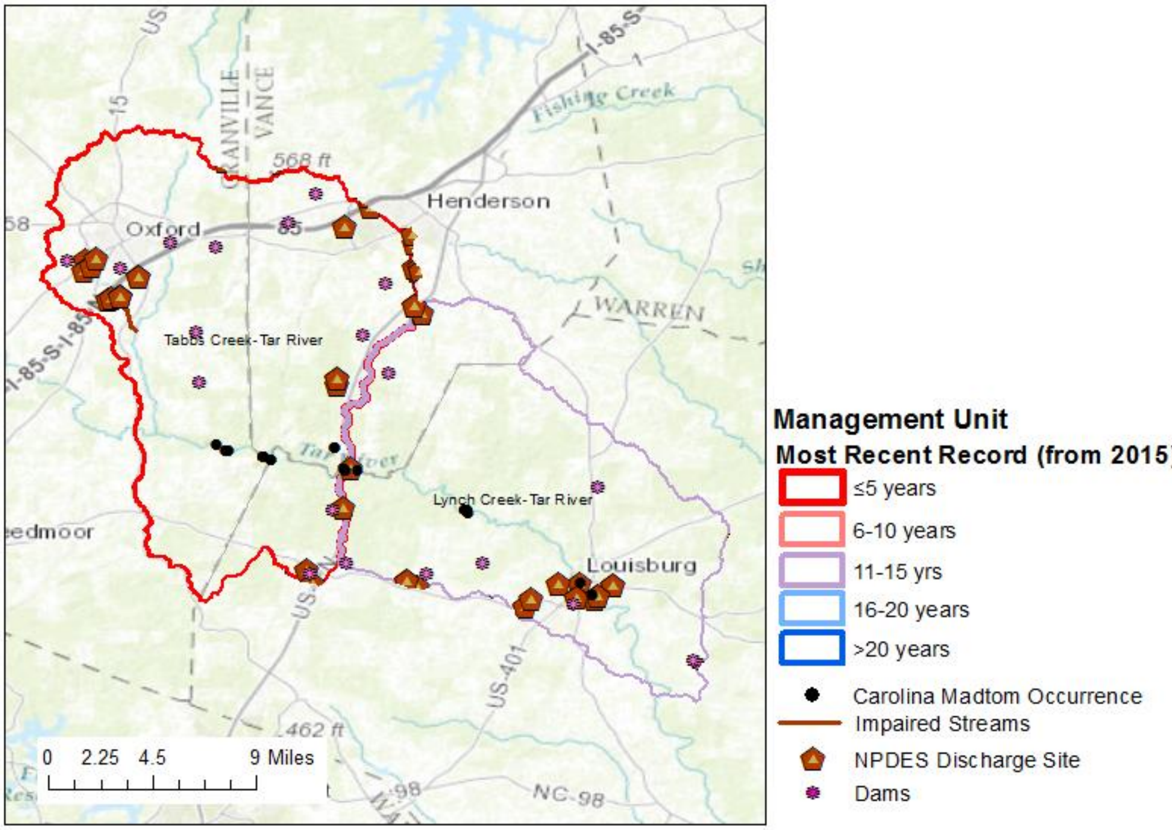
Appendix A – CAROLINA MADTOM DISTRIBUTION

Tar River Population

Consists of 5 MUs: Upper Tar; Middle Tar; Lower Tar; Fishing Creek Subbasin; Sandy-Swift Creek



Upper Tar River Management Unit

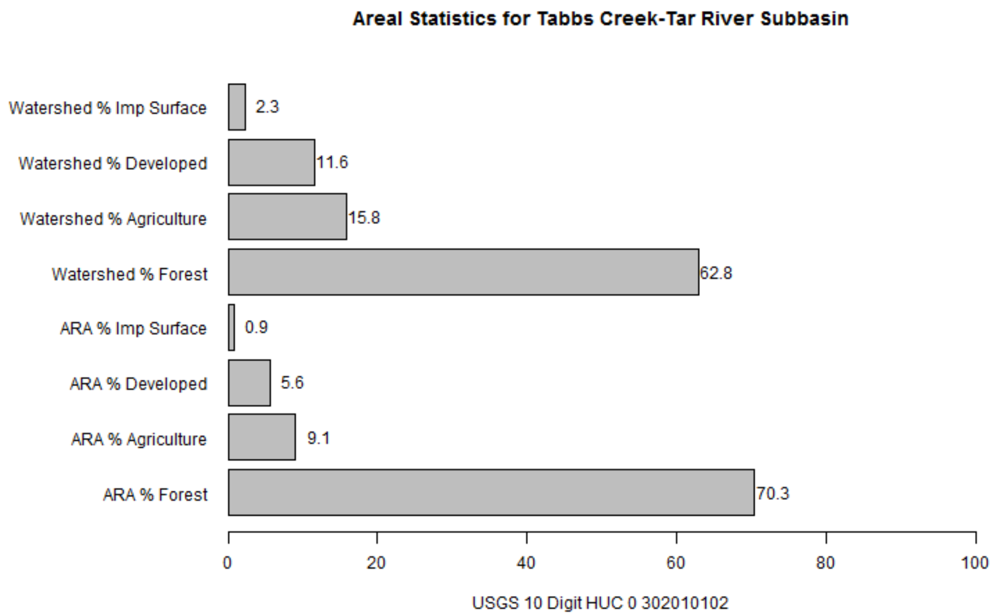


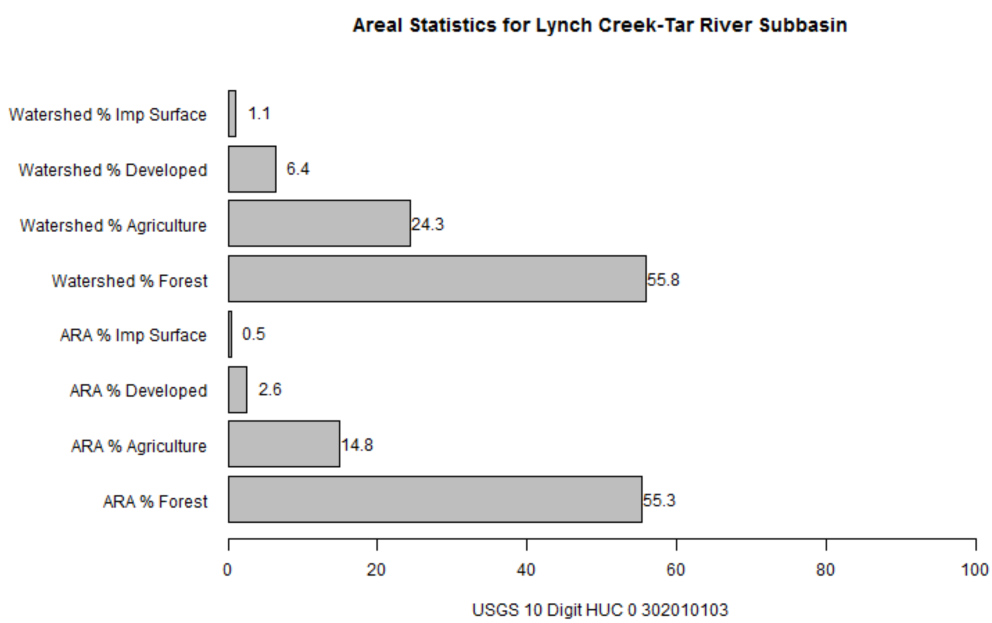
Survey Summary: This MU includes Tabbs Creek, Lynch Creek and the mainstem of the upper Tar River. Carolina Madtom has been documented from 20 locations in this MU between 1985 and 2016. Most surveys document a dozen to two dozen individuals per survey, with the most being 26 during a night snorkel survey specifically for this species (seen in the Tar mainstem in 2005). Madtom abundances have been described as "rare" to "common" in this MU. Recruitment was documented in 2007, and several younger individuals (40-50mm) were observed. A total of 122 live individuals have been observed over time in this MU, and the species was last observed in 2016 (NCWRC PAWS 2016).

Bucket of madtoms (credit: C.Wood)

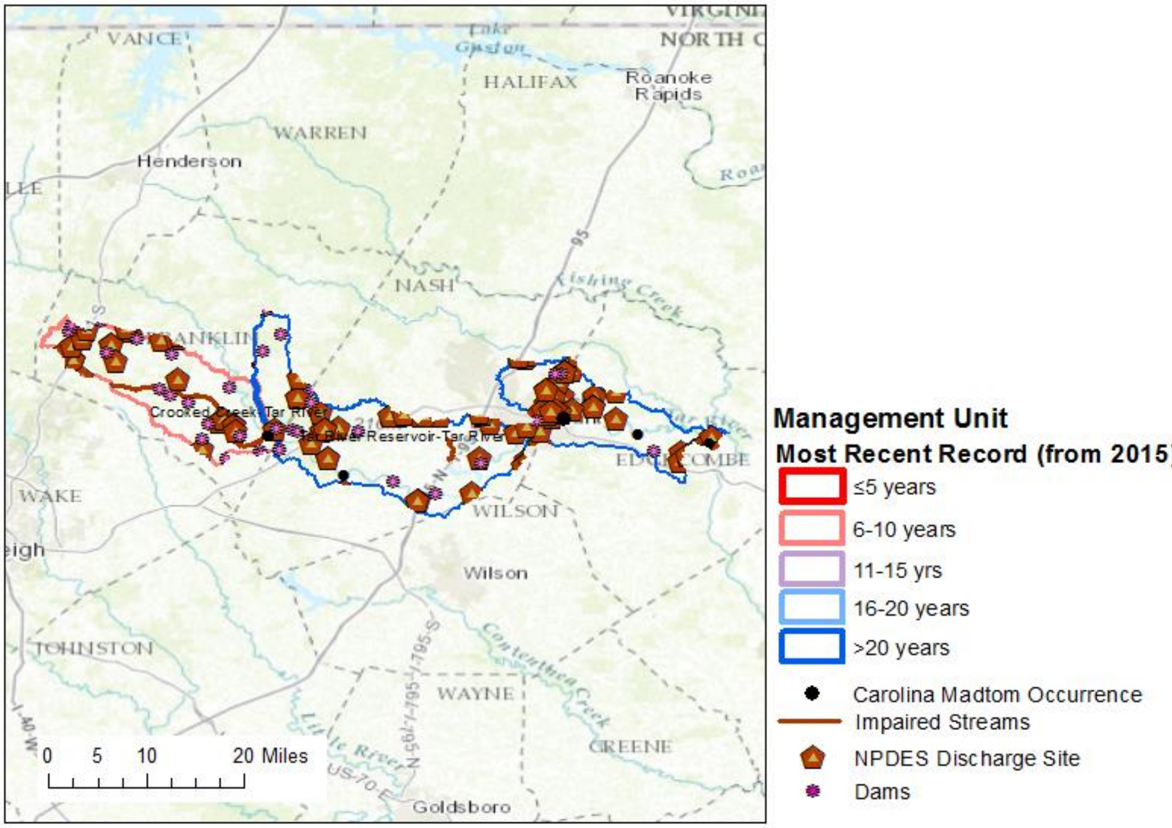
Water Quality Summary: Based on 2014 data, there are two impaired stream reaches totaling ~2 miles in this MU. The reasons for a designation of impairment are low benthic-macroinvertebrate assessment scores, and the entire basin being classified as Nutrient Sensitive Waters (NCDEQ 2016, pp.115-117). There are 41 minor and two major (Tar River WRF and Oxford WWTP) NPDES discharges in this MU.

Land Use Land Cover Summary:



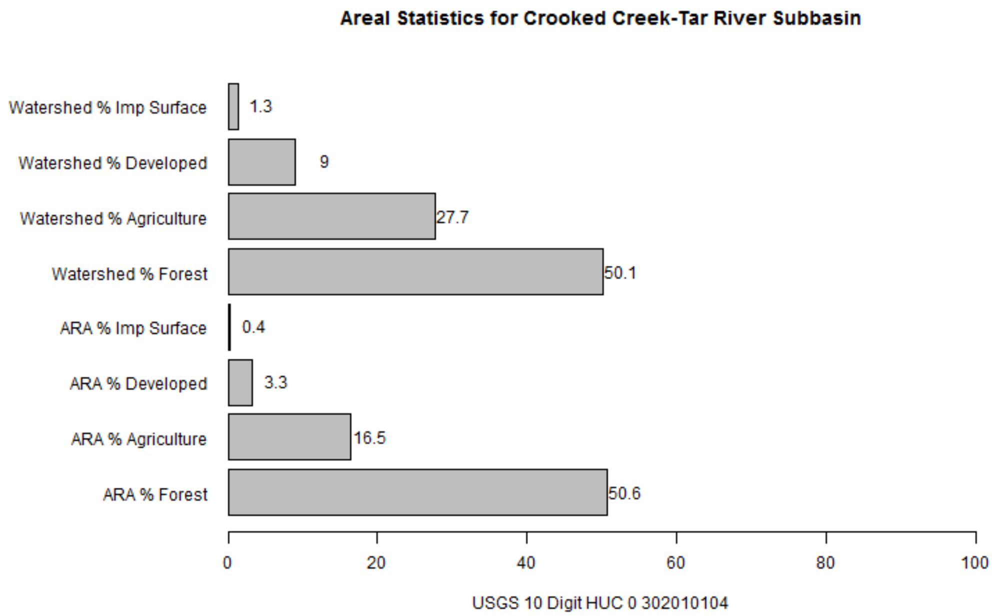


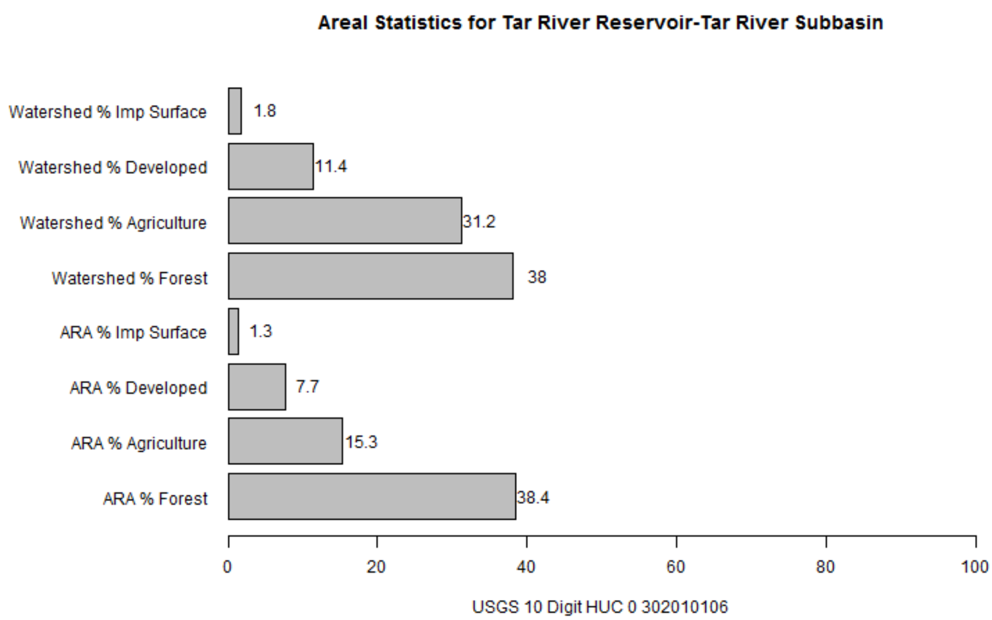
Middle Tar River Management Unit

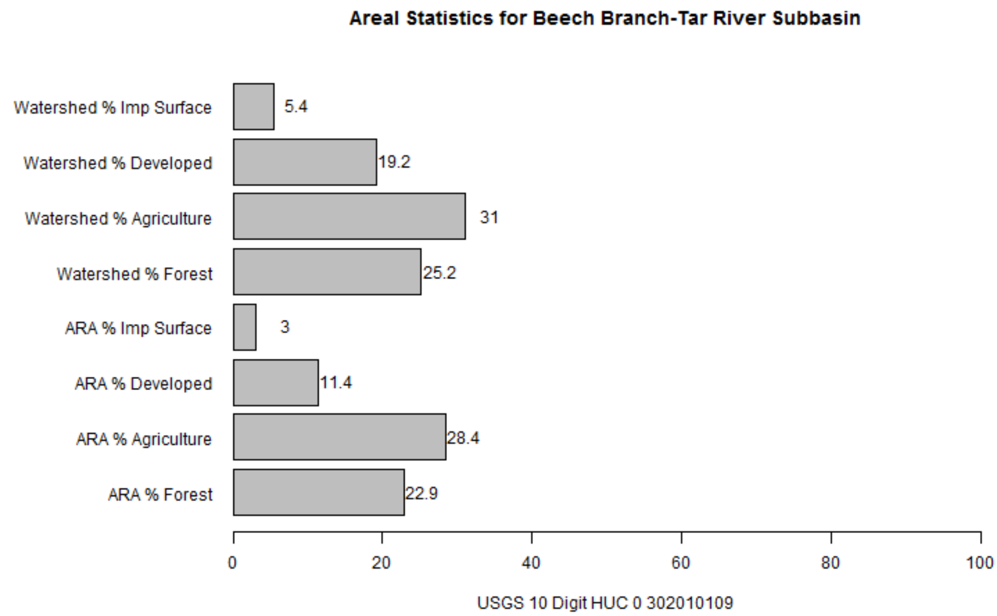


Survey Summary: This MU includes Crooked Creek and the mainstem of the middle Tar River. Several surveys have occurred in this MU – the Carolina Madtom has been documented at 6 locations, first observed in 1985, and most recently seen in 2007. The surveys often documented small numbers (fewer than 15) of individuals, and madtom abundances have been described as "rare" and "uncommon" in this MU. Recruitment has been documented; as several smaller (20-40mm) individuals were observed in 2007. A total of 31 live individuals have been observed over time in this MU (NCWRC PAWS 2016).

