Species Status Assessment Report
for the
Chowanoke Crayfish
(*Faxonius virginiensis*)
Version 1.0

Chowanoke Crayfish
(Credit: Michael A. Perkins, North Carolina Wildlife Resources Commission)

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U.S. Fish and Wildlife Service
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This document was prepared by Jennifer Stanhope (U.S. Fish and Wildlife Service (Service) - Virginia Field Office), Michelle Shoultz (Service - Headquarters), Sandra Lary (Service - North Atlantic-Appalachian Regional Office (NA-ARO)), Emily Wells (Service - Raleigh Field Office), Doug Newcomb (Service - Raleigh Field Office), Michael Fisk (North Carolina Wildlife Resources Commission (NCWRC)), Matthew Hinderliter (Service - NA-ARO) and Krishna Gifford (Service - NA-ARO).

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EXECUTIVE SUMMARY

This species status assessment (SSA) reports the results of the comprehensive status review for Chowanoke crayfish (*Faxonius virginiensis*) (Hobbs 1951), documenting the species' historical condition, and providing estimates of current and future condition under a range of different scenarios. The Chowanoke crayfish is a freshwater crustacean native to the Chowan and Roanoke River basins in Virginia and North Carolina. The species occurs in perennial streams and rivers with moderate to high gradient and flow, with rocky substrate, woody debris, and/or vegetation for shelter.

The SSA process can be categorized into three sequential stages. During the first stage, we used the conservation biology principles of resiliency, redundancy, and representation (together, the 3Rs) to evaluate species needs of the Chowanoke crayfish (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 viability of the Chowanoke crayfish, we assessed a range of conditions to allow us to consider the species' resiliency, representation, and redundancy. For the purposes of this assessment, we assume that Chowanoke crayfish populations are delineated based on the river basins that they historically occupied, which are the Chowan and Roanoke River basins. Because the river basin level is at a very coarse scale, subpopulations were further delineated using analysis units (AUs). AUs were defined as one or more Hydrologic Unit Code 10 (HUC10) watersheds within a HUC8 subbasin and identified by species experts 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 healthy populations distributed across its range to sustain populations through the natural range of favorable and unfavorable conditions into the future. A number of factors, including (but not limited to) instream habitat, water quality, water quantity, and habitat connectivity, may influence whether Chowanoke crayfish populations will occupy available habitat. As we considered the viability of the species, more subpopulations with high or moderate condition distributed across the known range of the species can be associated with higher species viability. The species currently occupies all six historically occupied AUs within its range and most of the AUs (83 percent) are designated as high condition, which provide high resiliency to environmental stochasticity.

Redundancy describes the ability of the species to withstand catastrophic disturbance events; for the Chowanoke crayfish, we considered whether the distribution of occupied HUC10 watersheds and healthy AUs within each basin and across the range was sufficient for minimizing the potential loss of the species from such an event. The Chowanoke crayfish continues to be observed in all six AUs in the Chowan and Roanoke River basins, in moderate or high condition, in a total of 24 HUC10 watersheds out of 28 that were historically occupied (14-percent decline). The occupied HUC10 watersheds are evenly distributed within AUs and both basins.

Representation characterizes a species' adaptive potential by assessing geographic, genetic, ecological, and niche variability. For the Chowanoke crayfish, we assume that the species' representation requirements are best met by retaining its distribution within the river basins and physiographic provinces. The species remains distributed in headwater streams (third order) to mainstem rivers (six order or larger) within both the Chowan and Roanoke River basins throughout its historical western to eastern extent and in the Coastal Plain and Piedmont provinces. Some of the representation of the Chowanoke crayfish has been lost in the Chowan and Roanoke River basins, with a 10-percent and 25-percent decline in occupied HUC10 watersheds, respectively. In the Piedmont and Coastal Plain province, a majority of the representation has been retained, with a 9-percent and 18-percent decline in HUC10 watersheds occupied, respectively.

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 condition and forecasted its future condition 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.

<u>Current Condition Summary</u>
The historical range of the Chowanoke crayfish included streams and rivers (third to eighth order) in the Chowan and Roanoke River basins, with documented historical distribution in six AUs within the two populations (i.e., basins) (Figure ES-1). The Chowanoke crayfish is extant in all six AUs and occupies 86 percent (24/28) of the historically occupied HUC10 watersheds, which are evenly distributed within AUs and both populations. Of the six AUs, five (83 percent) are estimated to have high resiliency and one (17 percent) moderate resiliency. Scaling up from the AU to the population level, both the Chowan and Roanoke populations are estimated to have high resiliency, but have lost some of their representation with a 10-percent and 25-percent decline in occupied HUC10 watersheds, respectively. The species is known to occupy streams/rivers in two physiographic regions and has lost some representation with an estimated 9-percent decline in occupied HUC10 watersheds in the Piedmont province and an estimated 18-percent decline in occupied HUC10 watersheds in the Coastal Plain province. The effects of land use change and climate change (e.g., increasing sea level rise (SLR)) have likely begun to occur in minor portions of the current Chowanoke range and may have contributed to some habitat degradation.

<u>Future Conditions Summary</u>
To assess the future condition of the Chowanoke crayfish, the primary threats of land use change, climate change, and nonnative crayfish and their (potential) effects on resiliency (i.e., overall condition) were considered. Populations with very 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 three plausible

future scenarios out to 50 years (Table ES-2). These scenarios were based, in part, on the results of urbanization (Terando et. al. 2014), climate models (International Panel on Climate Change 2014), and nonnative crayfish effects that were used to project changes in habitat used by the Chowanoke crayfish.

An important assumption of the future analysis was that future resiliency is largely dependent on water quality (including freshwater conditions), water quantity/flow, and riparian and instream habitat conditions. Our assessment predicted that some currently extant Chowanoke crayfish populations would experience negative changes to these important habitat requisites; predicted viability varied among scenarios and is summarized below, and in Tables ES-1 and ES-3 and Figure ES-1.

For Scenario 1, the "Continuation of Current Trends" option, a minor loss of resiliency, representation, and redundancy is expected at the end of 50 years. Under this scenario, we predicted that the species will continue to occupy all six AUs, with three (50 percent) AUs in high condition and three (50 percent) in moderate condition. More AUs with moderate condition are predicted in the eastern and southern portions of the range, mainly due to projected moderate increase in inundation of higher salinity waters and associated loss of suitable habitat caused by SLR and moderate decline in water quantity. However, instream habitat and water quality are projected to remain high for most of the AUs. Scaling up from the AU to the population level, the Chowan population is predicted to have high resiliency and the Roanoke population moderate resiliency; both populations will lose some representation with a 20-percent and 37-percent decline in occupied HUC10 watersheds, respectively. Redundancy would be reduced to 21 occupied HUC10 watersheds (75 percent of the historically occupied HUC10 watersheds) across the range, with uneven distribution in the Chowan and Lower Roanoke AUs and both populations. Representation is predicted to be the same for the Piedmont province, but predicted to exhibit a 35-percent decline in occupied HUC10 watersheds in the Coastal Plain province.

For Scenario 2, the "Increase in Rates of Land Use Changes and Climate Change Effects" option, we predicted additional losses of resiliency, representation, and redundancy at the end of 50 years. We predicted that the Middle Roanoke AU in the Roanoke population will likely be extirpated due to projected loss of significant instream habitat caused by nonnative virile crayfish, thereby displacing Chowanoke crayfish. However, the other five AUs in the Chowan and Roanoke populations will be in moderate or high condition, thus maintaining high (33 percent) and moderate (50 percent) resiliency in the remaining five subpopulations. More AUs with moderate condition are predicted in the eastern and southern portions of the range, mainly due to projected greater increase in inundation of higher salinity waters and associated loss of suitable habitat caused by SLR, moderate/low instream habitat condition, and low water quantity condition. The nonnative red swamp crayfish is also projected to contribute a decrease in instream habitat condition for all AUs. Scaling up from the AU to the population level, both the Chowan and Roanoke populations are predicted to have moderate resiliency and reduced representation with a 25-percent and 50-percent decline in occupied HUC10 watersheds, respectively. Redundancy would be further reduced to 19 occupied HUC10 watersheds (68 percent of the historically occupied HUC10 watersheds) across the range, with uneven distribution across the range and no occupied HUC10 watershed in the Middle Roanoke AU. Representation is also predicted to decline in both the Piedmont and Coastal Plain provinces, with an 18-percent and 41-percent decline in occupied HUC10 watersheds, respectively. With the range contracting in the western and eastern portions of the Roanoke basin and eastern portion of the Coastal Plain province under Scenario 2, the species' representation is predicted to be reduced, and the Chowanoke crayfish may not be as adaptive to changing conditions after the 50-year period.