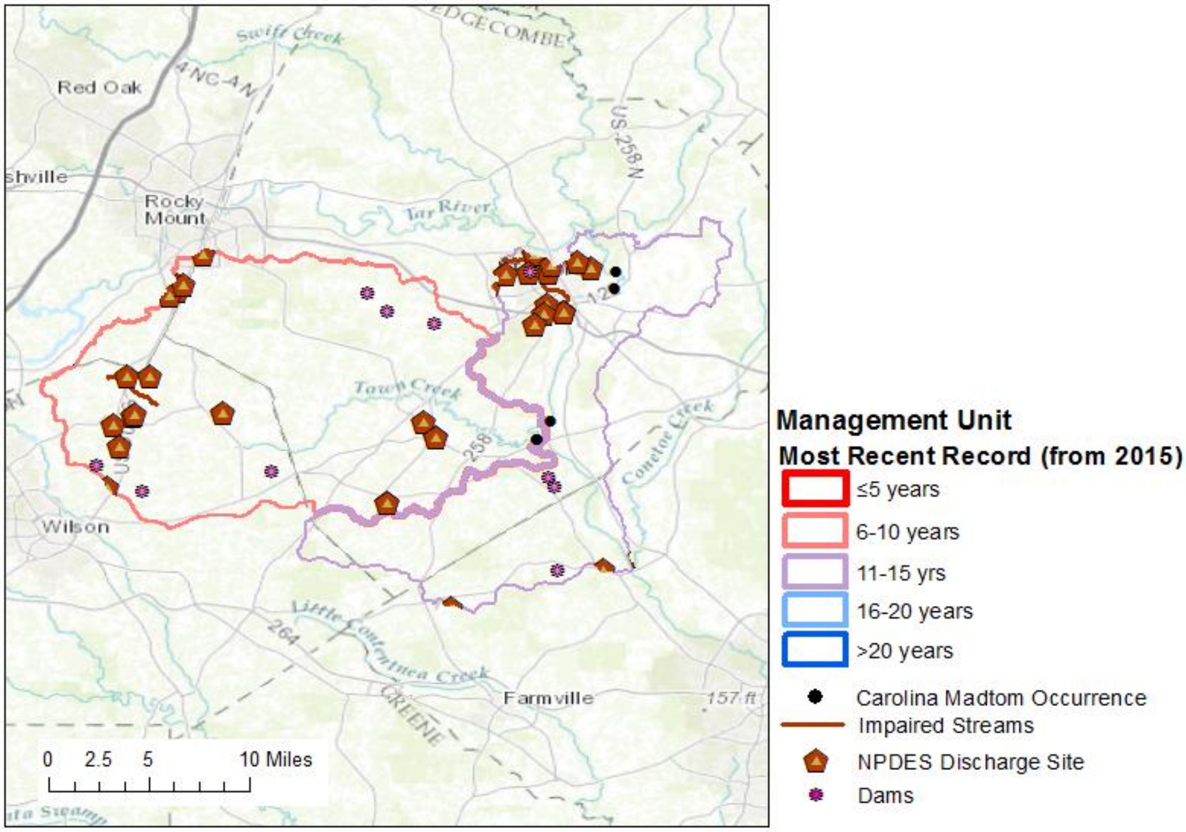
Water Quality Summary: Based on 2014 data, there are three impaired stream reaches totaling ~24 miles in this MU. Reasons for a designation of impairment are low DO, and the entire basin being classified as Nutrient Sensitive Waters (NCDEQ 2016, pp.115-117). There are 80 non-major NPDES and 2 major (Tar River Regional WWTP and Franklin County WWTP) NPDES discharges in this MU.


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


Areal Statistics for Tar River Reservoir-Tar River Subbasin
Watershed % Imp Surface
1.8
Watershed % Developed
11.4
Watershed % Agriculture
31.2
Watershed % Forest
38
ARA % Imp Surface
1.3
ARA % Developed
7.7
ARA % Agriculture
15.3
ARA % Forest
38.4
0
20
40
60
80
100
USGS 10 Digit HUC 0 302010106


Areal Statistics for Beech Branch-Tar River Subbasin
Watershed % Imp Surface
Watershed % Developed
Watershed % Agriculture
Watershed % Forest
ARA % Imp Surface
ARA % Developed
ARA % Agriculture
ARA % Forest
5.4
19.2
31
25.2
3
11.4
28.4
22.9
0
20
40
60
80
100
USGS 10 Digit HUC 0 302010109

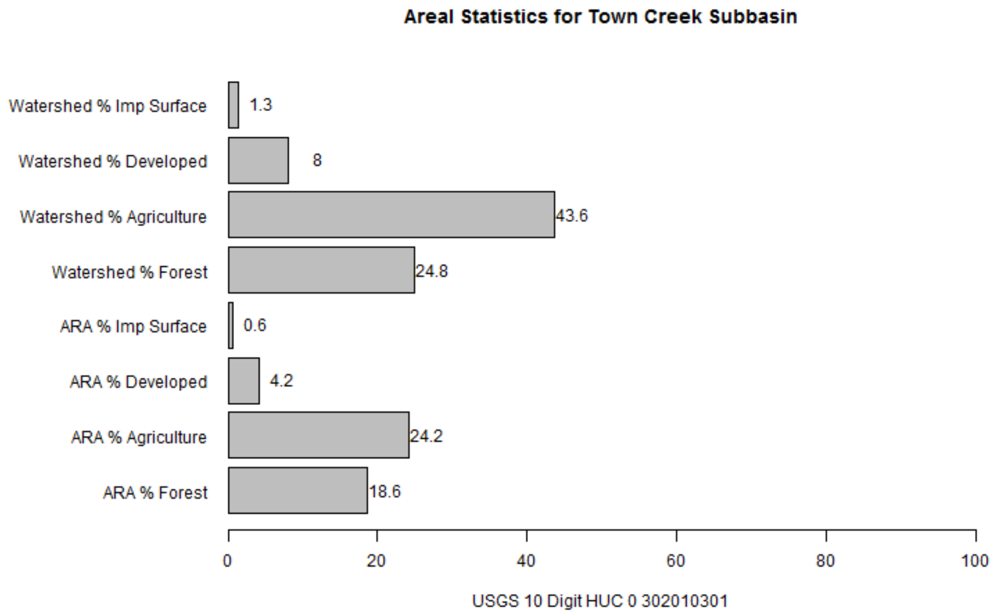
Lower Tar River Management Unit

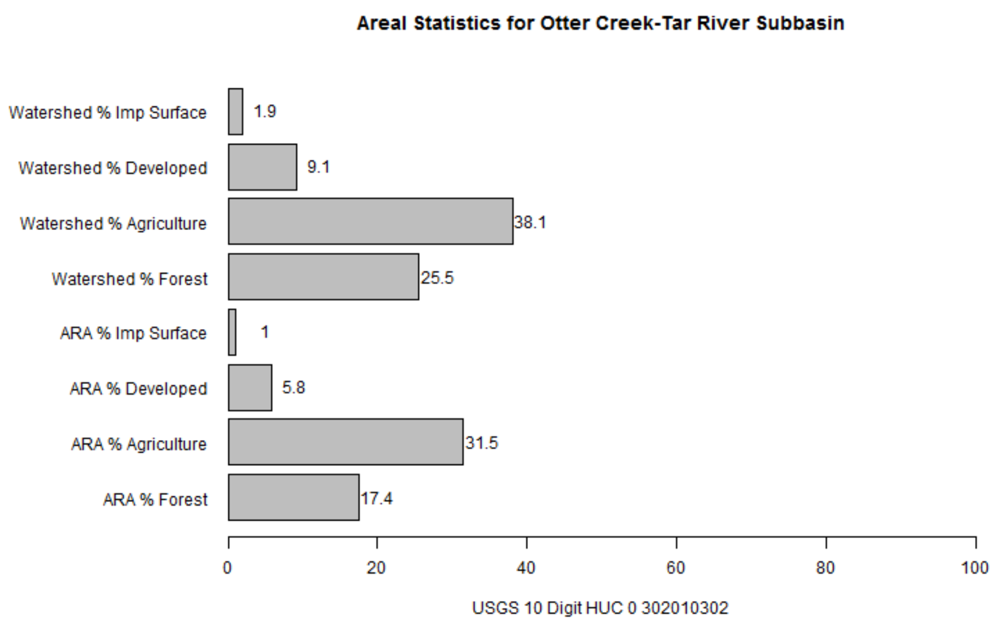


Survey Summary: This MU includes Town Creek and the mainstem of the lower Tar River below Tarboro, NC. Only a couple of surveys have occurred in this MU – the Carolina Madtom was first documented in 1984, and most recently seen in 2007. Madtom abundances have been described as "rare" in this MU. Recruitment has not been documented, and only larger (50-70mm) individuals have been observed. A total of 18 live individuals have been observed over time in this MU (NCWRC PAWS 2016).

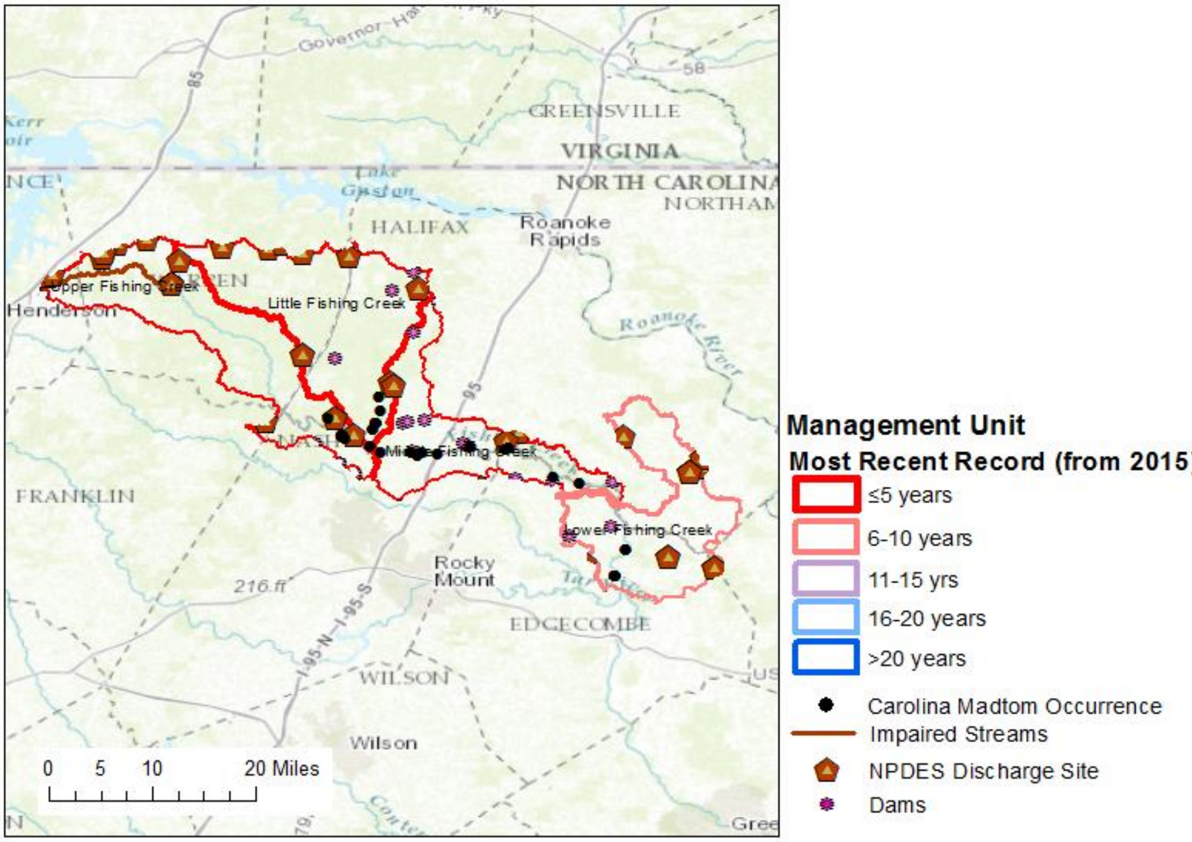
Water Quality Information: Based on 2014 data, there are two impaired stream reaches totaling ~7 miles in this MU. Reasons for a designation of impairment are severe benthic macroinvertebrate assessment scores and classification of the entire basin as Nutrient Sensitive Waters (NCDEQ 2016, pp.115-117). There are 33 non-major NPDES and 1 major (Tarboro WWTP) NPDES discharges in this MU.

Land Use Land Cover Summary Statistics:





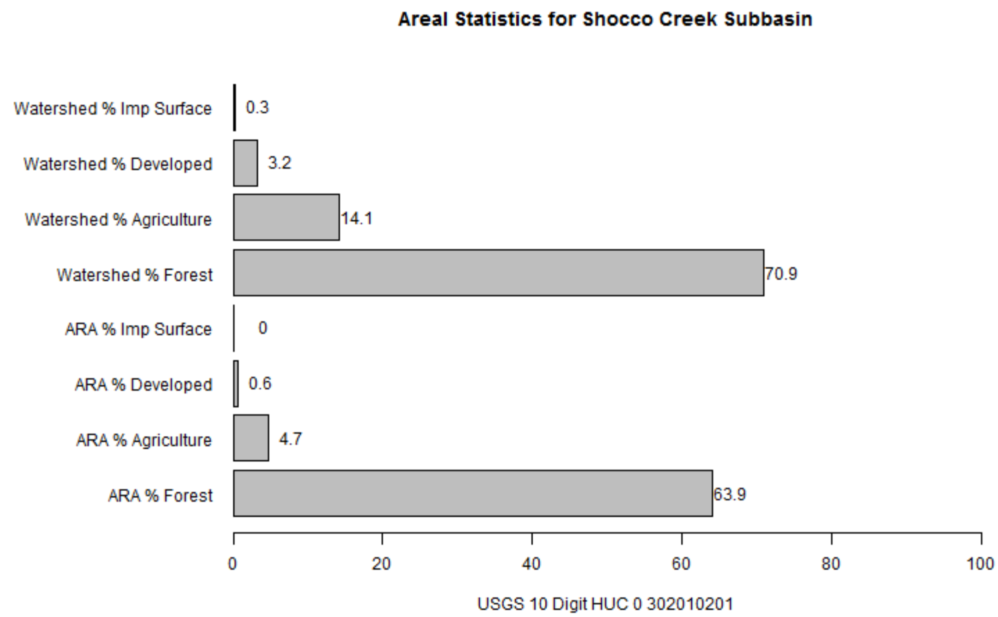
Fishing Creek Subbasin Management Unit

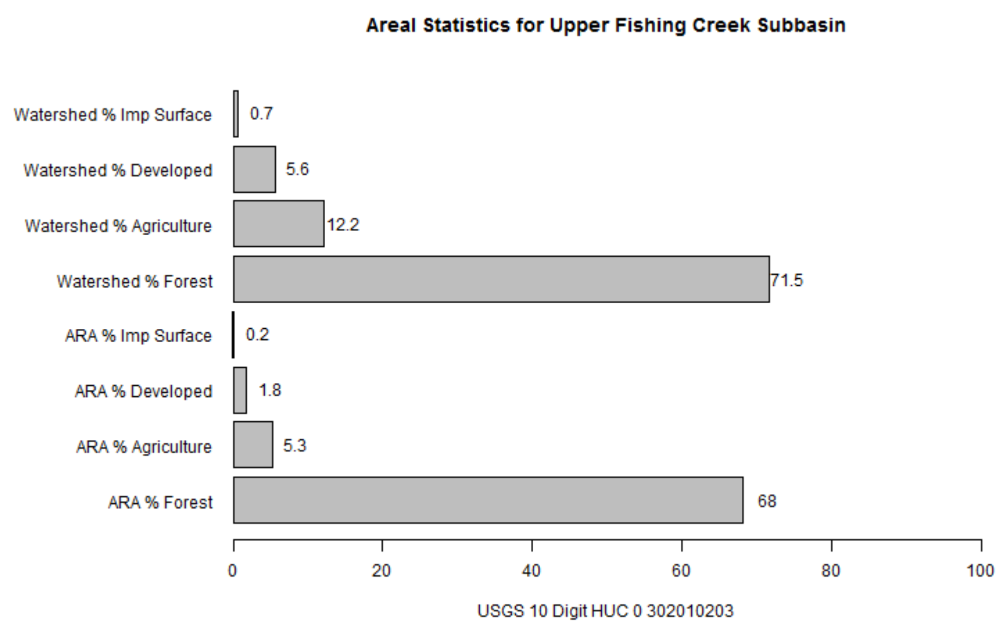


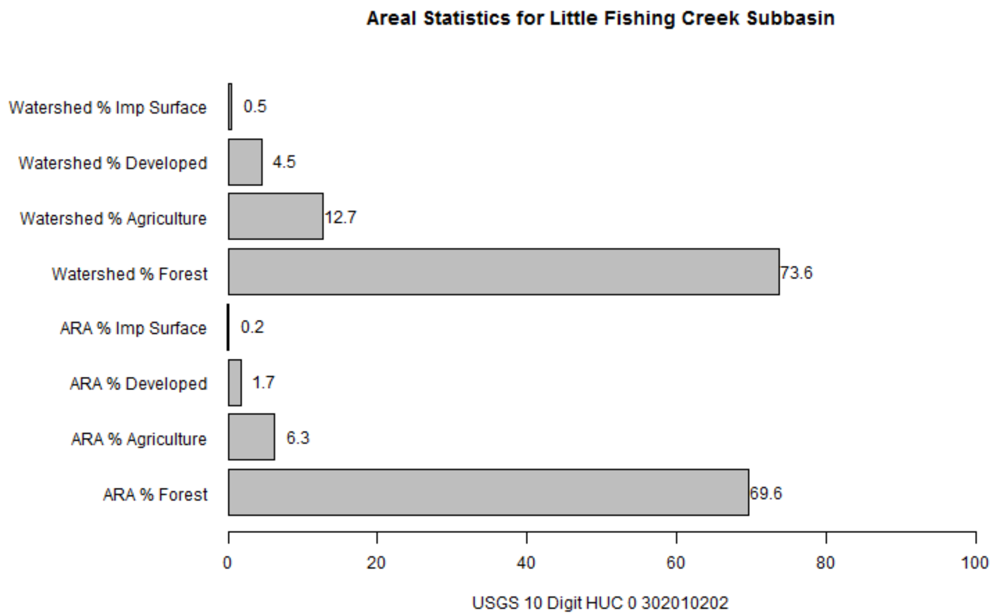
Survey Summary: This MU includes Fishing Creek and Little Fishing Creek. Carolina Madtoms have been documented at 22 locations in this MU; the species was first documented in 1963 and most recently seen in 2016. Most survey efforts document under 10 individuals, although as many as 51 live individuals have been seen in one survey (Fishing Creek in 2007). Madtom abundances have been described as "rare" to "common" in this MU. Evidence of recruitment has been documented, and several individuals under 30mm have been observed. A total of 147 live individuals have been observed over time in this MU (NCWRC PAWS 2016).

Water Quality Summary: Based on 2014 data, there is one impaired stream reach totaling ~14 miles in this MU. The primary reason for a designation of impairment is low DO. There are 33 non-major and one (Warrenton WWTP) NPDES discharges in this MU.

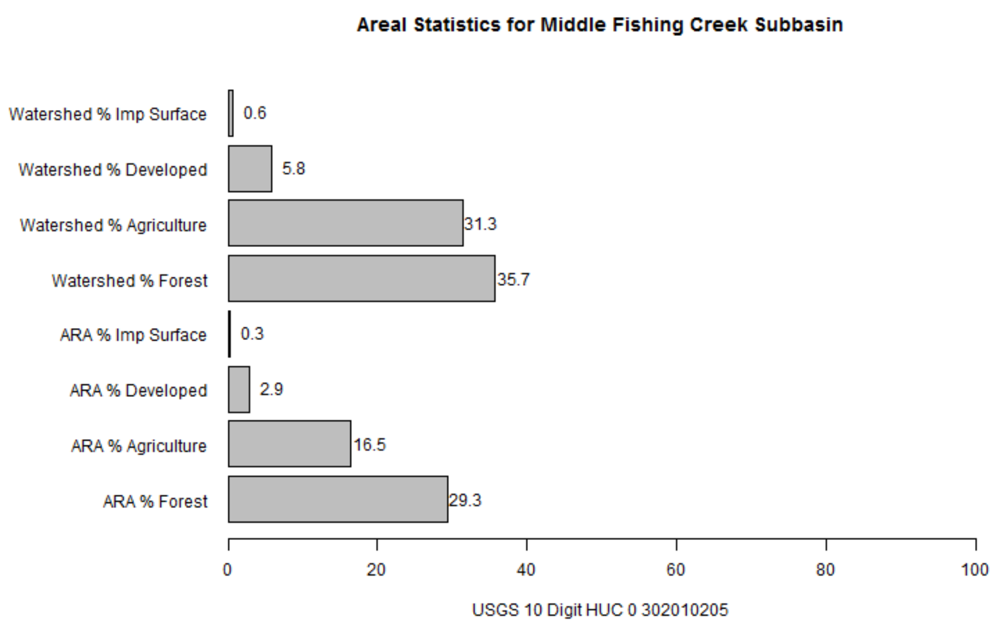
Land Use Land Cover Summary:



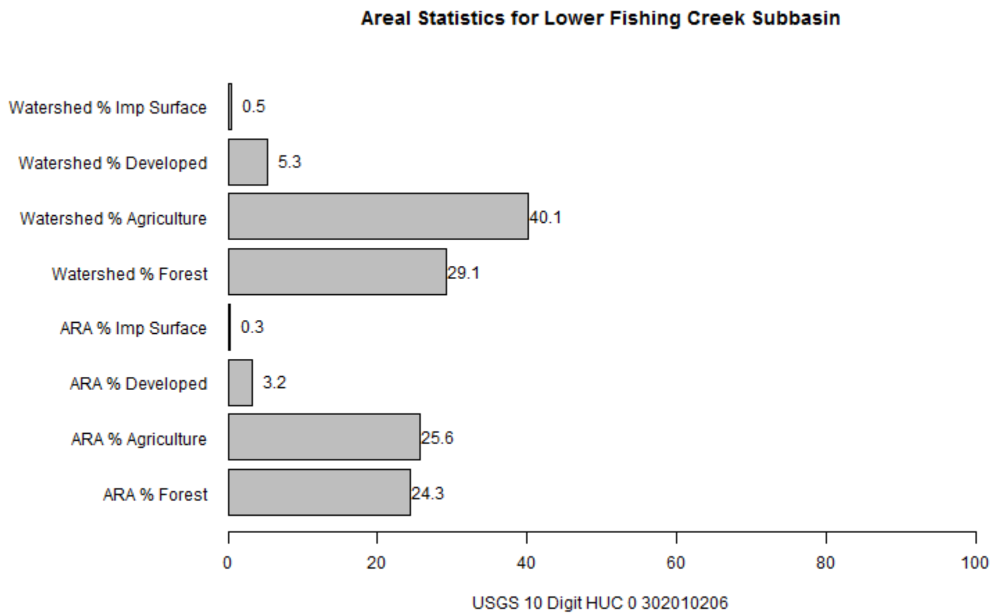




Areal Statistics for Little Fishing Creek Subbasin
Watershed % Imp Surface
0.5
Watershed % Developed
4.5
Watershed % Agriculture
12.7
Watershed % Forest
73.6
ARA % Imp Surface
0.2
ARA % Developed
1.7
ARA % Agriculture
6.3
ARA % Forest
69.6
0
20
40
60
80
100
USGS 10 Digit HUC 0 302010202

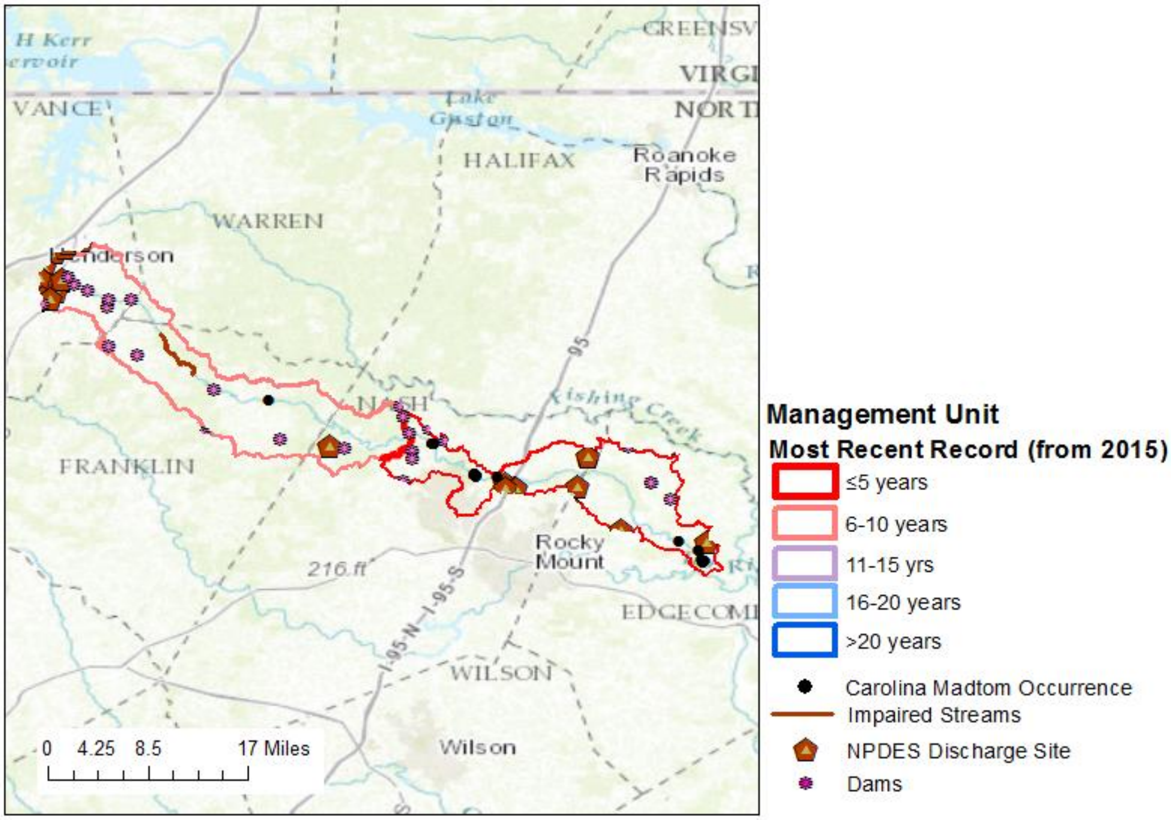


Areal Statistics for Middle Fishing Creek Subbasin
Watershed % Imp Surface
0.6
Watershed % Developed
5.8
Watershed % Agriculture
31.3
Watershed % Forest
35.7
ARA % Imp Surface
0.3
ARA % Developed
2.9
ARA % Agriculture
16.5
ARA % Forest
29.3
0
20
40
60
80
100
USGS 10 Digit HUC 0 302010205



Areal Statistics for Lower Fishing Creek Subbasin
Watershed % Imp Surface
0.5
Watershed % Developed
5.3
Watershed % Agriculture
40.1
Watershed % Forest
29.1
ARA % Imp Surface
0.3
ARA % Developed
3.2
ARA % Agriculture
25.6
ARA % Forest
24.3
0
20
40
60
80
100
USGS 10 Digit HUC 0 302010206

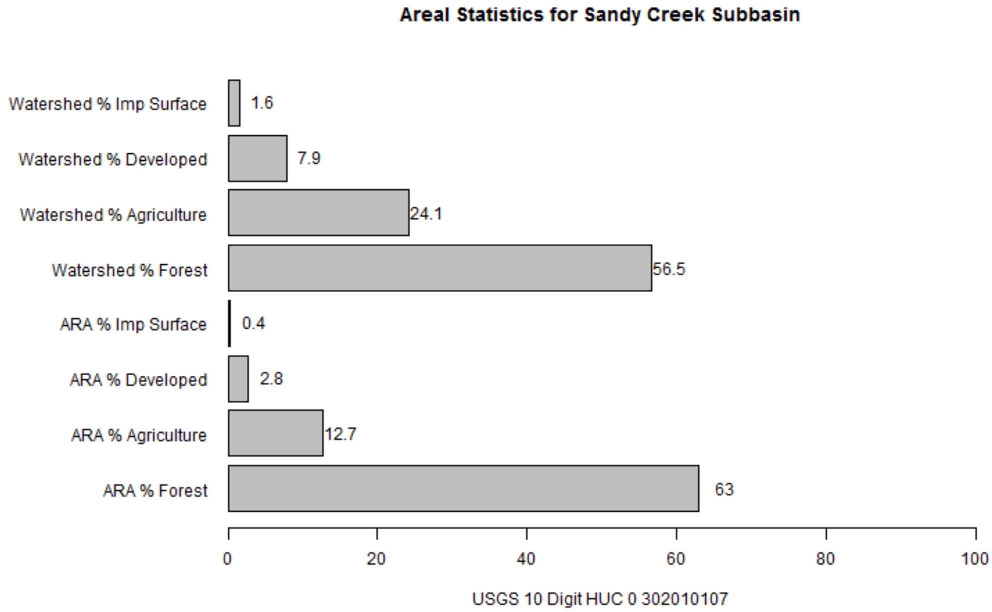
Sandy-Swift Creek Management Unit

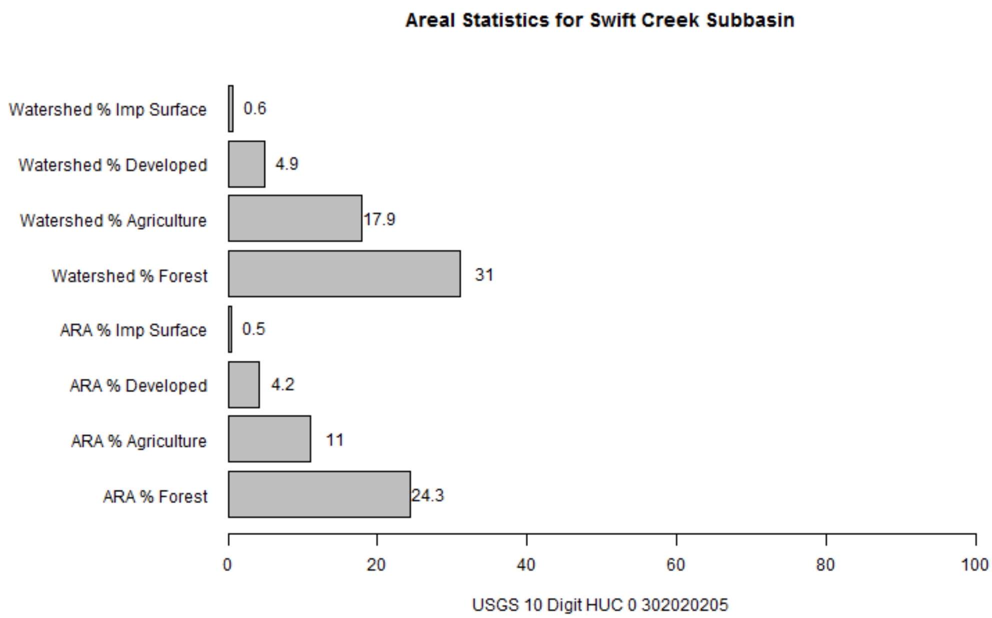


Survey Summary: Carolina Madtoms have been documented from eight locations in this MU. The species was first documented in 1985 and seen as recently as 2016. Abundances have been described as "rare", "patchy uncommon", and "common" with most surveys documenting fewer than 10 individuals, with the most being 17 observed in 2016. Recruitment was documented as recent as 2016, and a few individuals under 50mm have been documented. A total of 135 live individuals have been observed over time in this MU (NCWRC PAWS 2016).