For Scenario 3, the "Continuation Plus Conservation" option, we predicted high levels of resiliency, representation, and redundancy at the end of 50 years. We predicted that the species will continue to occupy all six AUs, with five (83 percent) AUs in high condition and one (17 percent) AU in moderate condition, because instream habitat and water quality is projected to remain high for most of the AUs, mainly due to continuing high percentage of forested/wetland land cover and a low percentage of impervious surfaces in the watersheds. In addition, with an intermediate level increase in SLR, it is not anticipated that salinity levels will become high enough to cause a significant loss of suitable, occupied habitat. Conservation actions will also contribute to protecting and maintaining high quality habitat for the Chowanoke crayfish. Redundancy and representation are predicted to remain the same as current conditions and the occupied HUC10s will be evenly distributed within AUs and both populations.

<u>Overall Summary</u>

The Chowanoke crayfish faces a variety of stressors from declines in water quality, reduction of stream flow, riparian habitat loss, and deterioration of instream habitats. The primary threats affecting the Chowanoke crayfish are land use modification, climate change, and nonnative crayfish, therefore these factors were included in our assessment of the future condition of the Chowanoke crayfish. When resiliency is very low, populations become more vulnerable to extirpation, in turn, resulting in concurrent losses in representation and redundancy. Based on current and projected future habitat conditions and population factors, estimates of current and future resiliency for Chowanoke crayfish are high to moderate in the Chowan and Roanoke populations, as are estimates for redundancy and representation for two future scenarios (1 and 3) at the end of 50 years. For Scenario 2, the Middle Roanoke AU in the Roanoke population is predicted to be likely extirpated, but the other five AUs in the Chowan and Roanoke populations will be in moderate or high condition, thus maintaining resiliency for five (83 percent) subpopulations. Redundancy is predicted to be reduced, but still at a moderate level across the range, with 68 percent of the HUC10 watersheds occupied. Representation in the Roanoke population and Coastal Plain province will decline, with the range contracting in the southwestern and eastern portions of the range. Under Scenario 2, the Chowanoke crayfish may not be as adaptive to changing conditions after the 50-year period.

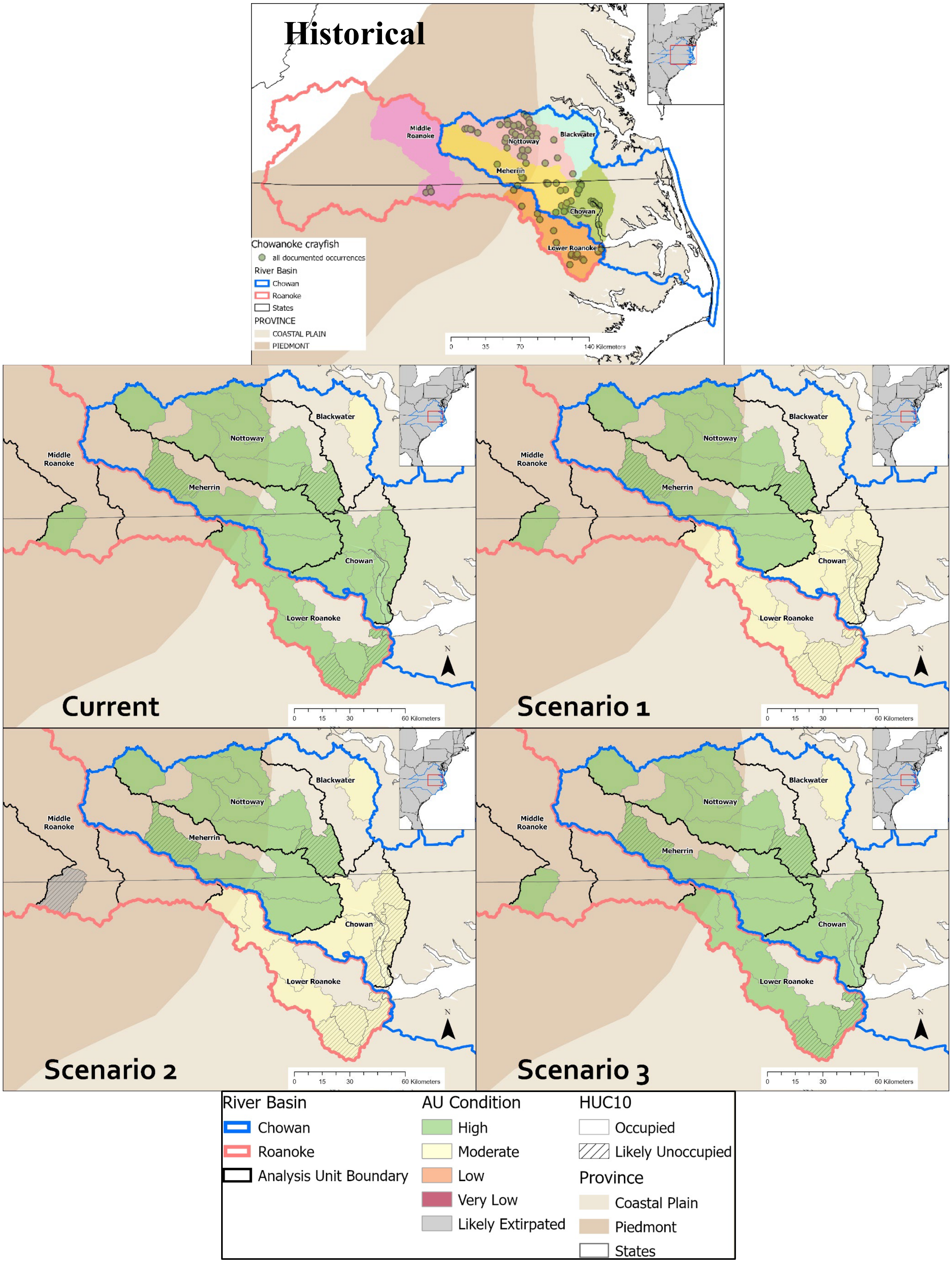


Figure ES-1. Maps of historical range, current condition, and predicted Chowanoke crayfish future conditions under each scenario (see Table ES-3).

Table ES-1: Summary results of the Chowanoke crayfish Species Status Assessment

3Rs	Requisites/ Description	Current Condition	Future Condition in 50 years
Resiliency (ability to withstand stochastic events)	Healthy populations and habitat. Subpopulations with: • Small to large sized stable streams; • Unembedded instream structure; • Sufficient water quality and quantity to provide food sources and maintain healthy habitat; • Healthy riparian and adjacent upland habitat; • Connectivity — waterways without significant barriers.	Each Analysis Unit (AU) with high or moderate current condition is thought to currently have adequate habitat and healthy subpopulations, thus has high or moderate resiliency. • 6 of 6 AUs are known to be extant. • AU status: – 5 of 6 AUs high condition – 1 of 6 AUs moderate condition	Scenario 1: All AUs extant – 3 high condition, 3 moderate condition Scenario 2: 1 AU likely extirpated, remaining AUs – 2 high condition, 3 moderate condition. Scenario 3: All AUs extant – 5 high condition, 1 moderate condition
Redundancy (ability to withstand catastrophic events)	Sufficient distribution of healthy populations/subpopulations to prevent catastrophic losses of species' adaptive capacity due to severe flood or drought events. Multiple occupied HUC10s within each AU and multiple occupied AUs within the species' range are important for the species' redundancy.	• Healthy AUs (moderate or high condition) evenly distributed within both basins and across the range. • Occupied HUC10s evenly distributed within AUs and both basins.	Scenario 1: More AUs with moderate condition in the eastern/southern portions of the range. Occupied HUC10s will be unevenly distributed within the Chowan and Lower Roanoke AUs and both basins. Scenario 2: More AUs with moderate condition in the eastern/southern portions of the range. High condition AUs will occur in the middle/northern portions of range. 1 AU in southwest likely extirpated. Occupied HUC10s will be unevenly distributed within the Chowan and Lower Roanoke AUs and both basins; no occupied HUC10 in the Middle Roanoke AU. Scenario 3: Healthy AUs evenly distributed across the range. Occupied HUC10s will be evenly distributed within AUs and both basins.
	Sufficient number of healthy populations/subpopulations to prevent catastrophic losses of adaptive capacity.	• 6 of 6 AUs are healthy (moderate or high condition). • 24 of 28 HUC10 watersheds (86%) currently occupied.	Scenario 1: All AUs moderate or high condition. 21 of 28 HUC10 watersheds (75%) occupied. Scenario 2: 5 of 6 AUs moderate or high condition; 1 AU likely extirpated. 19 of 28 HUC10 watersheds (68%) occupied. Scenario 3: All moderate or high condition. 24 of 28 HUC10 watersheds (86%) occupied.