Water Quality Summary: Based on 2014 data, there is one impaired stream reach totaling ~5 miles in this MU. The primary reason for a designation of impairment is due to low benthic-macroinvertebrate assessment scores. There are 24 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 2016).

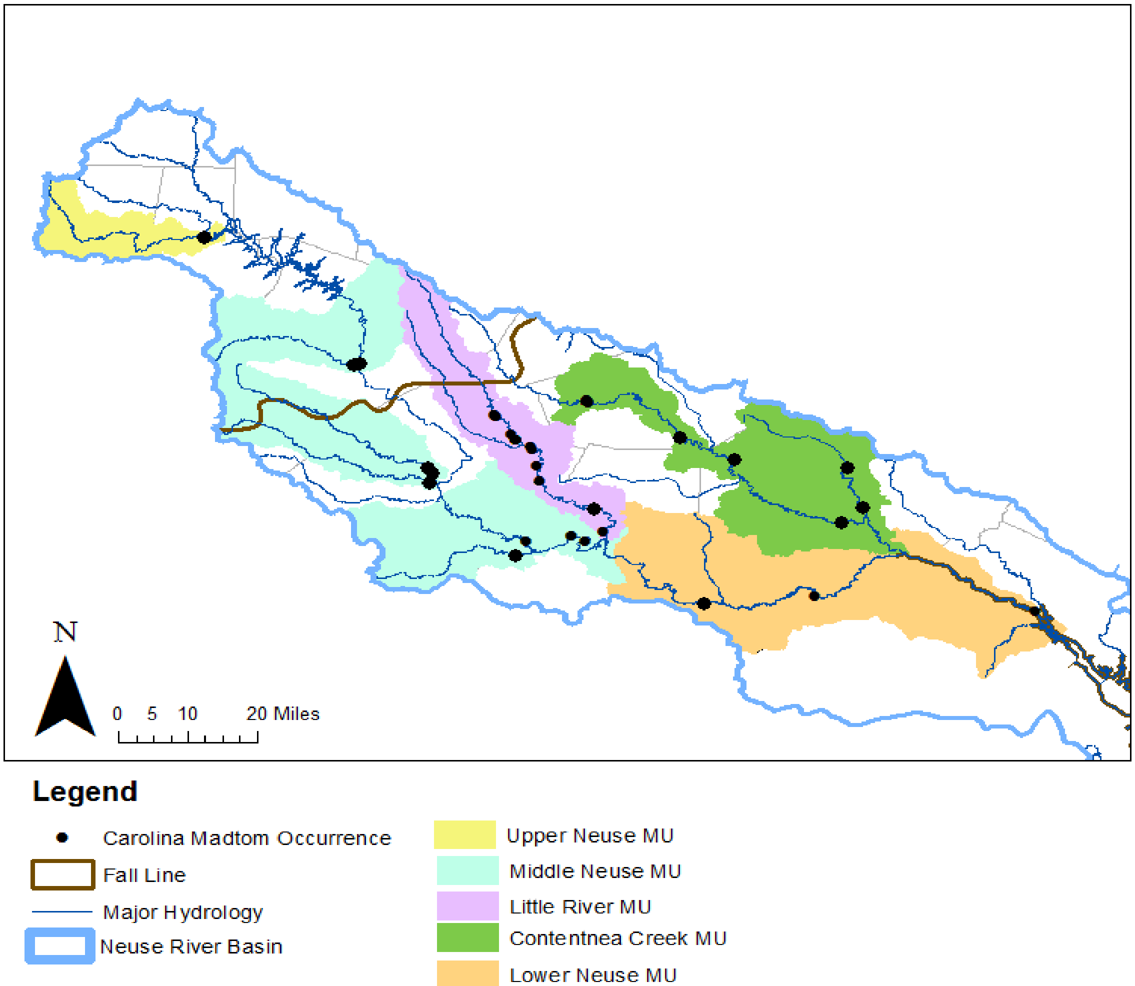
Land Use Land Cover Summary:



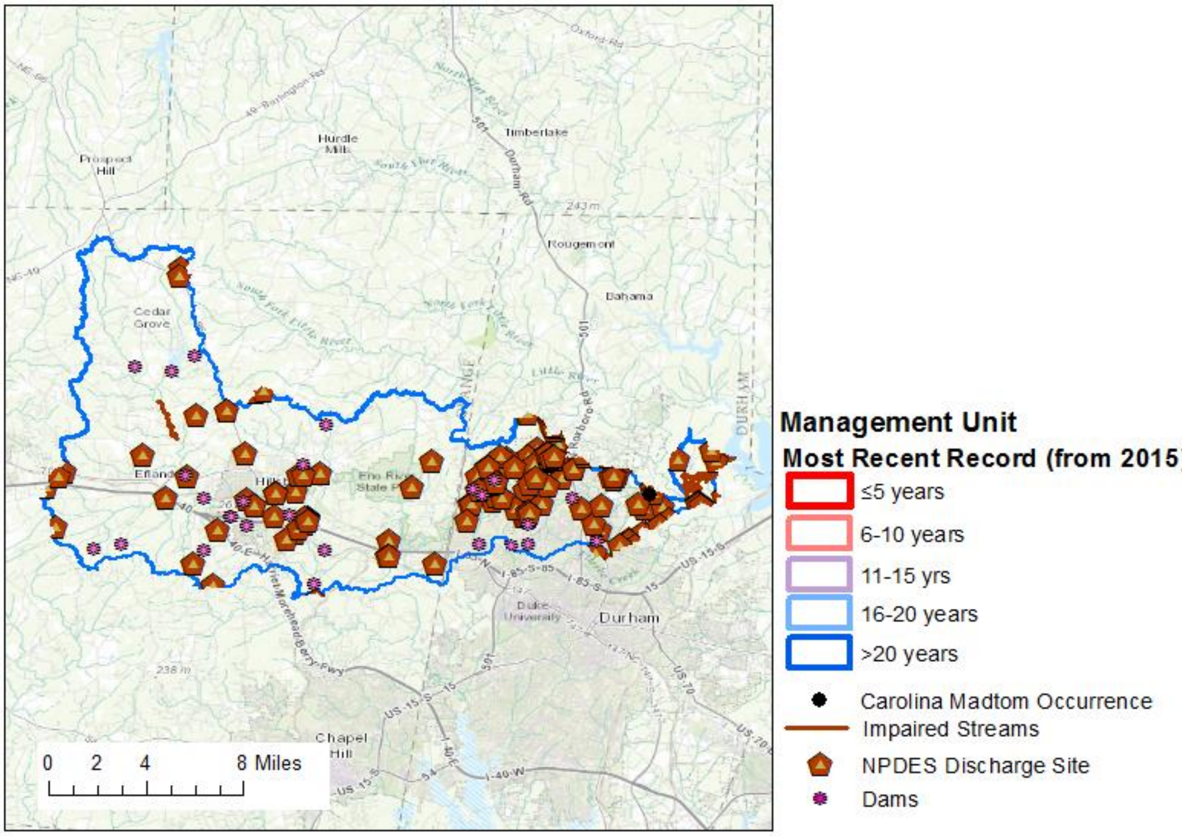


Neuse River Population

Consists of 5 MUs: Upper Neuse; Middle Neuse; Lower Neuse; Little River; Contentnea Creek



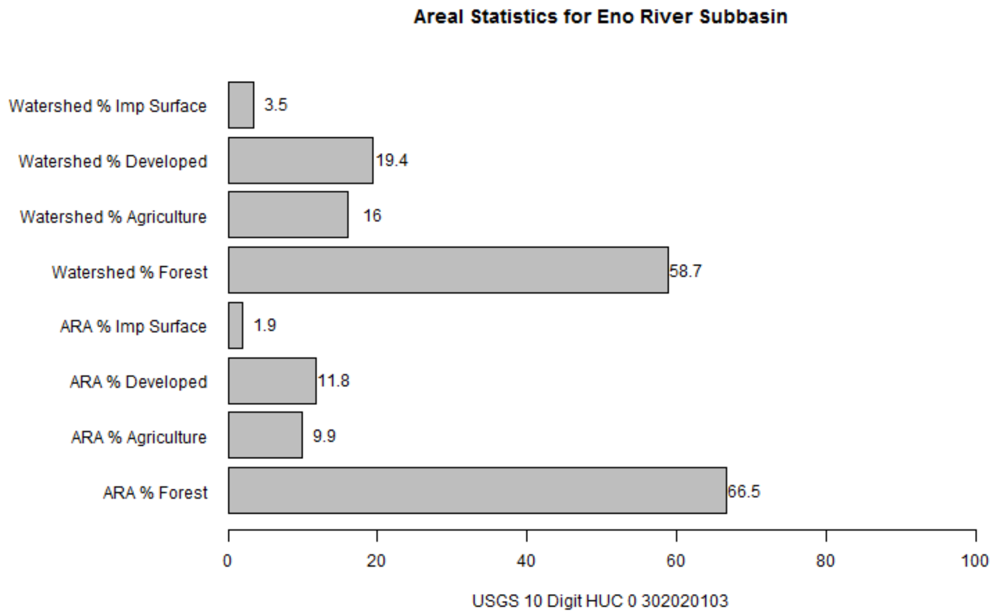
Upper Neuse Management Unit



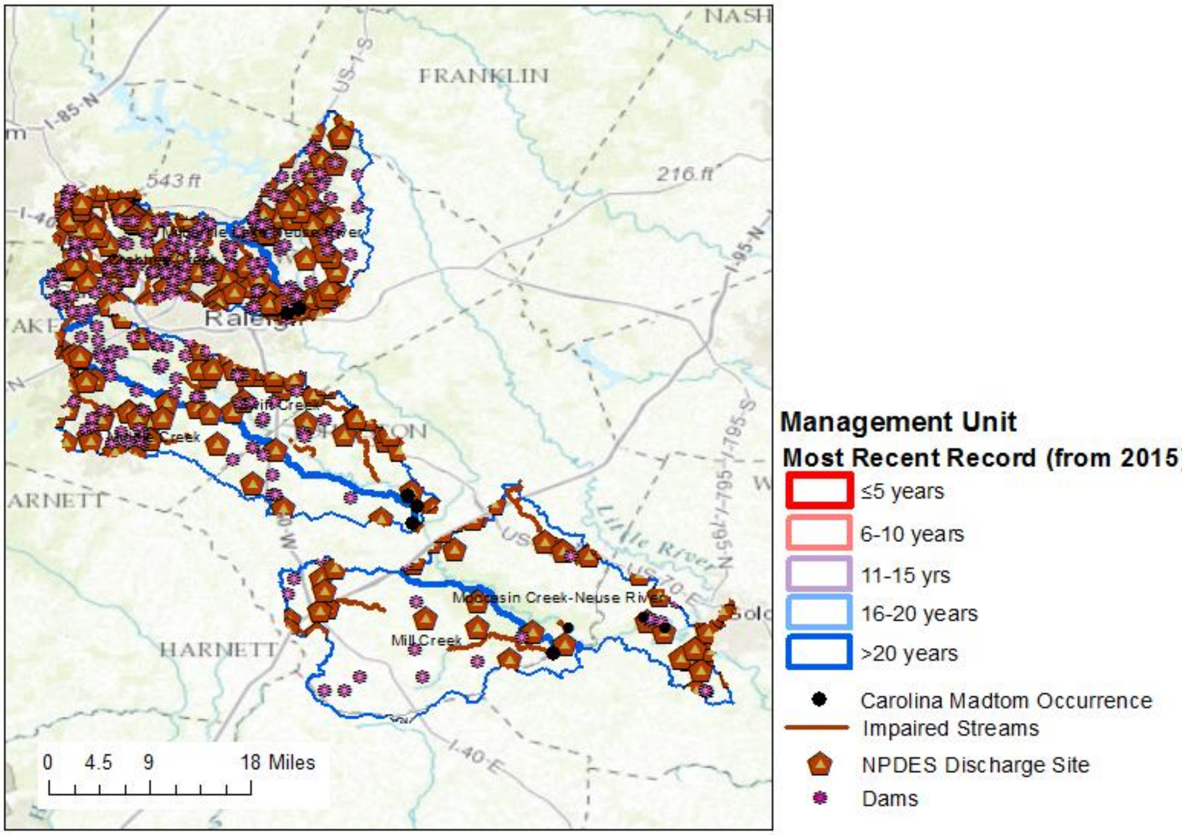
Survey Summary: There is an historical record of Carolina Madtom in this MU from 1961. Follow-up surveys in 2011 were unable to observe any individuals (NCNHP 2016).

Water Quality Information: Based on the 2014 data, there is one impaired stream reach totaling ~2 miles in this MU. Reasons for a designation of impairment are low benthic-macroinvertebrate assessment scores, and classification of the entire basin as Nutrient Sensitive Waters. There are also ~2700 acres of impaired waters in Falls Lake due to turbidity. There are 162 non-major and one major (Hillsborough WWTP) NPDES discharges in this MU.

Land Use Land Cover Summary Statistics:



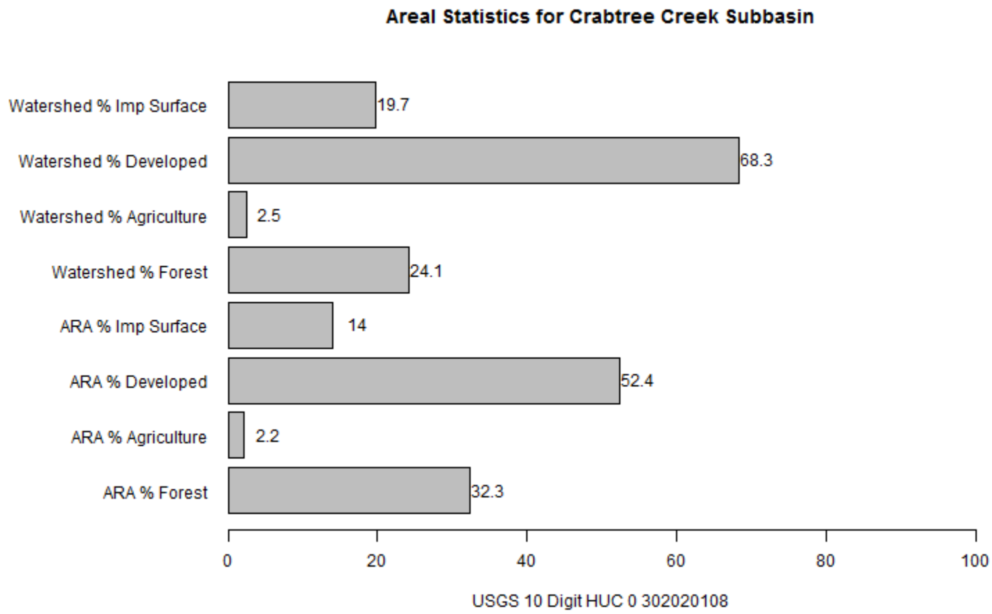
Middle Neuse Management Unit

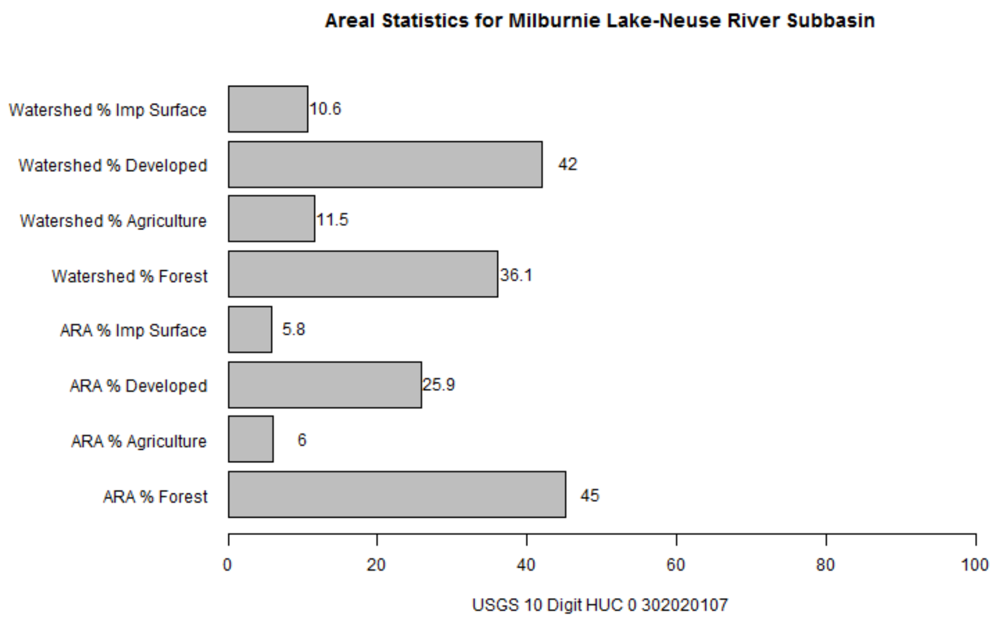


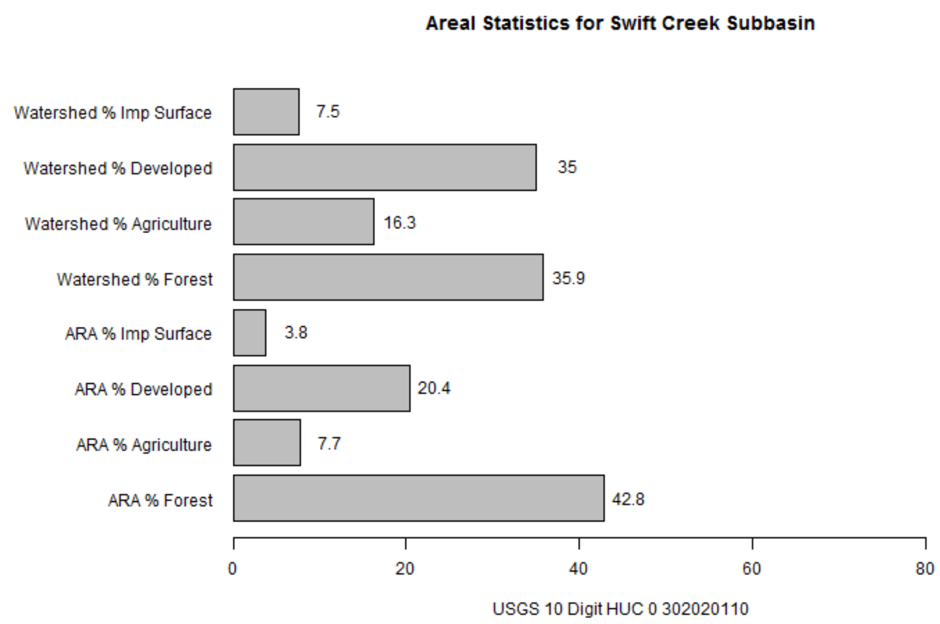
Survey Summary: This MU includes the Neuse River and several tributaries (Crabtree Creek, Swift Creek, Middle Creek, Mill Creek). Historical records of Carolina Madtoms have been documented from 9 locations in this MU. The species was first seen in 1888 in the mainstem of the Neuse River near Milburnie, with additional records in the MU from 1979 and 1985. Subsequent surveys have not detected the species. A total of 53 live individuals have been observed over time in this MU (NCNHP 2016).

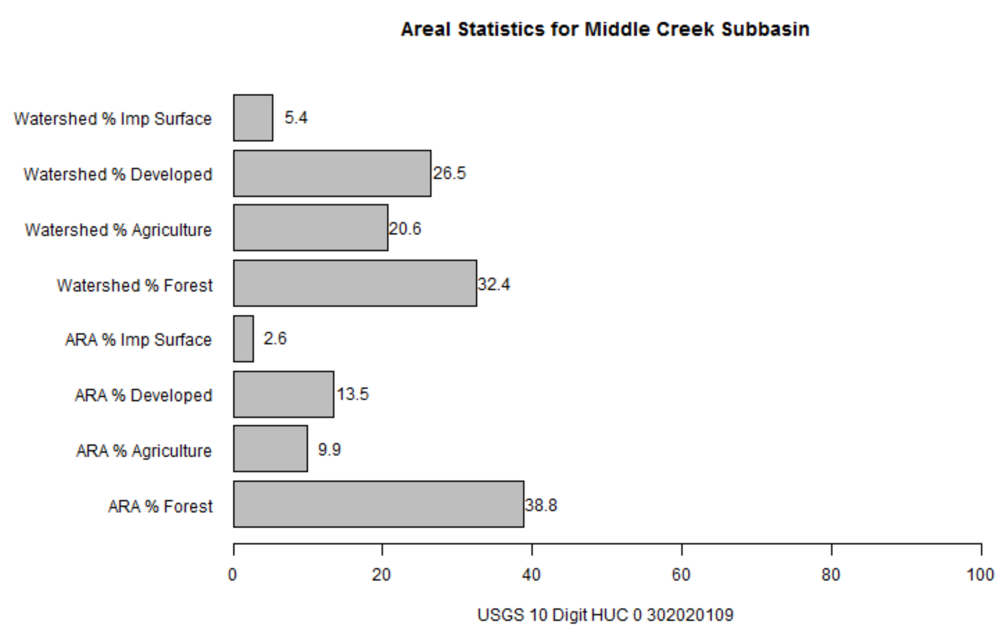
Water Quality Information: Based on the 2014 data, there are 33 impaired stream reaches totaling ~182 miles in this MU. There are many reasons for a designation of impairment, including low benthic-macroinvertebrate assessment scores, poor fish community scores, low DO, PCBs, and Copper. There are 272 non-major and 9 major (Apex WRF, CP&L, Little Creek WWTP, two Cary WWTPs, Dempsey Benton WTP, Benson WWTP, Smith Creek WWTP, and Terrible Creek WWTP) NPDES discharges in this MU.

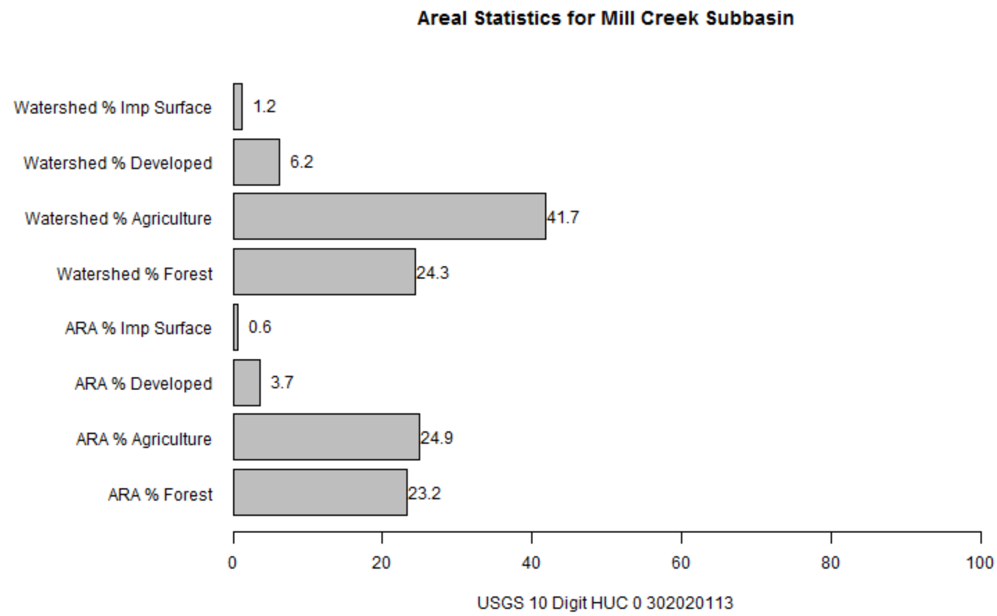
Land Use Land Cover Summary Statistics:

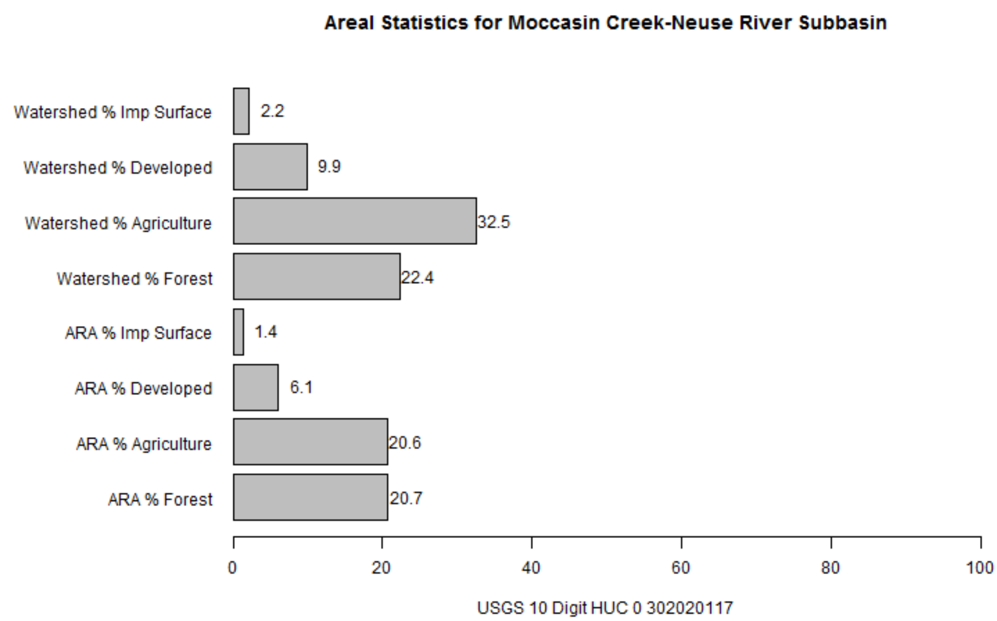




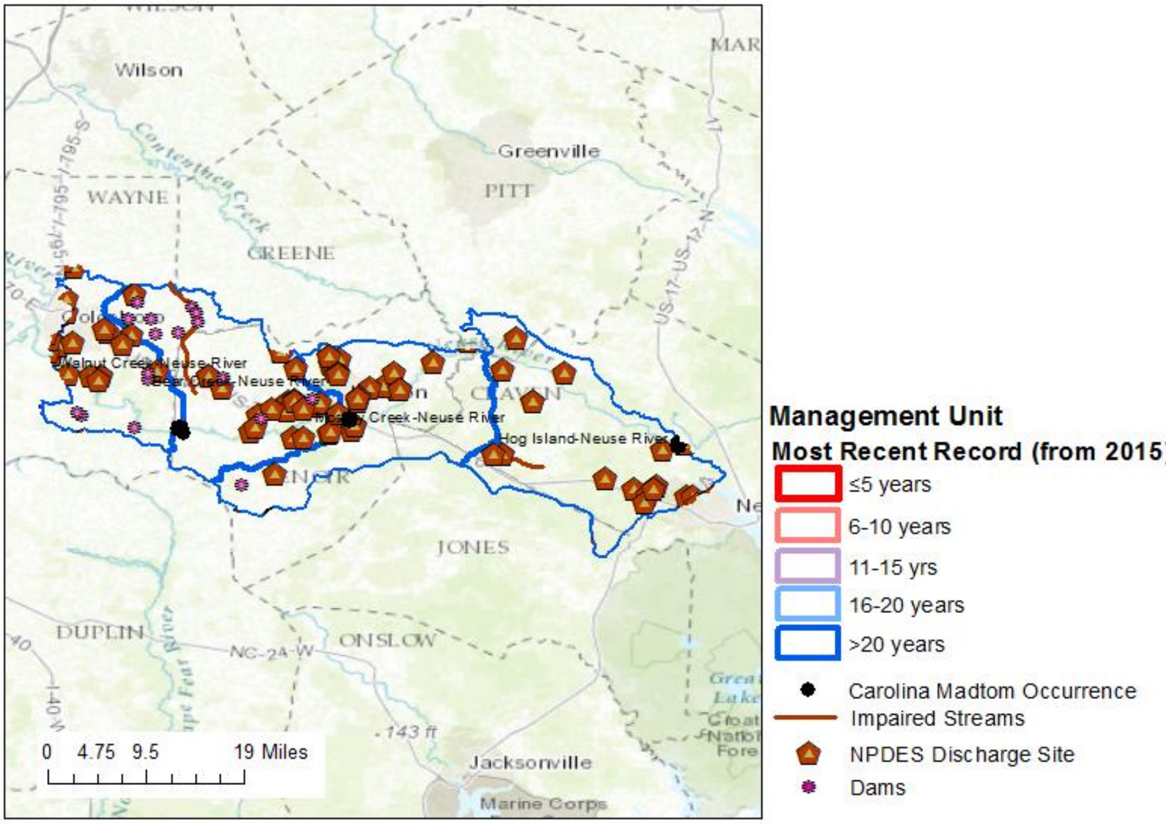

Areal Statistics for Swift Creek Subbasin
Watershed % Imp Surface
7.5
Watershed % Developed
35
Watershed % Agriculture
16.3
Watershed % Forest
35.9
ARA % Imp Surface
3.8
ARA % Developed
20.4
ARA % Agriculture
7.7
ARA % Forest
42.8
0
20
40
60
80
USGS 10 Digit HUC 0 302020110


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 Mill Creek Subbasin
Watershed % Imp Surface
1.2
Watershed % Developed
6.2
Watershed % Agriculture
41.7
Watershed % Forest
24.3
ARA % Imp Surface
0.6
ARA % Developed
3.7
ARA % Agriculture
24.9
ARA % Forest
23.2
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020113