3Rs	Requisites/ Description	Current Condition	Future Condition in 50 years
Representation (ability to adapt)	Sufficient capacity to adapt to new, continually changing environments. Occupied HUC10s distributed across the range, including the ecological diversity of river basins and physiographic provinces that contribute to and maintain adaptive capacity. Adequate dispersal ability for the species to migrate to suitable habitat and climate over time.	Connected, occupied HUC10s found in both river basins (populations) and physiographic provinces. **River basin:** • Chowan – 18 of 20 HUC10s (90%) occupied. • Roanoke – 6 of 8 HUC10s (75%) occupied. **Physiographic province:** • Piedmont – 10 of 11 HUC10s (91%) occupied. • Coastal Plain – 14 of 17 HUC10s (82%) occupied.	Scenario 1: **River basin:** Chowan – 16 of 20 HUC10s (80%) occupied. Roanoke – 5 of 8 HUC10s (63%) occupied. **Physiographic province:** Piedmont – HUC10 occupancy unchanged. Coastal Plain – 11 of 17 HUC10s (65%) occupied. Scenario 2: **River basin:** Chowan – 15 of 20 HUC10s (75%) occupied. Roanoke – 4 of 8 HUC10s (50%) occupied. **Physiographic province:** Piedmont – 9 of 11 HUC10s (82%) occupied. Coastal Plain – 10 of 17 HUC10s (59%) occupied. Scenario 3: **River basin:** Chowan – HUC10 occupancy unchanged. Roanoke – HUC occupancy unchanged. **Physiographic province:** Piedmont – HUC10 occupancy unchanged. Coastal Plain – HUC10 occupancy unchanged.

Table ES-2. Summary of Future Scenario influencing factors[1] as compared to current condition.

Influencing Factor	Scenario 1: Continuation of Current Trends	Scenario 2: Increase in Rates of Land Use Changes and Climate Change Effects	Scenario 3: Continuation Plus Conservation
Habitat Factors			
Instream Habitat/ Water Quality (% forested/ wetlands)	↓ (due to moderate increase in urbanization)	↓↓ (due to maximum increase in urbanization)	↓ (due to moderate increase in urbanization)
Water Quality (% impervious surface)	↓ (due to moderate increase in urbanization)	↓↓ (due to maximum) increase in urbanization)	↓ (due to moderate increase in urbanization)
Water Quantity/Flow (drought)	↓	↓↓	↓
Salinity (SLR)	↑↑ (Intermediate High)	↑↑↑ (High)	↑ (Intermediate)
Climate Projection	RCP 8.5	RCP 8.5	RCP 4.5
Climate Effects	↑ air temperature and variation in precipitation and flooding	↑↑ air temperature and variation in precipitation and flooding	↑ air temperature and variation in precipitation and flooding
Red swamp crayfish and virile crayfish's effects on instream habitat	Same	↑	Same
Conservation Actions			
Conservation Actions (habitat enhancement and restoration, non-native species control, etc.)	Same	Same	↑
Population Factors			
Distribution (AU Occupancy Decline)	↓	↓	Same
Demography (Approximate Abundance)[2]	Same	↓	Same

[1] Influencing Factor Rate of Change Compared to Current Condition: some increase (↑), greater increase (↑↑), greatest increase (↑↑↑), some decrease (↓), greater decrease (↓↓), no change in rate (Same).

[2]Approximate abundance remains the same, except decreases due to overall low habitat quality condition or crayfish condition becomes very low. See Appendix C for additional information.

Table ES-3. Predicted Chowanoke crayfish overall conditions (resiliency) under current and three plausible, future scenarios in 50 years.

			Future Scenarios of Overall Conditions		
Population	**Analysis Units**	**Current**	**#1: Continuation of Current Trends**	**#2: Increase in Rates of Land Use Changes and Climate Change Effects**	**#3: Continuation Plus Conservation**
Chowan		**High**	**High**	**Moderate**	**High**
	Nottoway	High	High	High	High
	Meherrin	High	High	High	High
	Blackwater	Moderate	Moderate	Moderate	Moderate
	Chowan	High	Moderate	Moderate	High
Roanoke		**High**	**Moderate**	**Moderate**	**High**
	Middle Roanoke	High	High	**Likely Extirpated**	High
	Lower Roanoke	High	Moderate	Moderate	High

CHAPTER 1 BACKGROUND

1.1 Background

This report summarizes the results of a species status assessment (SSA) conducted for the Chowanoke crayfish (*Faxonius virginiensis*). In 2010, we, the U.S. Fish and Wildlife Service (Service), received a petition to list 404 aquatic, riparian, and wetland species, including the Chowanoke crayfish, as endangered or threatened under the Endangered Species Act of 1973, as amended (Act) (Center for Biological Diversity (CBD) 2010, pp. 1–66, 192–193). On September 27, 2011, the Service published a 90-day finding indicating that the petition presented substantial scientific or commercial information indicating that the listing of 374 species, including the Chowanoke crayfish, may be warranted (76 FR 59836). Thus, we conducted an SSA to compile the best scientific and commercial information available regarding the species' biology and factors that influence the species' viability.

1.2 Analytical Framework

The SSA report, the product of conducting an SSA, is intended to be a concise review of the species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain viability. The intent is for the SSA report to be updated as new information becomes available, and to support all functions of the Endangered Species Program. As such, the SSA report is a living document upon which other documents, such as listing rules, recovery plans, and 5-year reviews, would be based if the species warrants listing under the Act. If the species does not warrant listing, the SSA report can serve as the foundation for identifying conservation needs of the species and the habitat it requires.

This SSA report for the Chowanoke crayfish is intended to provide the biological support for the decision on whether or not to propose to list the species as threatened or endangered and if so, whether or not to propose critical habitat. The process and this SSA report do not represent a decision by the Service whether or not to list a species under the Act. Instead, this SSA report provides a review of the best scientific and commercial information available strictly related to the biological status of the Chowanoke crayfish. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and a decision will be announced in the *Federal Register*.

Using the SSA framework (Figure 1), we consider what a species needs to maintain viability. Viability is the ability of a species to maintain populations in the wild over time. To assess viability, we use the conservation biology principles of resiliency, redundancy, and representation (Shaffer and Stein 2000, pp. 308-311). To sustain populations over time, a species must have the capacity to withstand:

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

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

Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time and in this case for the Chowanoke crayfish, within 50 years. This represents approximately 14 Chowanoke crayfish life cycles, and the available data suggest changes in the species' status are likely to occur within a similar timeframe. Fifty years is also a period that allows us to reasonably predict the potential effects of the various stressors within the range of the species.

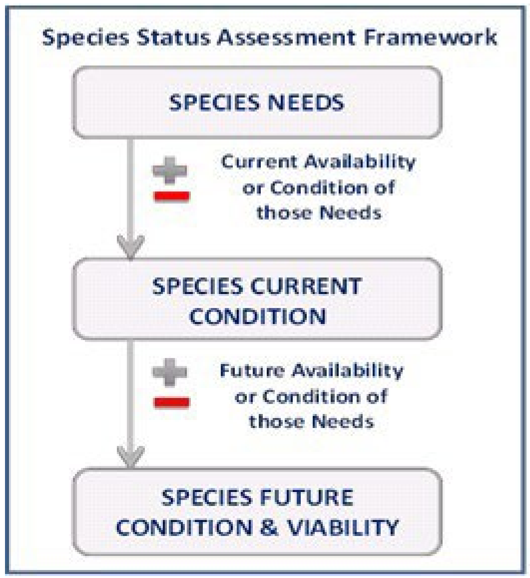


Figure 1. Species Status Assessment Framework

The 3Rs are defined as follows:

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

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

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

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

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

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

The 3Rs, and their core autecological parameters of abundance, distribution and diversity, are the key characteristics that contribute to a species' ability to sustain populations in the wild over time. When combined across populations, they measure the health of the species as a whole.

The decision whether to list a species is based *not* on a prediction of the most likely future for the species, but rather on an assessment of the species' risk of extinction. Therefore, to inform this assessment of extinction risk, we describe the species' current biological status and assess how this status may change in the future under a range of scenarios to account for the uncertainty of the species' future. We evaluate the current biological status of the species by assessing the primary factors negatively and positively affecting the species to describe its current condition in terms of resiliency, redundancy, and representation (together, the 3Rs). We then evaluate the future biological status by describing a range of plausible future scenarios representing a range of conditions for the primary factors affecting the species and forecasting the most likely future condition for each scenario in terms of the 3Rs. As a matter of practicality, the full range of potential future scenarios and the range of potential future conditions for each potential scenario are too large to individually describe and analyze. These scenarios do not include all possible futures, but rather include specific plausible scenarios that represent examples from the continuous spectrum of possible futures. This future scenario analysis is intended to inform the determination of the risk that extinction will be the future experienced by the species within each timeframe analyzed.

CHAPTER 2 SPECIES DESCRIPTION AND INDIVIDUAL NEEDS

2.1 Taxonomy

The Chowanoke crayfish is in the family Cambaridae (Hobbs 1951, pp. 122–128). The Chowanoke crayfish is a unique species and recognized as a valid taxon in the Integrated Taxonomic Information System (ITIS) database (Hobbs 1951, pp. 122–128; Fitzpatrick 1967, p. 168; Hobbs 1989, p. 38; McLaughlin et al. 2005, p. 232; ITIS 2019). The first description of the species was in 1951 (Hobbs 1951, pp. 122–128) and identified as *Orconectes virginiensis.* Specimens examined for this description were collected in tributaries of the Nottoway River in Greensville, Brunswick, and Dinwiddie Counties, Virginia. The classification of Chowanoke crayfish changed in 2017 from genus *Orconectes* to genus *Faxonius* when an updated classification of crayfish worldwide based on recent taxonomic and phylogenetic distinctions was developed. Genus *Faxonius* are surface-dwelling crayfish that only dig shallow holes or tunnels while the genus *Orconectes* are cave-dwelling crayfish (Crandall and De Grave 2017, pp. 619, 631).