Areal Statistics for Moccasin Creek-Neuse River Subbasin
Watershed % Imp Surface
2.2
Watershed % Developed
9.9
Watershed % Agriculture
32.5
Watershed % Forest
22.4
ARA % Imp Surface
1.4
ARA % Developed
6.1
ARA % Agriculture
20.6
ARA % Forest
20.7
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020117

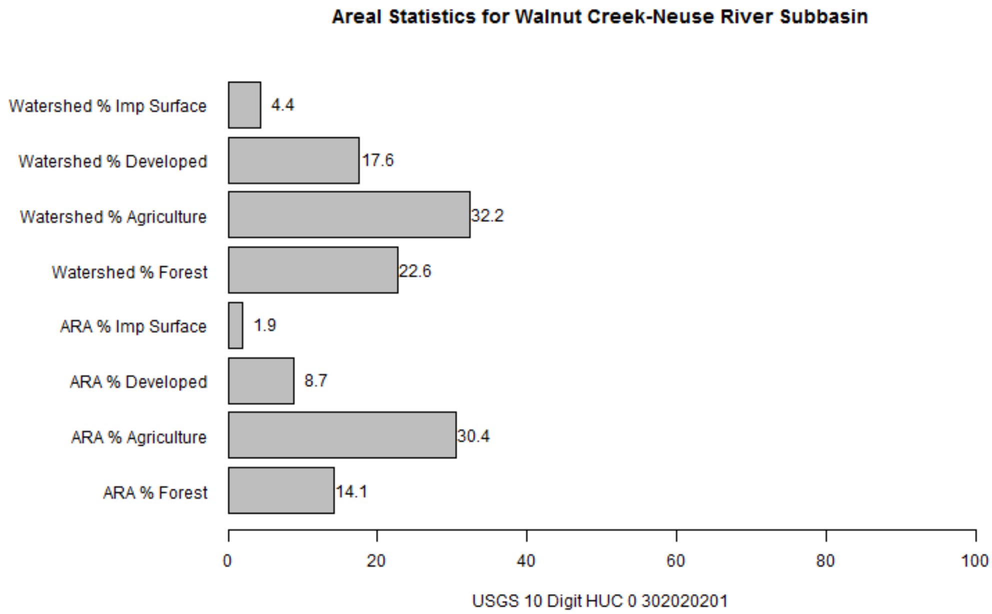
Lower Neuse Management Unit

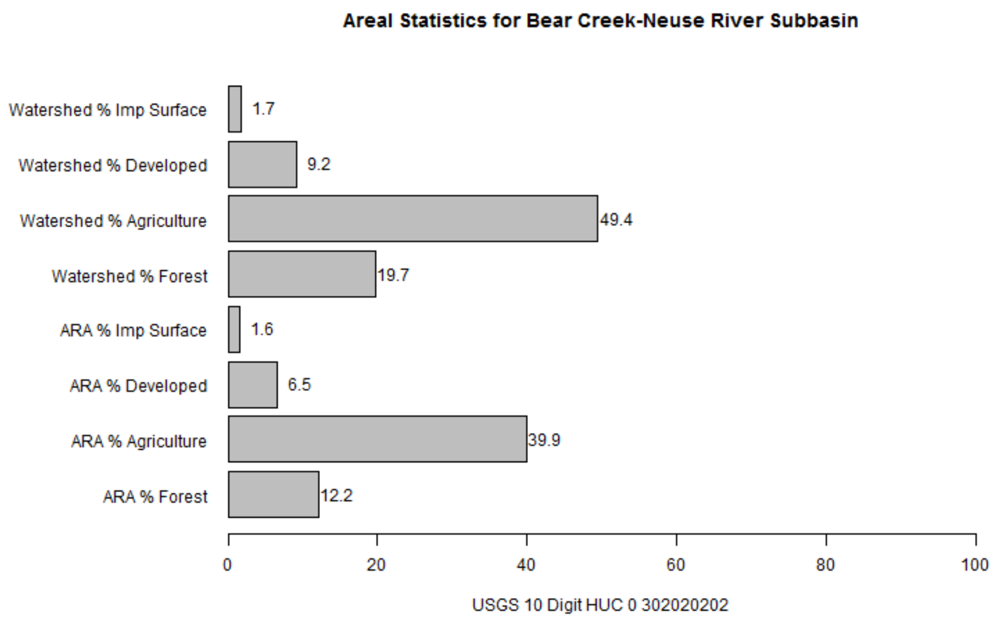


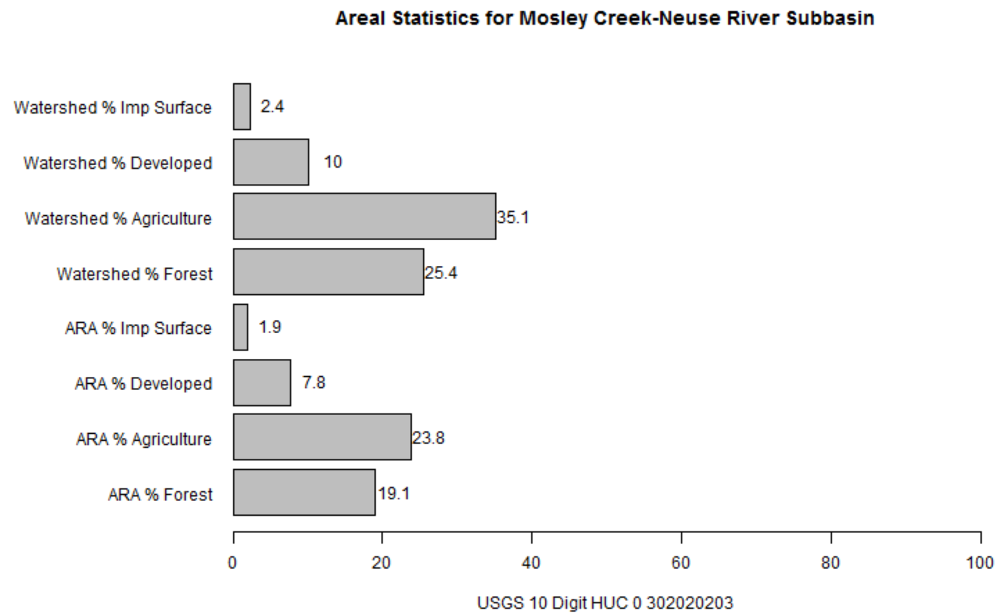
Survey Summary: First observation of the species was in 1960. Surveys in 1981 and 1985 found the species in a few mainstem Neuse locations. Follow-up surveys in 2012 and 2015 (NCDWR 2016) have not observed any live Carolina Madtoms. A total of 35 live individuals have been observed over time in this MU (NCNHP 2016).

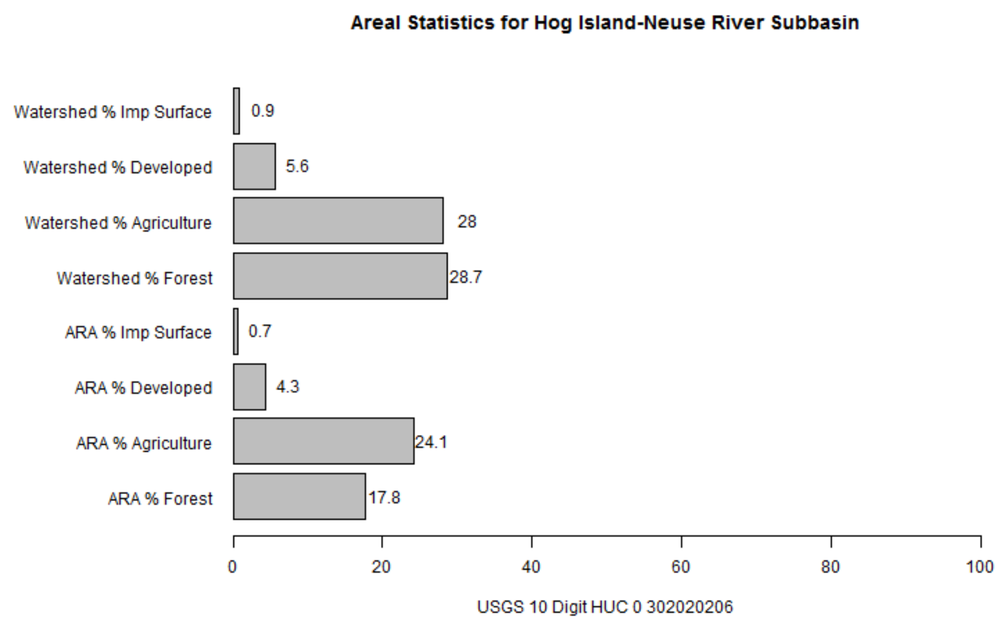
Water Quality Information: Based on the 2014 data, there are 3 impaired stream reaches totaling ~15 miles in this MU. The reason for a designation of impairment was primarily due to severe to low benthic-macroinvertebrate assessment scores. There are 80 non-major and 3 major (Goldsboro WRF, Kinston WRF and WWTP) NPDES discharges in this MU.

Land Use Land Cover Summary Statistics:

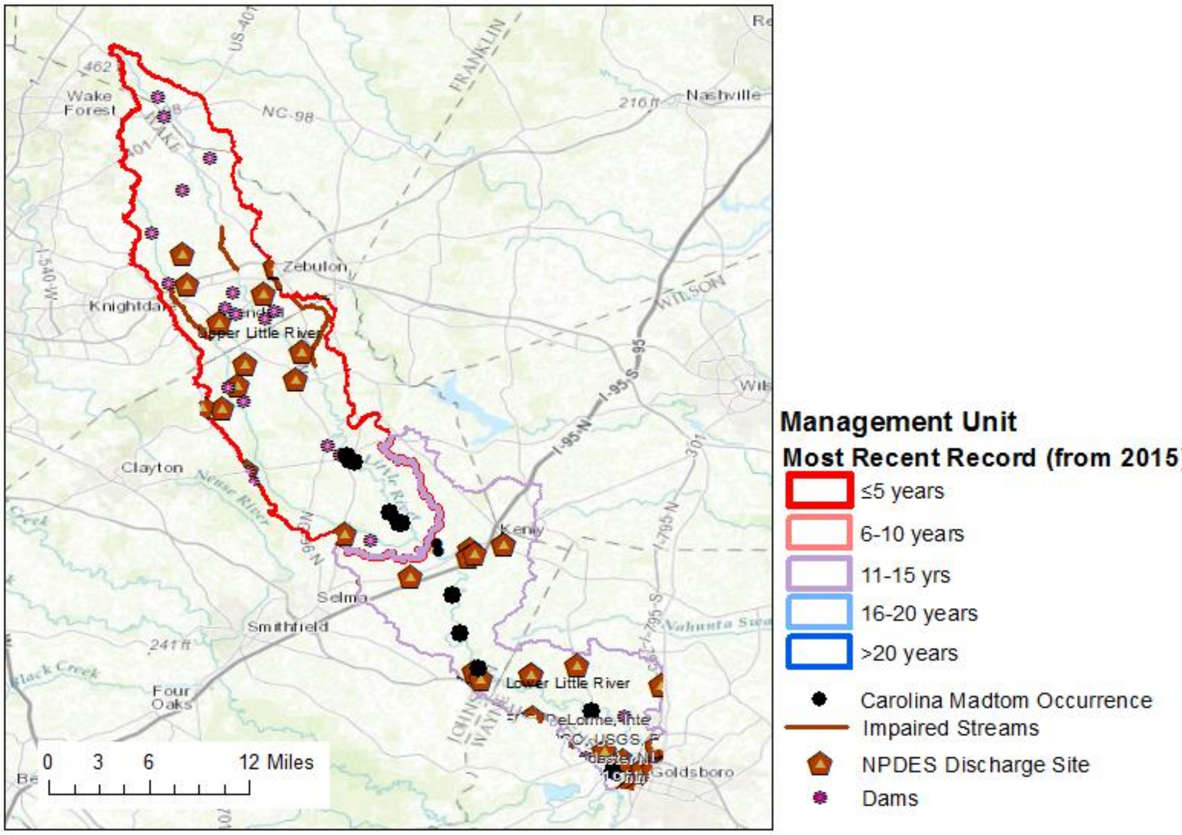





Areal Statistics for Mosley Creek-Neuse River Subbasin
Watershed % Imp Surface
2.4
Watershed % Developed
10
Watershed % Agriculture
35.1
Watershed % Forest
25.4
ARA % Imp Surface
1.9
ARA % Developed
7.8
ARA % Agriculture
23.8
ARA % Forest
19.1
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020203


Areal Statistics for Hog Island-Neuse River Subbasin
Watershed % Imp Surface
0.9
Watershed % Developed
5.6
Watershed % Agriculture
28
Watershed % Forest
28.7
ARA % Imp Surface
0.7
ARA % Developed
4.3
ARA % Agriculture
24.1
ARA % Forest
17.8
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020206

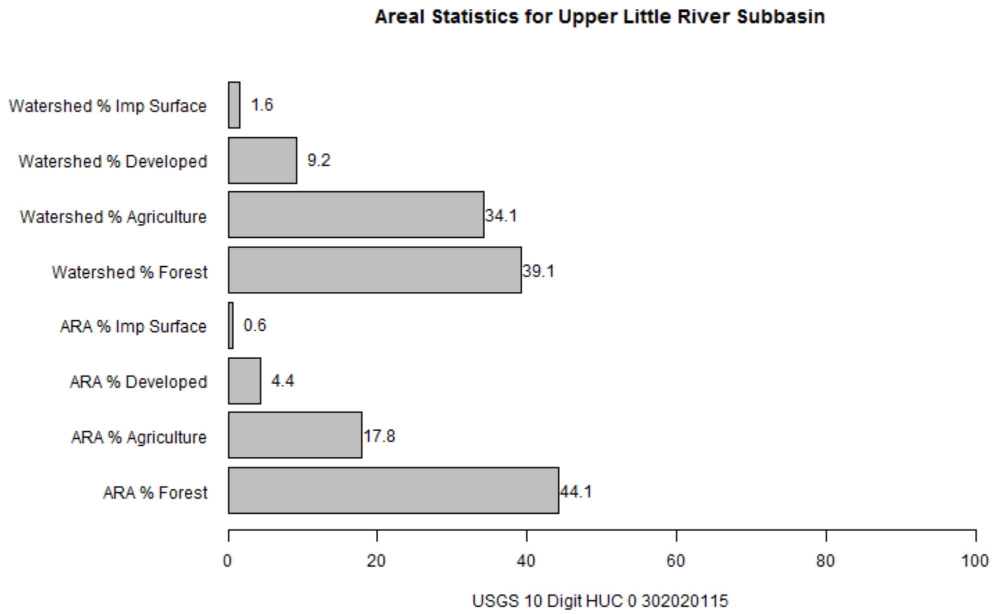
Little River Management Unit

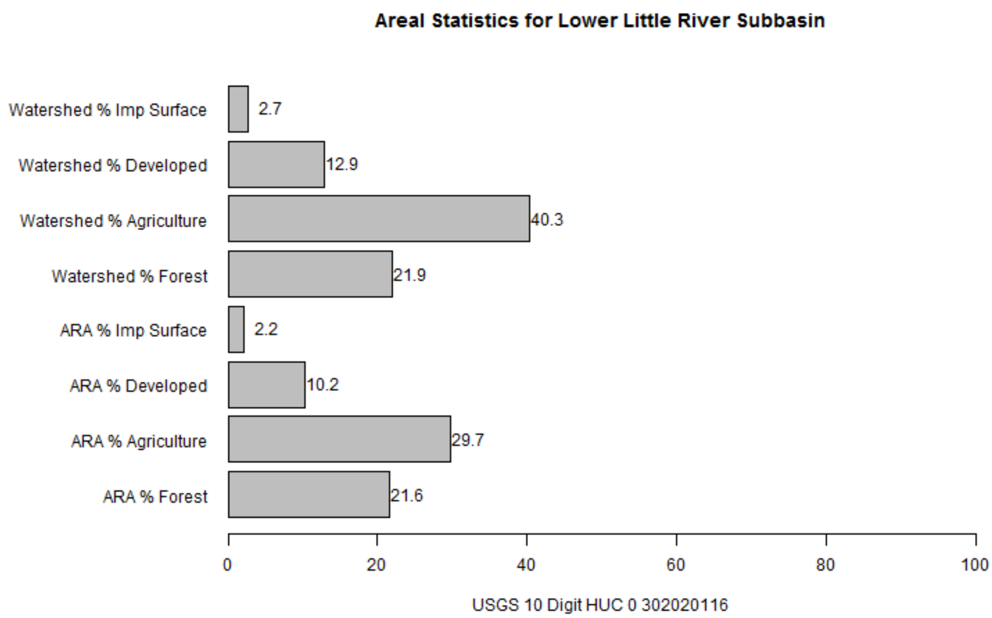


Survey Summary: First observation of the species was in 1961. This MU includes the Upper and Lower Little River. Carolina Madtoms have been documented at 10 locations in this MU – the species was first documented in 1979, and most recently seen in 2016 during surveys for the Atlantic Coast Pipeline (ESI 2016, p.34). Most surveys document fewer than a handful of individuals per survey, with the most being 16 (seen in 1961). Madtom abundances have been described as "rare" in this MU. Recruitment has not been documented, and only larger/older individuals (>60mm) have been observed. A total of 56 live individuals have been observed over time in this MU (NCWRC PAWS 2016).