There has been limited genetic analysis conducted on this species, but studies thus far support that the Chowanoke crayfish is a distinct species. Early studies suggested that the Chowanoke crayfish may be a sister species to the Carolina spiny crayfish (*F. carolinensis*) and closely related to the spiny-cheek crayfish (*F. limosus*), Allegheny crayfish (*F. obscurus*), belted crayfish (*F. harrisoni*) and rusty crayfish (*F. rusticus*) (Taylor and Hardman 2002, pp. 877–879; Taylor and Knouft 2006, p. 6). A more recent study also suggested that Chowanoke crayfish may be a sister species to the Carolina spiny crayfish and closely related to the Allegheny crayfish (Gangloff et al. in prep, pp. 12–13). However, all three studies had small sample sizes, with one to three specimens per species analyzed, except for Chowanoke crayfish in Gangloff et al. (in prep), and utilized a single genetic marker. Future studies should focus on increasing the sample size and number of species included, and using multiple genetic markers to improve resolution of these phylogenetic relationships.

2.2 Morphological Description

The Chowanoke crayfish, as described by Cooper and Cooper (1977, pp. 214–215), is tan colored with a distinctive dark blue or blue-black saddle across the carapace (Figure 2-1). The chelae (claws) have a dark band, orange tips, have bristly patches of hairs, and a portion of the claws have a dark outer edge (Cooper and Cooper 1977, pp. 214–215). Blue color phase variants of Chowanoke crayfish have been observed on rare occasions (Black 2021, pers. comm.); this trait has been observed for other crayfish species, possibly due to diet, environment, or a recessive gene (Momot and Gall 1971, pp. 363–364). Total length of adults is approximately 50 millimeters long (2 inches). Diagnostic features of the species are described in Hobbs 1951 (pp. 126–127), Fitzpatrick 1967 (pp. 161, 164–165), and NatureServe 2019 (p. 4). We are not aware of any documented morphological variation throughout the species' range. The Carolina spiny crayfish has a similar appearance but can be differentiated by location and slight morphological differences. The Carolina spiny crayfish does not occur in the Roanoke or Chowan basins; one may have been collected in the upper Roanoke basin in 2001, however it is now believed that the location was mislabeled and none have been collected in the Roanoke basin since then (Cooper 2002, p. 175; Black 2021, pers. comm.). Carolina spiny crayfish is endemic to the Tar and Neuse basins. When compared to Carolina spiny crayfish, Chowanoke crayfish's tubercles on the mesial portion of the chelae are less robust and have shorter, more dense setae. On Form I males, Chowanoke crayfish have shorter terminal elements (Fisk 2020a, pers. comm.).

Figure 2-1. Photos of Chowanoke crayfish (Credit: T. Black, Meherrin River, 2014).

2.3 Life History

2.3.1 *Life Cycle and Longevity*

Life history information specific to Chowanoke crayfish is limited (Adams et al. 2010, pp. 1–3; North Carolina Wildlife Resources Commission (NCWRC) 2015, pp. 84, 90, 536–537, 606–607; NatureServe 2019, p. 4). Their life history is presumed to be similar to many other stream dwelling crayfish (Thoma 2014, p. 27; Service 2019a, p. 4), as shown in life cycle diagram Figure 2-2.

Faxonius spp., such as Chowanoke crayfish, may be habitat generalists. Like other *Faxonius* spp., they may produce up to several hundred offspring (Muck et al. 2002, pp. 7–8; Service 2015b, p. 4) that grow rapidly and are not long lived, exhibiting an r-selected life history pattern which can be beneficial in unpredictable or varied habitat types (Reynolds et al. 2013, p. 200; Loughman and Welsh 2018, p. 55; Service 2019b, p. 1).

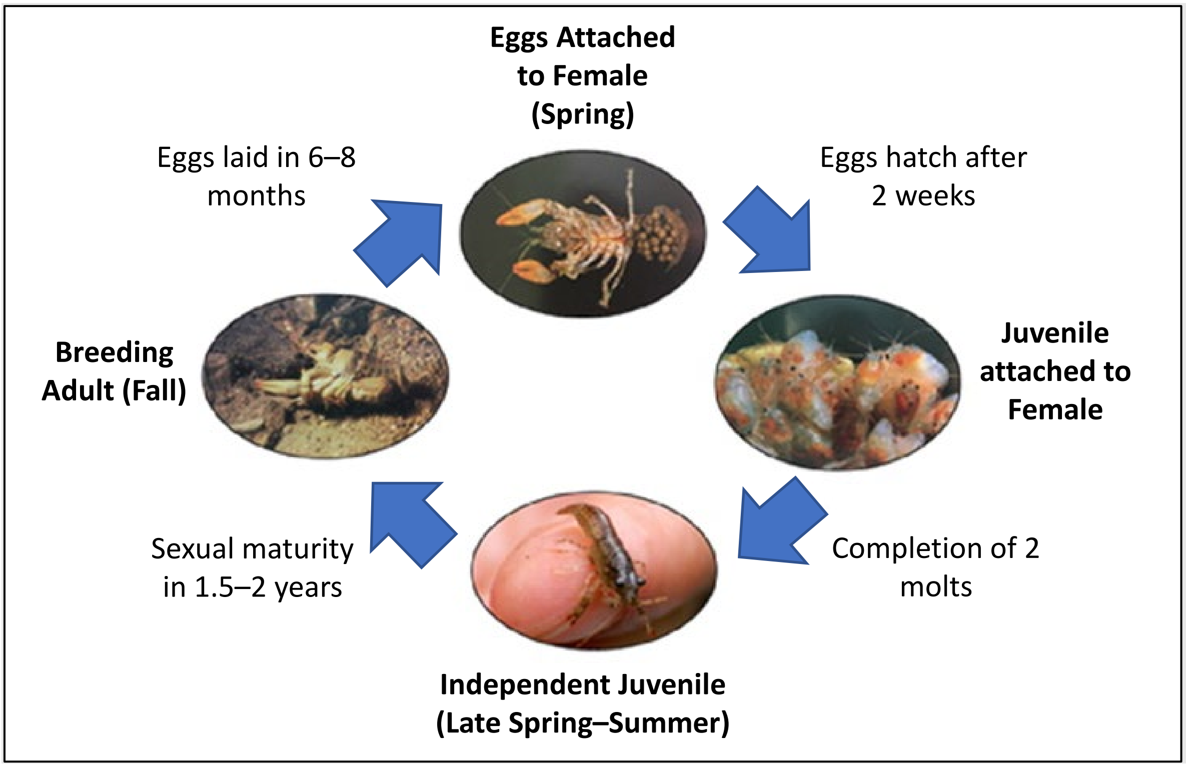


Figure 2-2. Likely life cycle diagram of Chowanoke crayfish. Photos of breeding adults, eggs, and juveniles attached to females modified from Service 2018 (p. 12) and Pflieger 1996 (pp. 28–29).

The Chowanoke crayfish lifecycle begins in the spring when fertilized eggs are extruded by the female and are attached with an adhesive substance (glair) to swimmerets located on the underside of the female's tail/abdomen. After hatching, the young remain attached to the female with threadlike structures for approximately four molts. During a molt, crayfish shed their carapace, then grow and harden a new, larger one. In general, juvenile crayfish often stay with the mother as long as possible, while food and shelter are provided, even after they become unattached (free living) (Pflieger 1996, pp. 26–29; Taylor et al. 1996, p. 27; Loughman and Welsh 2018, p. 48; Service 2019a, entire; Service 2019b, entire).

Chowanoke crayfish may be sexually mature at approximately 1.5 to 2 years old, as with other species of the same genus (Fielder 1972, p. 143; Service 2019a, p. 3). Total carapace length is used to age crayfish, and the graphed peaks and valleys of the carapace length are used to interpret age. *Faxonius* spp. usually have three peaks, and most crayfish in Virginia have a mass molt event twice a year (spring molt and late summer molt) (Loughman and Simon 2011, pp. 43–44; Service 2019b, p. 2). Although there are no data on the lifespan of wild Chowanoke crayfish, it is estimated to be 3 to 4 years (Service 2019a, p. 3).

2.3.2 *Reproduction*

The reproductive status of a crayfish, regardless of sex, is described as its form. Reproductively active crayfish are Form I, while reproductively inactive crayfish are Form II. There are morphological differences in the reproductive structures (gonopods) of Form I and Form II male crayfish (Pflieger 1996, p. 27). Form II females have been documented in Family Cambaridae, and it is assumed that Chowanoke crayfish have two female forms (Service 2019b, p. 2) as do many species of the same genus (*Orconectes:Faxonius*) (Wetzel 2002, pp. 326–337). In other *Faxonius* spp., Form I females have larger chela to defend themselves and their young from predators (Wetzel 2002, pp. 326–337). Their abdomen is wider, with increased surface area, which enables them to release and hold more eggs as long as adequate environmental conditions are present (food, shelter, quality habitat, and normal competition and predation rates). Crayfish with larger chelae have also been observed to back into their burrow and use the chela to block the hole and push to wedge themselves in the hole to prevent predation by fish (Service 2019b, p. 2).

Amplexus (mating position) or brooding for this species is similar to other crayfish species, as observed by Virginia Department of Wildlife Resources (VDWR) and NCWRC biologists (Figure 2-3) (Black 2021, pers. comm.; Watson 2021, pers. comm.). In general, male crayfish transfer sperm to a receptacle in the female in the fall. A sperm plug is deposited over the receptacle to retain the sperm until the female is ready to lay her eggs. She produces a sticky substance called "glair" on her tail, to which the sperm and eggs are released, typically in the spring, and eggs are then subsequently fertilized (Pflieger 1996, p. 28). Females protect the eggs by tucking the tail forward under the abdomen and aerates them by fanning the swimmerets (Pflieger 1996, p. 29).

Figure 2-3. Chowanoke crayfish mating (Credit: T. Black, Little Grassy Creek, 2018).

While many stream dwelling crayfish species mate primarily in the fall and the females lay eggs and carry the juveniles in the spring months, there are occasional observations of Chowanoke crayfish mating in the spring and females carrying eggs and juveniles in the fall (Service 2019a, p. 4; Service 2019b, p. 2). Based on occurrence data through 2019, Chowanoke crayfish mating has been observed three times by surveyors in September and November (Appendix A). Females have been recorded in all months except January and February (Table 2-1), and eight females in glair (when glair glands are active/enlarged, prior to spawning) have been documented in October (two females) and December (six females) (Appendix A). Seven egg-bearing females have been observed in the months of March, April, May, and September (Thoma 2014, p. 27; NCWRC 2019a, unpublished data; Smithsonian 2019, unpublished data). Chowanoke crayfish have been observed every month, except January, and most often during the summer and early fall months (Table 2-1); however, experts indicated that surveys are not frequently conducted during the winter months (Service 2019a, p. 3). Therefore, the data may be skewed toward the months that were sampled most frequently. Reproductive males (Form I males) and juveniles were observed during most of the year (Table 2-1; Figure 2-3).

While Chowanoke crayfish Form II females likely do occur (Wetzel 2002, pp. 326–337; Service 2019b, p. 2), surveys of Chowanoke crayfish have not recorded Form I and II data (Service 2019a, p. 5) (Table 2-1). Data from both Virginia and North Carolina indicate the following pooled percentage of each demographic (n = 750): Form I males (20.4 percent); Form II males (16.3 percent), adult females (32.4 percent), egg-bearing ("in berry") females (0.9 percent), juveniles (28.9 percent), and unknown (1.1 percent) (Appendix A). The pooled estimate of adult male to female ratio is 1.1:1. Sex was recorded in 92 of the 164 total records. Within juveniles (n = 217), the percentage of each demographic is: male (29.0 percent), female (47.5 percent), unknown/not recorded (23.5 percent).

Table 2-1. Total number of Chowanoke crayfish records by month and when juveniles and sex type (X) were recorded (1939-2019) (Appendix A).

	Jan	**Feb[1]**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Number of Chowanoke crayfish records	0	4	8	6	9	25	24	12	31	30	12	3
Number of juvenile records			1	1		9	2	1	13	5	1	
Male Form I			X	X		X	X	X	X	X	X	X
Male Form II				X	X	X	X	X	X	X	X	X
Female			X	X	X	X	X	X	X	X	X	X

[1]For February, sex and juvenile information were not recorded. Female Form I and II were not recorded.

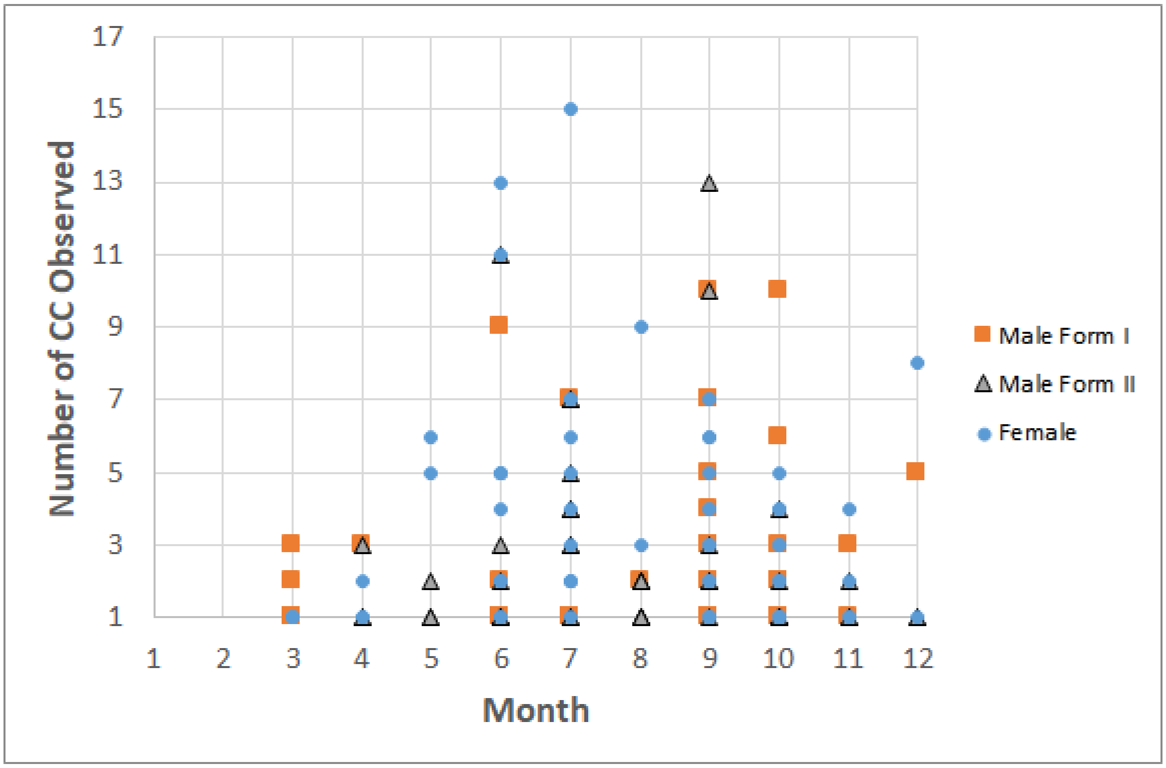


Figure 2-3. Numbers of Chowanoke crayfish (CC) observed by sex type (Male Form I, Male Form II, female) versus month, in surveys when the information is provided in the occurrence data compiled and reviewed for this SSA (1939-2019) (Appendix A). Each symbol represents an observation made at a specific location during a single survey.

2.4 Diet and Home Range

Crayfish are most active between dusk and dawn when they abandon cover to forage for food (Taylor et al. 1996, pp. 26–27). There are no data on Chowanoke crayfish diet; however, field observations and lab studies of other *Faxonius* spp. indicate they are likely nocturnal and generalist omnivores, preferring invertebrates, periphyton, and live plant material (Service 2019a, p. 1). They may also feed on dead plant material and detritus as a last resort (NatureServe 2019, p. 4; Service 2019a, p. 1). However, some research suggests that crayfish are primarily carnivores, gaining most of their nutrients from invertebrates, and ingest herbaceous and detrital materials only as they search for and ingest animal protein (Momot 1995, pp. 33–63; Magoulick and Piercey 2016, p. 240). They benefit from other natural sources of protein, such as arthropods, bee larvae, plant seeds, and plant pollen (Momot 1995, pp. 45-48). The phylogenetic origin of the protein is important because protein from native or natural sources provides optimum juvenile crayfish growth, while earthworms and manufactured bait have been found to stunt crayfish growth (Momot 1995, pp. 47–48). Therefore, healthy habitat conditions that support native invertebrate populations, riparian areas, and forests are likely important components of Chowanoke crayfish habitats (Momot 1995, pp. 33–63, 56).

Little is known regarding the minimal habitat patch size or degree of connectivity necessary to support Chowanoke crayfish populations. However, other *Faxonius* spp., such as the virile crayfish *(F. virilis)* and spiny-cheeked crayfish, have been observed to be nomadic and move upstream and downstream to locate food and cover, even in high gradient streams, or move overland for short distances (Puky 2014, 143; p. Service 2019b, p. 2); both of these species are nonnative, invasive crayfish that have displaced other native crayfish in other areas. Chowanoke crayfish typically utilize eddy habitats during the day as refuge and move into mid-channel habitats during the night (Service 2019b, p. 2). When they are presented with water quality stressors such as low dissolved oxygen, they will find the edges of water bodies and stay there until conditions are suitable. A classic downstream drift behavior of pre-young of the year and adult *Faxonius* spp. observed in the lab is to flip up into the air and fall backward into the current in order to move downstream faster. Although one source indicates that the home range of the Chowanoke crayfish probably does not exceed 25 meters (NatureServe 2019, p. 4), some researchers indicate that stream dwelling crayfish may move distances up to 1 km in a lifetime (Service 2019a, p. 2; Service 2019b, pp. 1–2). It is likely that habitat connectivity and heterogeneity are important for various life stages of individuals moving among microhabitat areas that provide adequate food, shelter, food, and water quality, and which shift in riverine environments.