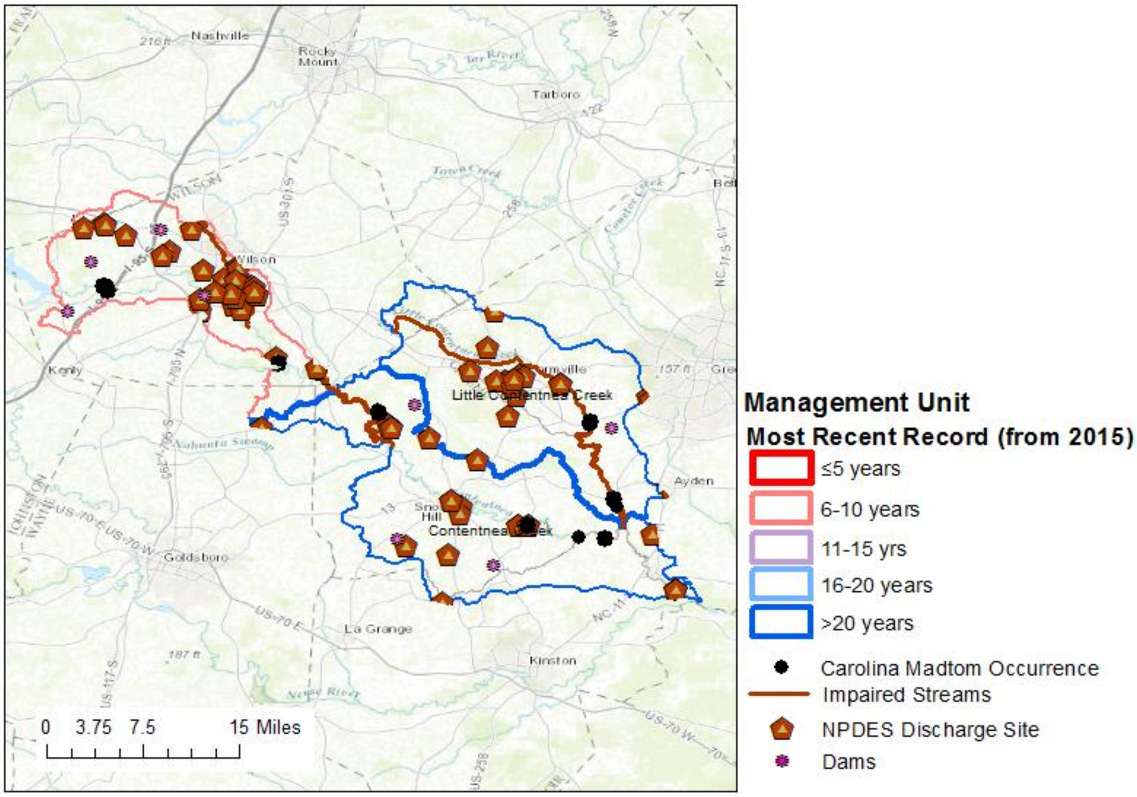
Water Quality Information: Based on the 2014 data, there are 4 impaired stream reaches totaling ~17 miles in this MU. The reason for a designation of impairment was due to primarily low benthic-macroinvertebrate assessment scores, low pH, and low DO. There are 32 non-major and no major NPDES discharges in this MU.

Land Use Land Cover Summary Statistics:





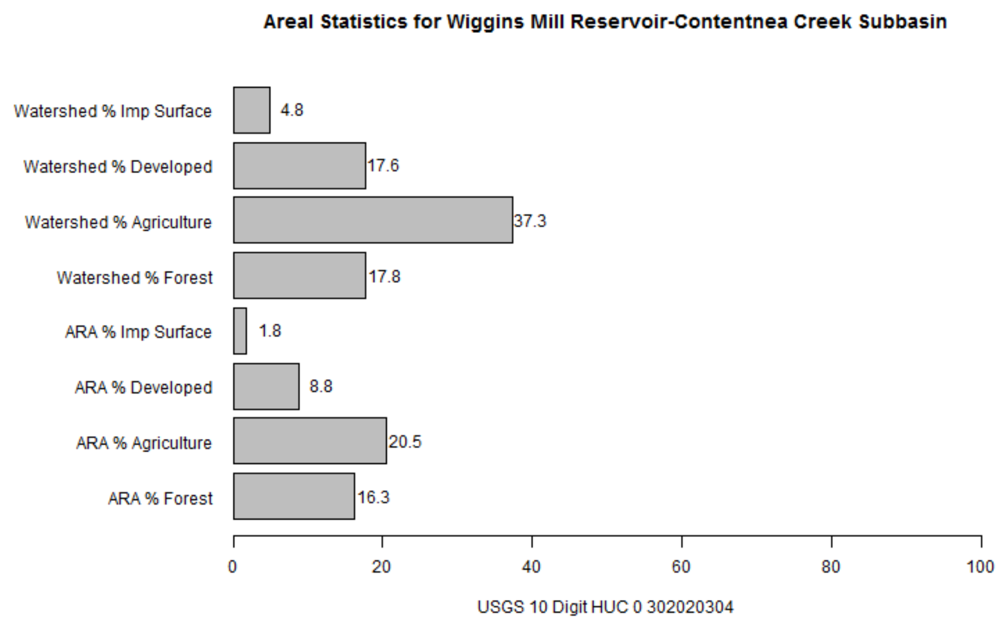
Contentnea Creek Management Unit

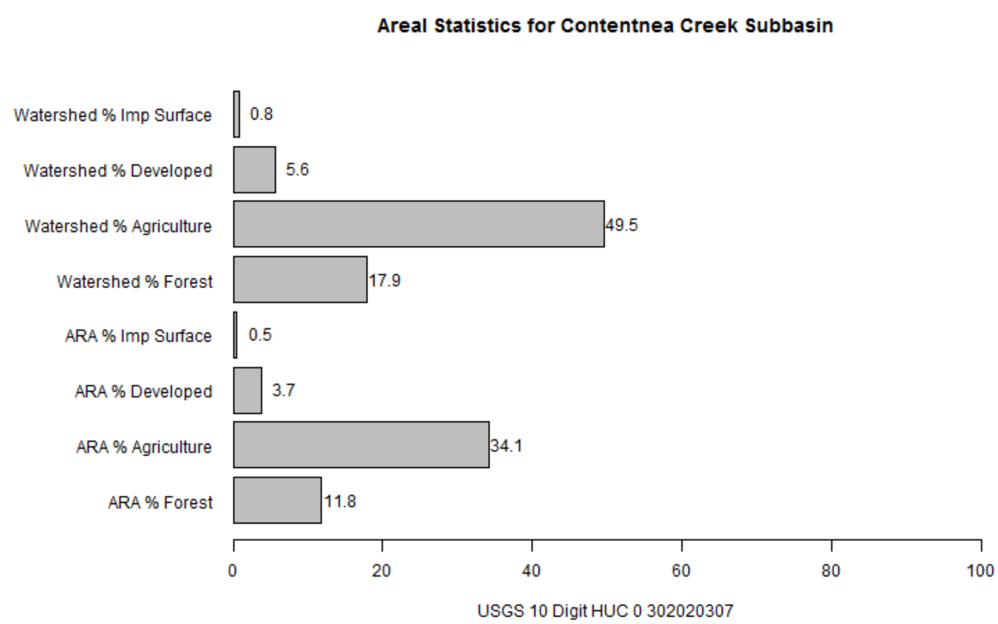


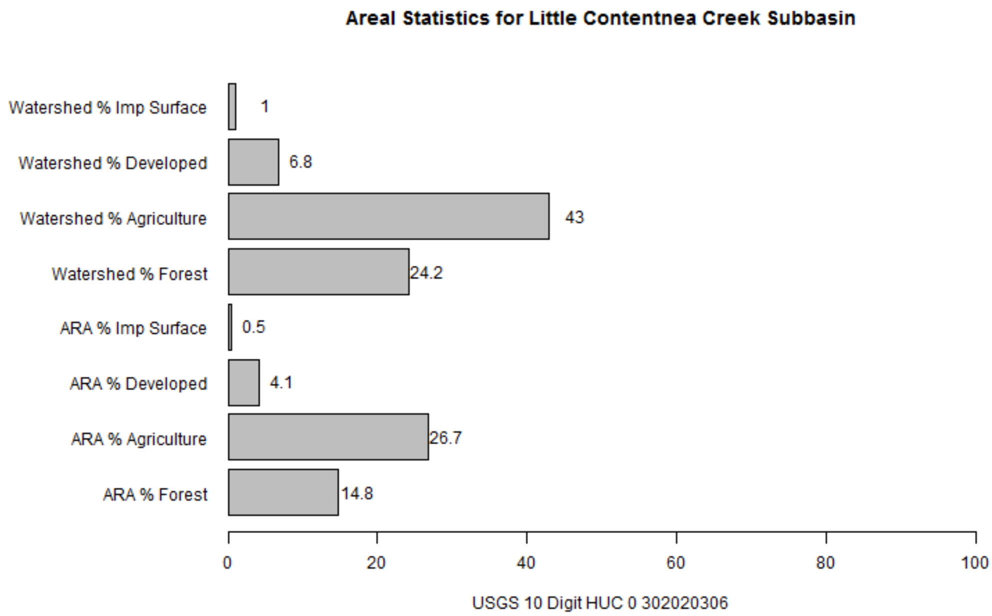
Survey Summary: This MU includes Little Contentnea Creek and Contentnea Creek. Carolina Madtoms have been documented at 7 locations in this MU – the species was first documented in 1960. Most surveys document low numbers of individuals per survey, with the most being 13 (seen in 2007). Madtom abundances have been described as “uncommon” to “common” in this MU. Recruitment has been documented as recently as 2007, although mostly larger individuals (>60mm) have been observed. A total of 63 live individuals have been observed over time in this MU (NCWRC PAWS 2016).

Water Quality Information: Based on the 2014 data, there are 2 impaired stream reaches totaling ~21 miles in this MU. The primary reason for a designation of impairment was due to low benthic-macroinvertebrate assessment scores. There are 77 non-major and 3 major (Wilson WWTP, Farmville WWTP, Contentnea Sewer District) NPDES discharges in this MU.

Land Use Land Cover Summary Statistics:



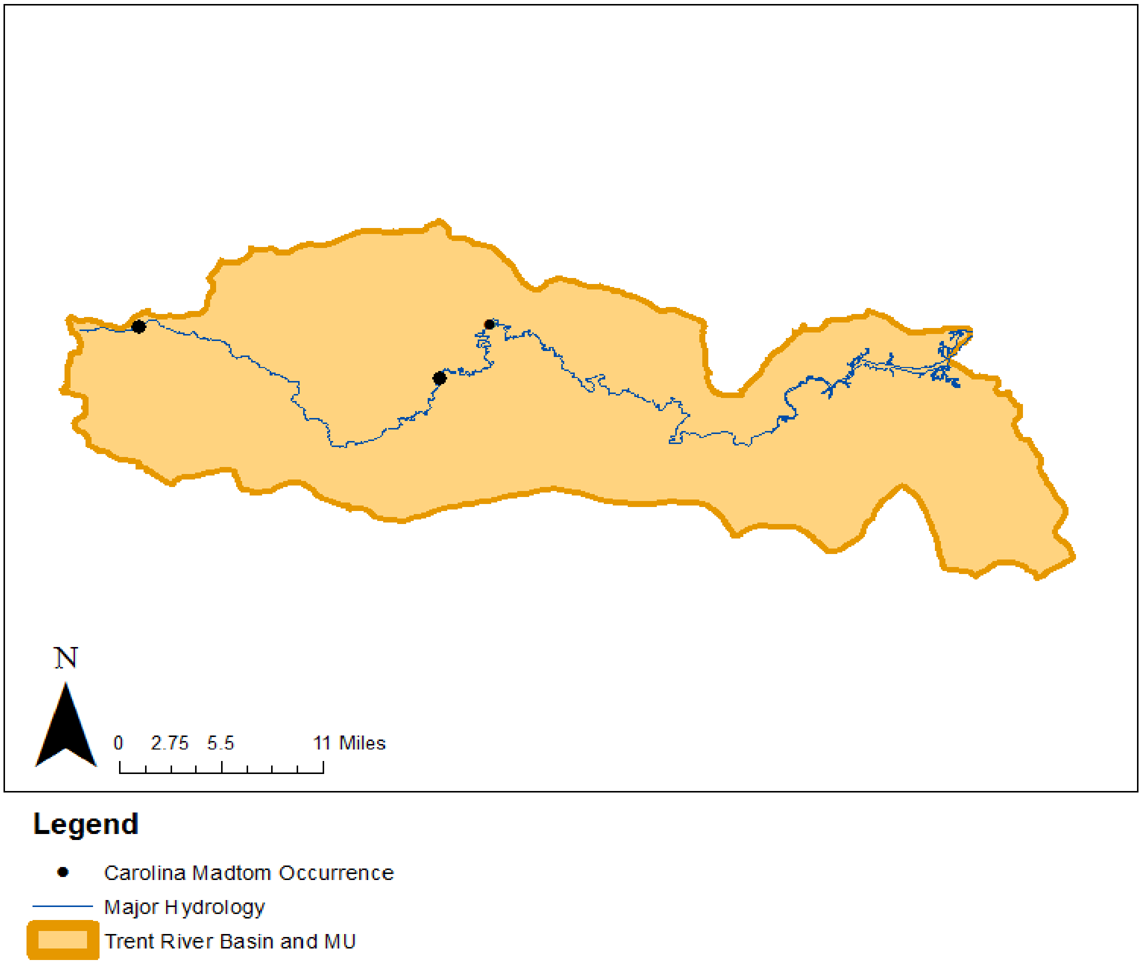




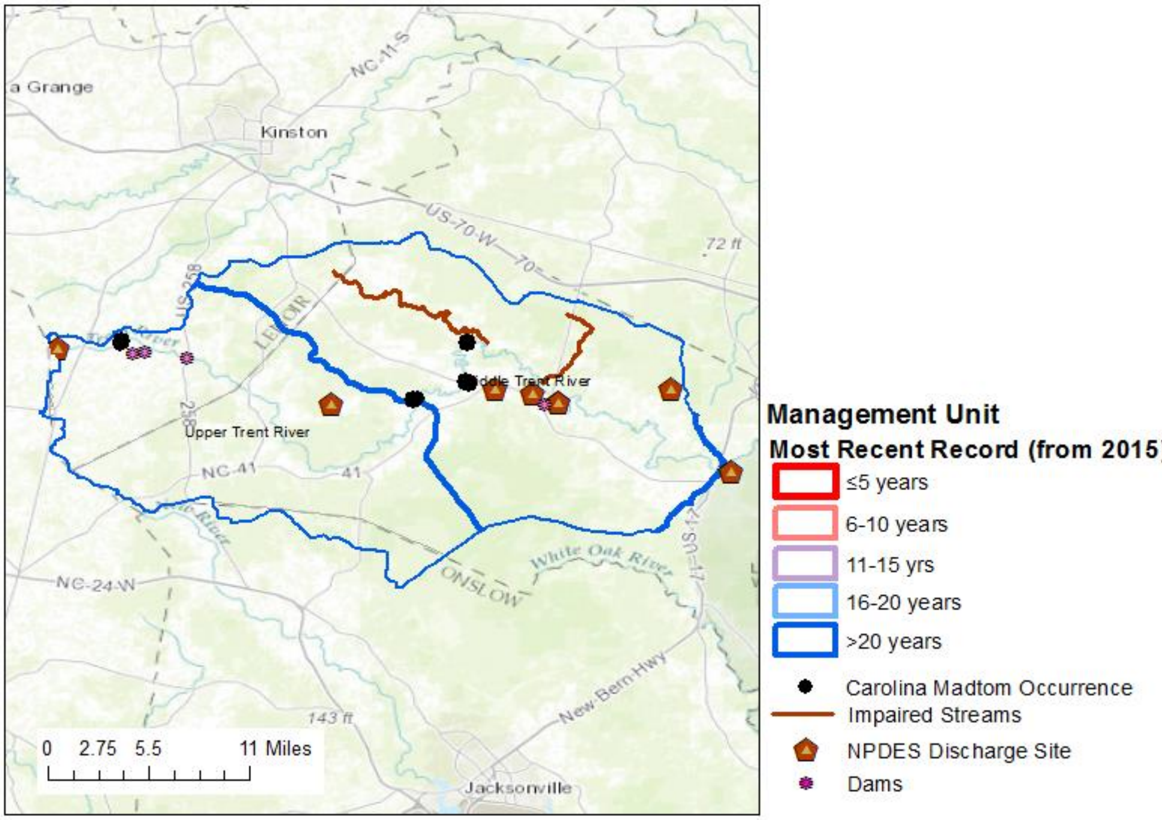
Areal Statistics for Little Contentnea Creek Subbasin
Watershed % Imp Surface
1
Watershed % Developed
6.8
Watershed % Agriculture
43
Watershed % Forest
24.2
ARA % Imp Surface
0.5
ARA % Developed
4.1
ARA % Agriculture
26.7
ARA % Forest
14.8
0
20
40
60
80
100
USGS 10 Digit HUC 0 302020306

Trent River Population

Consists of one Management Unit (Trent River MU):



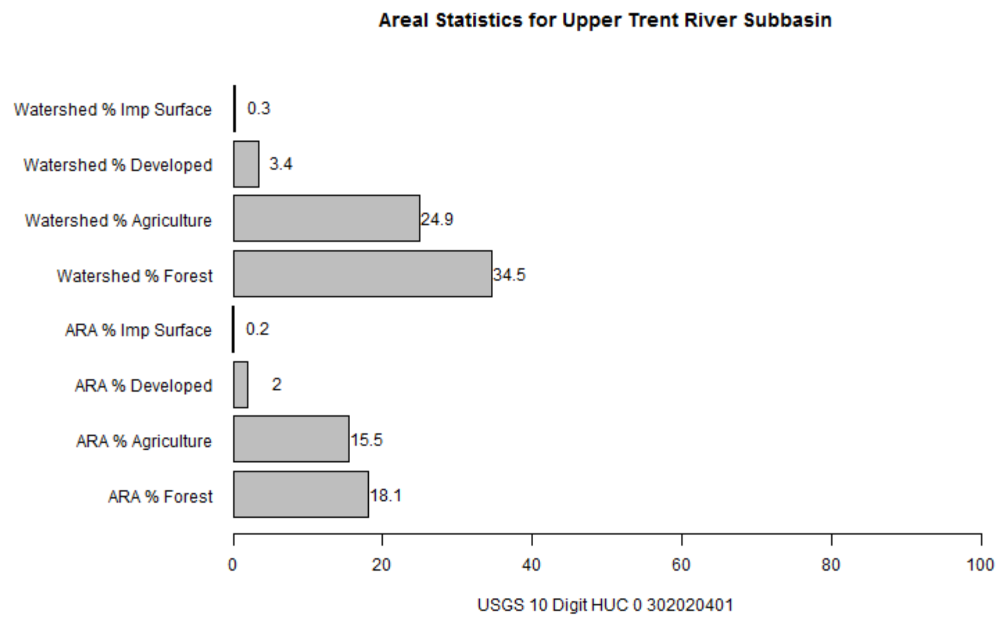
Trent River Management Unit

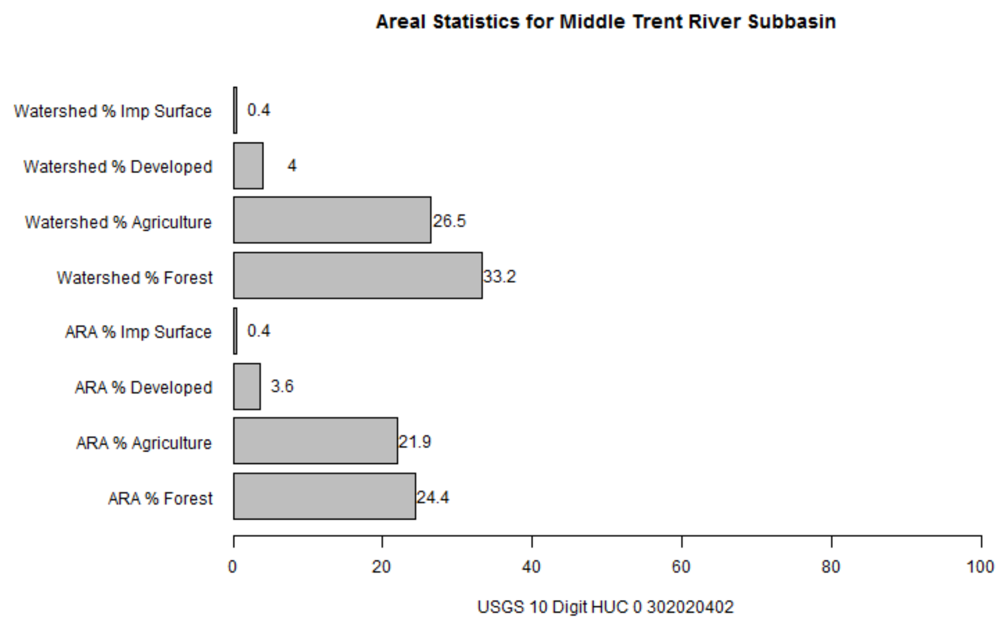


Survey Summary: The species was first observed in 1960. There are a few historical records of Carolina Madtom in this MU from 1985-1986. Follow-up surveys in 2007 and 2015 were unable to observe any individuals (NCDWR 2015). A total of 16 live individuals have been observed over time in this MU (NCNHP 2016).

Water Quality Information: Based on the 2014 data, there are 2 impaired stream reaches totaling ~18 miles in this MU. The primary reason for a designation of impairment was primarily due to severe to low benthic-macroinvertebrate assessment scores. There are 7 non-major and no major NPDES discharges in this MU.

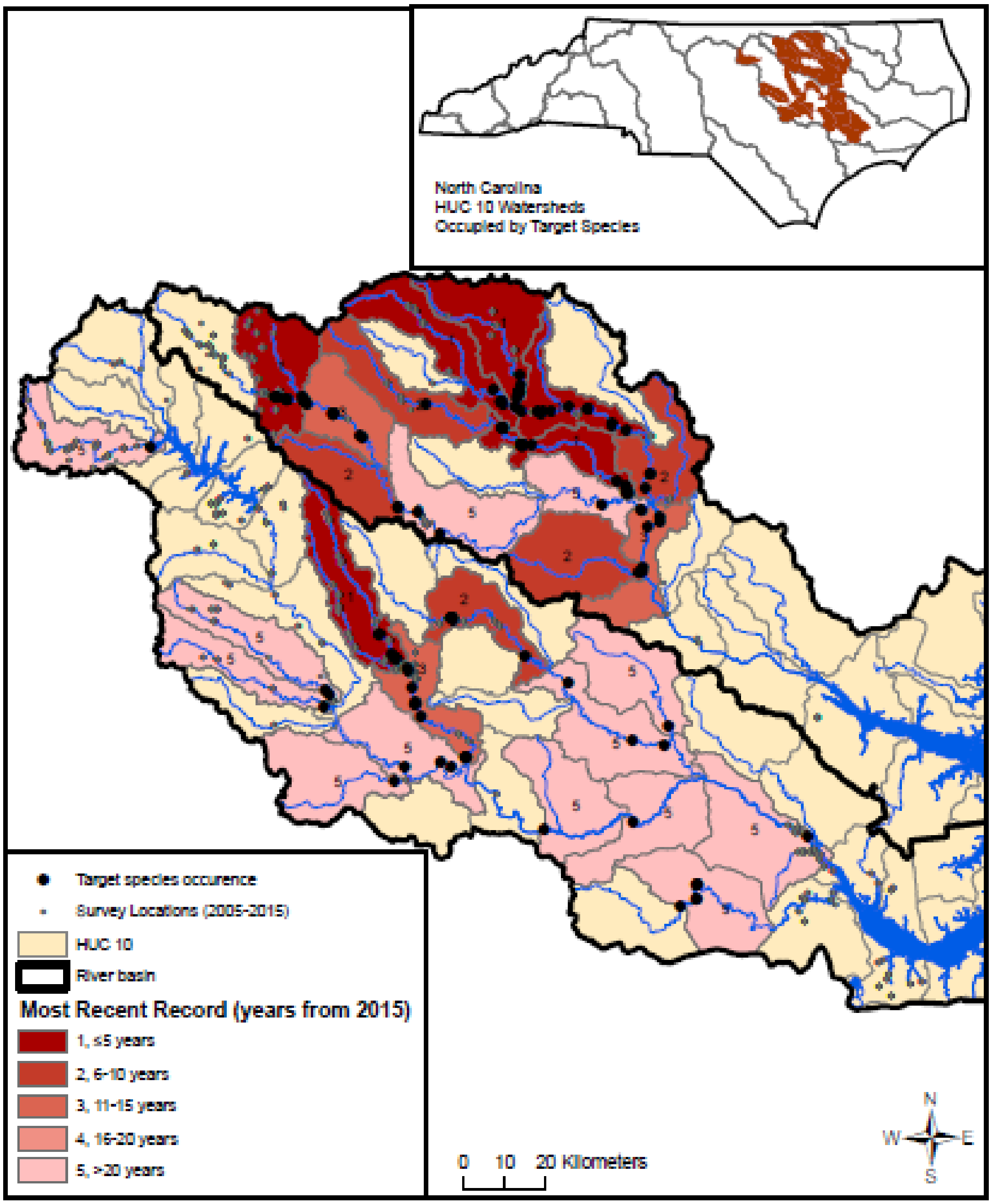
Land Use Land Cover Statistics:





Appendix B – Carolina Madtom Heat Map

Occurrences by HUC 10 Watershed of the Carolina Madtom (*Noturus furiosus*) and Survey Locations



Map created by: Tyler Black, Ph.D., 1/11/2016
Data sources: NC Wildlife Resources Commission and NC Museum of Natural Sciences

Appendix C – Data for Population Factors and Habitat Elements

Population/ Management Unit	# of Historically Occupied MUs	# of Currently Occupied MUs	# Historically Occupied HUC10s	# Currently Occupied HUC10s	% Decline	MU Occupancy Condition	Approx Abundance (#live over time)	Recent (past 10-years) Large # Observed?	Recent (past 5-years) Large # Observed?	Date Last Observed	Number Last Observed	Approx Abundance Condition	Recent (past 5-years) Reproduction/ Recruitment	# of Recent Sites	# of Recent Recruitment Sites	% sites with evidence of recent reproduction	Reproduction Condition	Current Condition - Population Factors
	Occupancy Factors						Abundance Factors						Reproduction Factors					
Tar	5	3	13	7	**46**	**L**						**L**					**L**	**L**
Upper Tar			2	2	0	H	122	Y	N	2016	2*	L	N	9	1	11	L	L
Middle Tar			3	0	100	Ø	31	Y	N	2007	22	L	N	3	0	0	Ø	Ø
Lower Tar			2	0	100	Ø	18	N	N	2007	1	L	N	0	0	0	Ø	Ø
Fishing Ck Subbasin			4	3	25	H	147	Y	N	2016	1	L	Y	25	3	12	L	M
Sandy-Swift			2	2	0	H	135	Y	Y	2016	17	M	Y	20	2	10	M	H
Neuse	5	1	16	1	**94**	**VL**						**VL**					**VL**	**VL**
Upper Neuse			1	0	100	Ø	1	N	N	1961	1	VL	N	0	0	0	Ø	Ø
Middle Neuse			6	0	100	Ø	53	N	N	1985	4	VL	N	0	0	0	Ø	Ø
Lower Neuse			4	0	100	Ø	35	N	N	1985	1	VL	N	0	0	0	Ø	Ø
Little River			2	1	50	L	56	N	N	2016	occupied	L	N	2	0	0	VL	L
Contentnea			3	0	100	Ø	63	Y	N	2007	13	L	N	6	1	17	L	Ø
Trent	1	0	2	0	**100**	**Ø**	8	N	N	1985	1	**VL**	N	0	0	0	**Ø**	**Ø**

* two surveys in 2012 documented CMT as "present" without #s provided

Population/ Management Unit	#HUC10s	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 (NC layer)	# of Dams (NID)	# of Road Crossings	Avg # Rd Crossings	Overall Connectivity Condition	Avg ARA % Forest	Avg Watershed % Imp Surface	Overall Instream Habitat (Substrate) Condition - combine ARA Forest + Watershed Impervious Surface	Current Condition - Habitat Elements
				Water Quality				Water Quantity			Connectivity					Instream Habitat			
Tar							**M**			**M**					**M**			**M**	**M**
Upper Tar	2	797	308	2	2	41	M	channels	2008, 2009, 2010	L	64	20	543	272	M	63	1.7	H	M
Middle Tar	3	1142	441	24	2	80	M	none	2008, 2009, 2010	M	67	30	911	304	M	37	2.8	M	M
Lower Tar	2	837	323	7	1	33	M	none	2010	M	15	10	517	259	H	18	1.6	L	M
Fishing Ck Subbasin	4	1637	632	14	1	33	M	Y - beavers	2008, 2009, 2010	M	23	16	764	191	M	48	0.6	M	M
Sandy Swift Ck	2	705	272	5	0	24	H	windthrow	2008, 2009, 2010	L	31	25	431	216	M	44	1.3	M	M
Neuse							**L**			**L**					**M**			**L**	**L**
Upper Neuse	1	401	155	2	1	162	L	Y	2008, 2009, 2010,	L	33	27	657	657	M	67	3.5	M	M
Middle Neuse	6	2353	908	182	9	272	L	Y	2008, 2009, 2010,	L	287	197	3973	662	L	34	7.8	L	L
Lower Neuse	4	1889	729	15	3	80	L	none	2010	M	23	17	1768	442	M	16	2.3	L	M
Little River	2	817	315	17	0	32	M	Y - beavers	2008, 2009, 2010	L	30	21	749	375	M	33	2.2	M	M
Contentnea Creek	3	1356	524	21	3	77	L	Y?	2010	L	11	8	1113	371	H	14	2.2	L	L
Trent							**H**			**M**					**H**			**M**	**H**
Trent	2	970	375	18	0	7	H	none	2010	M		4	502	251	H	21	0.4	M	H