2.5 Habitat

Crayfish depend on rocky substrate, woody debris, and vegetation for shelter and often require habitat heterogeneity to survive the various life stages (Taylor et al. 2007, p. 374; Reynolds et al. 2013 pp. 200–204). Chowanoke crayfish find shelter in interstitial spaces between rocks and woody debris, beneath undercut stream banks, in leaf litter, under dense, emergent vegetation such as water willow (*Justicia americana*), near undercut clay banks, and in abandoned tertiary burrows of other crayfish (Foltz 2019, pers. comm.; Service 2019a, p. 3; Service 2019b, p. 1). They have also been observed to find shelter under unnatural habitat, including riprap/rocky rubble near bridges, railroad ties, old bridge timbers, asphalt slabs, and other materials that have fallen into the streams (e.g., truck door, cooler lid) (Foltz 2019, pers. comm.; Service 2019a, p. 3). In the sandy blackwater streams of Virginia, the species finds shelter under wood, which is the dominant hard, natural substrate and vegetation (e.g., water willow), and undercut banks. In the Coastal Plain province of North Carolina, where hard substrate and cobble are not abundant, Chowanoke crayfish are observed around woody debris and leaf mats in stream thalwegs and beneath undercut banks (Service 2019a, p. 3). *Faxonius* spp., such as the Chowanoke crayfish, are tertiary burrowers and burrow only during the breeding season and/or during drought conditions (NatureServe 2019, p. 5). Chowanoke crayfish appear to be poor burrowers and burrow in loose sandy substrate. *Faxonius* spp. are very gregarious, and if a large-bodied *Cambarus* sp. dies, a few crayfish will move into and use the single *Cambarus* sp. burrow (Service 2019b, p. 1). In streams with high densities of the animals or in streams with virtually no hard substrate for cover, they will utilize clay banks, typically forming shallow burrows under a piece of hard substrate on the bank, such as under a log or partly buried boulder. They do not appear to form deep clay burrows like other species of *Faxonius* spp. (Foltz 2019, pers. comm.).

Chowanoke crayfish prefer perennial streams and rivers with moderate to high gradient and flow and noticeable current (Service 2019a, p. 2). While they have been found in sluggish streams with sandy/silt-laden substrates, they occur there in very low numbers (Thoma 2014, p. 25, VDGIF 2015, p. 26-71). They are not known to occur in stagnant water (Service 2019a, p. 3). Thoma (2014, p. 25) found that the majority of sites with less than 10 individuals were low gradient streams with a lower percentages of course material (3-13 percent), while sites with 10 or more individuals were moderate to high gradient streams with a higher percentage of coarse material (average of 21.5 percent). Thoma (2014, p. 27) also indicated that heavy loads of sand and silt negatively affect Chowanoke crayfish habitat by filling in interstitial spaces of rocks and cobble.

Chowanoke crayfish are found in perennial streams/rivers classified as third order or greater, with the exception of a single occurrence in a second order stream in 1997, based on U.S. Geological Survey (USGS) National Hydrography Dataset Plus High Resolution GIS data (Table 2-2, Figure 2-4 and 2-5) (USGS 2018; Appendix A). When surveying in North Carolina, Black and Nichols (2015, entire) observed that detection rates were greater in mainstem rivers and major tributaries (sixth order or larger) (Black and Nichols 2015, entire). Most of the occupied streams and rivers are freshwater, except for near the mouth of the Roanoke River and Chowan River in North Carolina. For example, within the Roanoke River in North Carolina, one adult Chowanoke crayfish female was found in a submerged log in a brackish estuary where the river was about 200 meters wide and slow moving, with abundant water lily on the shoreline and dead wood on the bottom. Algae growths in the area suggested enrichment and while fauna was primarily freshwater, there were estuarine taxa as well (Cooper and Braswell 1995, p. 106). Monthly average salinity data and gage height inside the mouth of the Roanoke River (USGS monitoring station 0208114150) from November 1997 to March 2020 indicate that this site is predominantly tidal freshwater (salinity less than or equal to 0.5 parts per thousand (ppt)) (USGS 2020a). More than 85 percent of the monthly average salinity data is less than or equal to 0.5 ppt. The occurrence of Chowanoke crayfish near the river mouth with estuarine taxa suggests that they may have some tolerance to infrequent low salinity conditions.

Table 2-2. Number of Chowanoke crayfish records (i.e., surveys where Chowanoke crayfish was detected) by stream order.

Stream Order	Number Of Records
2	1
3	14
4	46
5	50
6	5
7	18
8	27
unknown	3
total	**164**

Figure 2-4. Typical Chowanoke crayfish habitat. From top left clockwise: Potecasi Creek (Chowan River basin, NC), Grassy Creek (Roanoke River basin, NC), Chowan River, NC, and Three Creek (Chowan River basin, VA). Photo credit: for North Carolina, Michael Fisk, NCWRC; for Virginia, Brian Watson, VDWR.

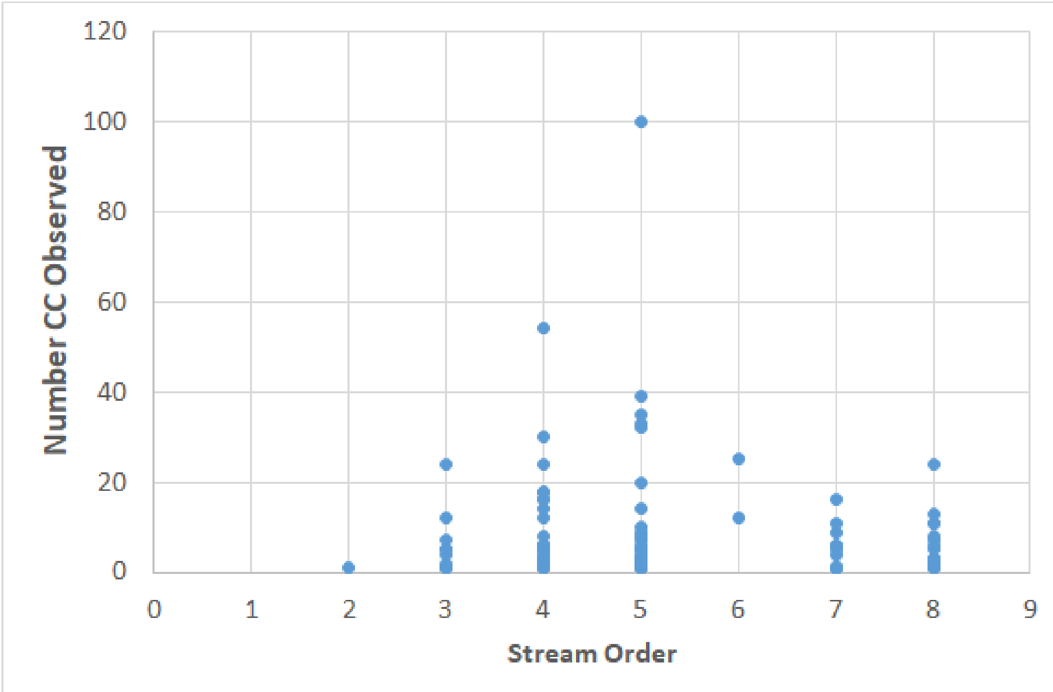


Figure 2-5. Number of Chowanoke crayfish observed at a survey site versus stream order. Note that the three highest observations were made in the same stream at two different sites: 39 and 100 at a fifth order site (in 2013 and 2019, respectively) and 54 at a fourth order site. Also some surveys only noted presence or provided a qualitative description of abundance, such as present or abundant, without any numbers indicated; therefore that survey data is not included in this figure.

2.6 Historical Range and Distribution

The Chowanoke crayfish's historical range is the Chowan River basin in southeastern Virginia and northeastern North Carolina, and the Roanoke River basin in northcentral and northeastern North Carolina (Figure 2-6) (Cooper and Braswell 1995, p. 106–107; Adams et al. 2010; Black and Nichols 2015, entire; LeGrand et al. 2015, p. 54; Global Biodiversity Information Facility (GBIF) 2019).

In Virginia, the first collection of the species was in 1935 (Thoma 2014, p. 25), and they were reported in several Nottoway River tributaries within the Chowan River basin prior to 1950, including Three Creek (Greensville County), Waqua Creek (Brunswick County), Rowanty Creek (Sussex County), and Hatcher Run (Dinwiddie County) (Hobbs 1951, pp. 122–128; Hobbs 1989, p. 38; Stinson 1997, p. 29; Smithsonian 2019, unpublished data; Virginia Department of Conservation Recreation-Division of Natural Heritage (VDCR-DNH) 2019, unpublished data; VDWR 2019a, b, unpublished data). In the Chowan River basin of North Carolina, they were described as occurring in Cutawhiskie Creek in 1974 (tributary to Potecasi Creek) and the Meherrin River in Hertford County, NC in 1985 (Cooper and Cooper 1977, p. 215; Cooper and Braswell 1995, pp. 105–106; GBIF 2019; North Carolina Natural Heritage Program (NCNHP) 2019, unpublished data). In the lower Roanoke River basin, they were documented in Ready Branch in 1949 and 1980, a tributary of Sweetwater Creek in Martin County, NC (Cooper and Cooper 1977, p. 215; Cooper and Braswell 1995, pp. 105–106; NCNHP 2019, unpublished data;

Smithsonian 2019, unpublished data). In 1986–1987, Chowanoke crayfish were recorded at additional locations of the Roanoke River in Bertie and Halifax Counties (Cooper and Braswell 1995, pp. 105–106; GBIF 2019, unpublished data; NCNHP 2019, unpublished data; Smithsonian 2019, unpublished data).

Knowledge of the distribution of Chowanoke crayfish within North Carolina prior to 2010 was limited. Due to the relatively limited amount of historical data prior to 2010 in North Carolina (Table 2-3), the historical range is assumed to include current occurrences (2010-2019). Given the species' longevity, evidence of reproduction, and lack of information to the contrary, we assume the streams occupied in 2010 or later to be currently occupied for the purposes of this SSA. In the Chowan River basin, the species is known from the Blackwater, Chowan, Meherrin, and Nottoway subbasins (hydrological unit code (HUC) 8 watersheds) in Virginia and North Carolina. In the Roanoke River basin, the species is known in the Lower Roanoke subbasin and the lower portion of the Middle Roanoke subbasin in North Carolina only. They have been documented in both the Coastal Plain and Piedmont provinces.

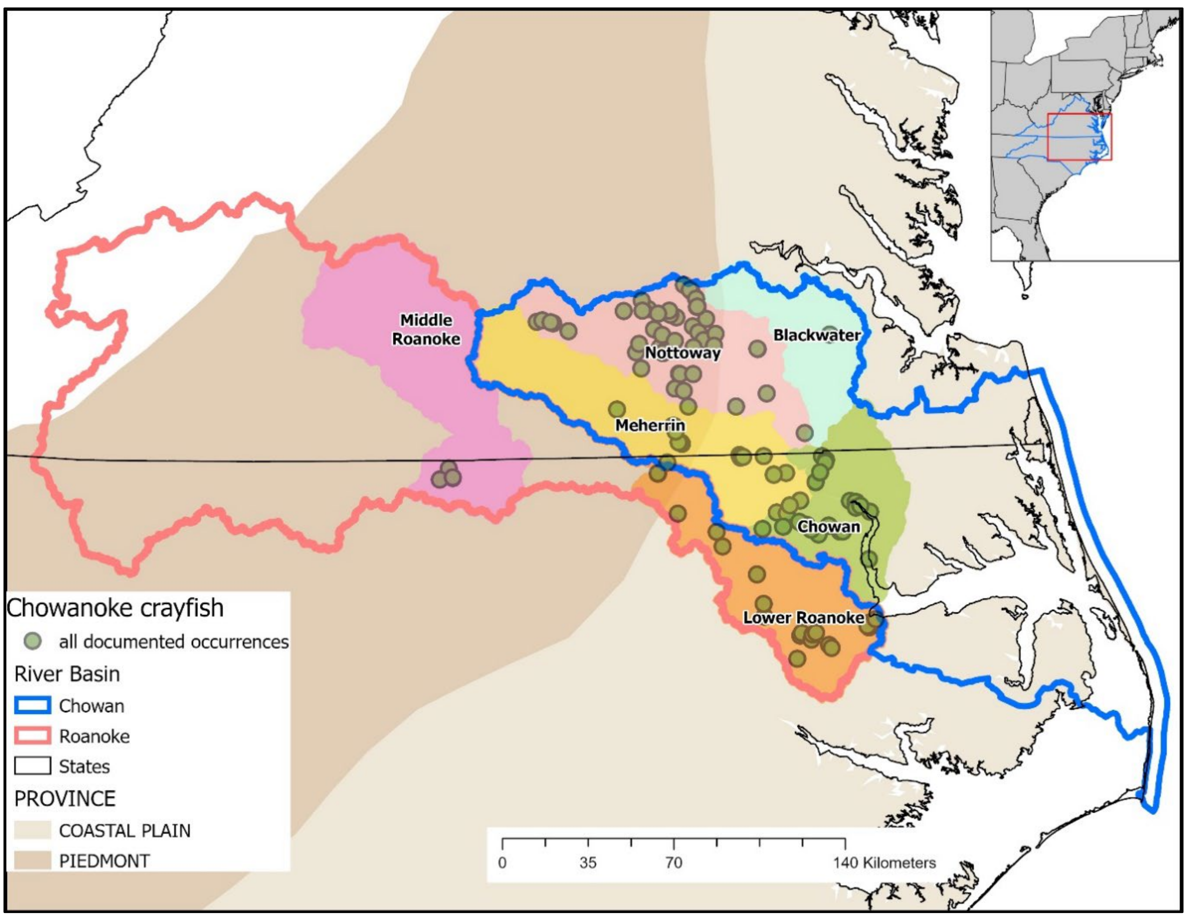


Figure 2-6. All historical and current occurrences of Chowanoke crayfish in the Chowan and Roanoke River basins (HUC6). HUC8 subbasins are shown by colored polygons and names.

Table 2-3. Number of records of Chowanoke crayfish by state and time period.

State	Number of Historical Records (1935–2009)	Number of Current Records (2010–2019)
NC	32	53
VA	53	26

2.7 Current Range and Distribution

Both the Chowan and Roanoke River populations have Chowanoke crayfish occurrences within the last 10 years (current period: 2010–2019), based primarily on targeted surveys for crayfish by Roger Thoma in 2011 to 2013 in Virginia (Thoma 2014, pp. 2–4, 25–27; Thoma 2019, unpublished data), Tyler Black in 2011 to 2014 in North Carolina (NCWRC 2019a, unpublished data) and Bronwyn Williams and David Foltz in 2019 in Virginia (Williams and Foltz 2019, unpublished data). Chowanoke crayfish have also been observed during surveys for other species (e.g., freshwater mussels) (NCWRC 2019a, unpublished data; VDWR 2019a, unpublished data). Non-detect survey data were also provided by NCWRC (2019a, unpublished data) and Thoma (2019, unpublished data). These data indicate where Chowanoke crayfish were not observed during crayfish-targeted surveys. However, at sites where Chowanoke crayfish were previously observed, the non-detect data do not conclusively indicate that Chowanoke crayfish are no longer present because crayfish surveys do not have 100-percent detection rates (Black 2019, pers. comm.; Service 2019a, pp. 9–15).

There is limited information available regarding the demographic or genetic processes that define the spatial structure of Chowanoke crayfish populations. Gangloff et al. (in prep, pp. 1, 28) conducted genetic analysis based on the mtDNA COI gene from 65 Chowanoke crayfish specimens from 5 and 7 sites, respectively, in the Roanoke and Chowan River basins. The data suggested recent gene flow among populations within a basin, and some level of past genetic exchange between the Chowan and Roanoke River basins, but with more recent isolation between the two (Gangloff et al. in prep, pp. 8-9, 13-14, 28). However, due to limited sample sizes within each basin at individual sites (95 percent of specimens were collected from North Carolina) and use of a single marker, additional studies are needed to reliably determine that the two basins are genetically distinct throughout its range.

For the purposes of this assessment, we assume that Chowanoke crayfish populations are delineated based on the river basins that they historically occupied, which are the Chowan and Roanoke River basins (HUC6 codes 030102 and 030101, respectively) (Figure 2-7). HUC6 boundaries provide geographic separation of land based on surface water drainage to a point. From here forward, we will use these terms to refer to populations (e.g., Chowan River population).

Because the river basin level is at a coarse scale, subpopulations were further delineated using analysis units (AUs). AUs were defined as one or more HUC10 watersheds within a HUC8 subbasin and identified by species experts as most appropriate for assessing population-level resiliency. Comprehensive, range-wide species occurrence data from state agency databases, museum online databases, and crayfish experts/surveyors were used to create “occurrence heat maps” that discretize HUC10 watersheds into 5-year increments based on the date of observed occurrences (see Appendix A). These heat maps display HUC10 watersheds with recently observed occurrences using various shades of green, while older observed occurrences are displayed in yellow, orange, and red (e.g., Figure 2-7). Documented species occurrences are included to show distribution within HUC10s. Throughout this section, heat maps are used to characterize the historic and current distribution of Chowanoke crayfish among AUs for each of the two populations.

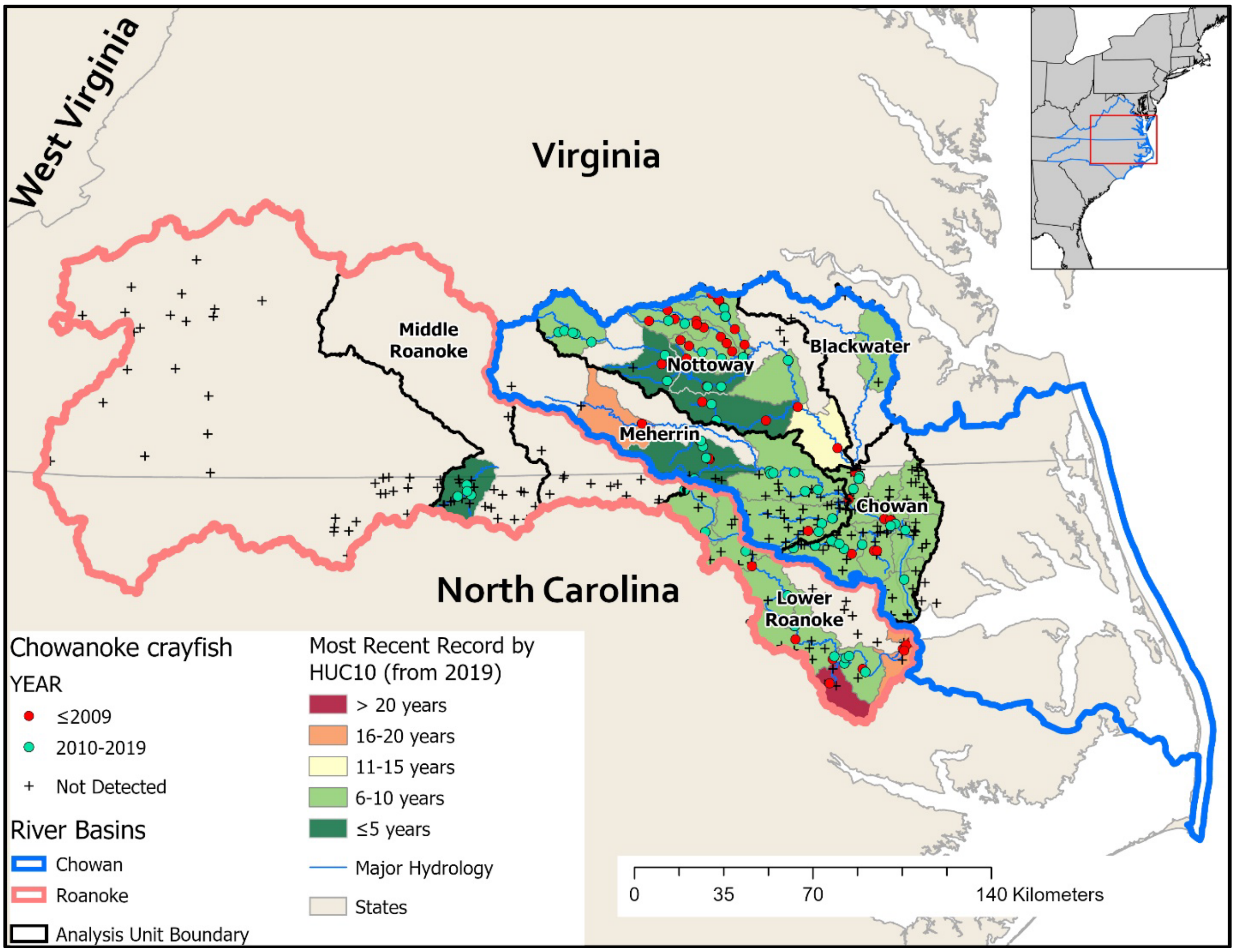


Figure 2-7. Current and historical range of Chowanoke crayfish in the Chowan and Roanoke River basins. Analysis units are shown by name.

2.7.1 *Chowan River Population*

The Chowan River population occurs in Virginia and North Carolina and consists of four AUs, hereafter referred to as the Nottoway, Meherrin, Blackwater, and Chowan (Figure 2-8).

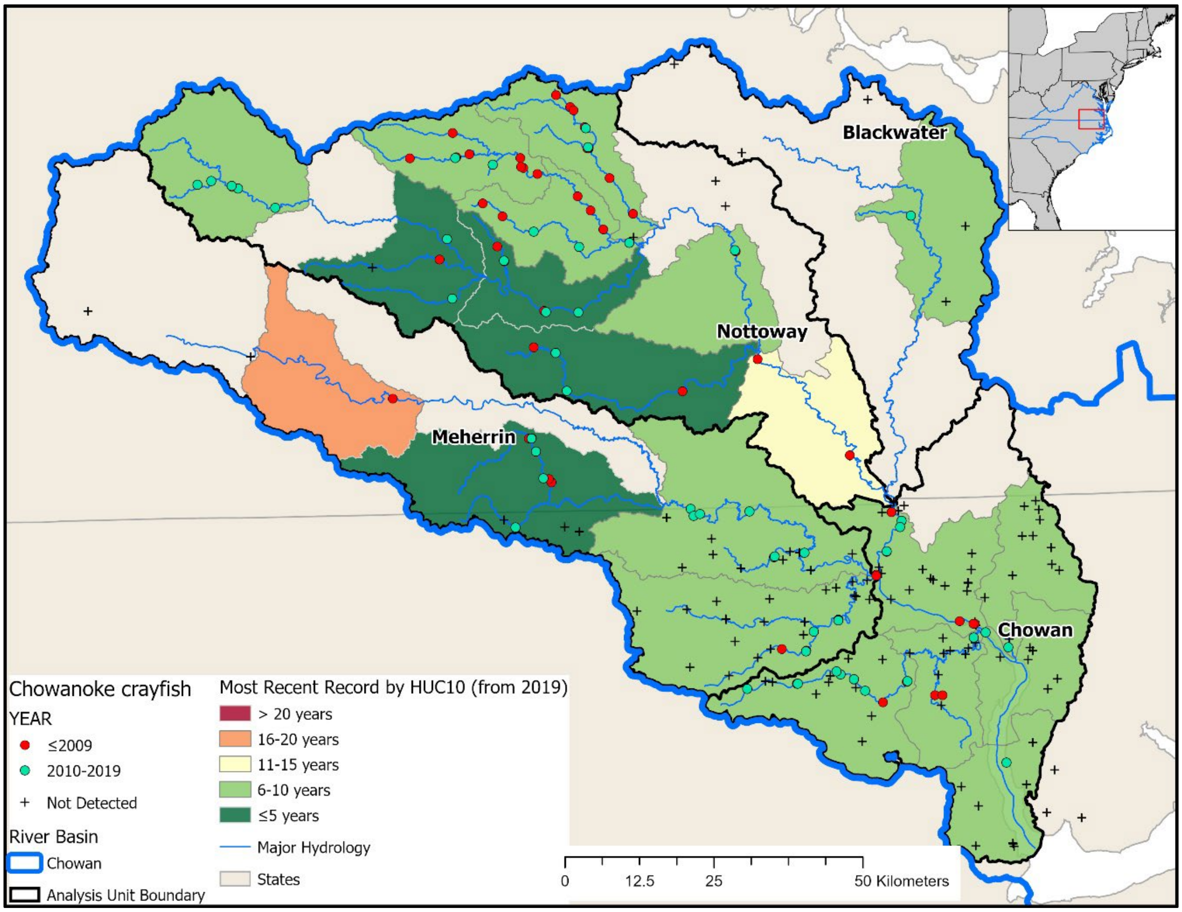


Figure 2-8. Chowanoke crayfish Chowan River population. Analysis units are shown by name.

<u>Nottoway AU</u> – This AU has documented occurrences in the following waterbodies in Virginia: Buckskin Creek, Butterwood Creek, Gravelly Run, Hatcher Run, Modest Creek, Nottoway River, Picture Branch, Rowanty Creek, Sappony Creek, Stony Creek, Sturgeon Creek, Three Creek, unnamed tributary of Rocky Run, Waqua Creek, and White Oak Creek. All streams have recent observations of the Chowanoke crayfish since 2010, except Picture Branch, Rowanty Creek, Waqua Creek, and White Oak Creek. However those sites were not resurveyed in the last 10 years during the crayfish-specific surveys, except at a different site in Waqua Creek, and experts believe that the species is likely still present because habitat has not changed significantly and the species is fairly tolerant of minor disturbances (Service 2019a, p. 12). The federally listed endangered Roanoke logperch (*Percina rex*) also occurs in the Nottoway River and Waqua Creek, as well as other tributaries through the Nottoway AU; therefore, conservation measures related to maintaining water quality and quantity for Roanoke logperch would also benefit the Chowanoke crayfish.

Crayfish-specific surveys in 2011 to 2013 (Thoma 2019, unpublished data) documented more than 10 individuals in Sappony Creek at each of 2 sites, 10 individuals in Nottoway River at each of 2 sites, and more than 20 individuals in each of Buckskin Creek (1 site) and Stony Creek (1 site). In Three Creek, 39 and 54 individuals were documented in 2013 at 2 sites, and over 100 individuals were documented in 2019 at 1 of the same sites (Thoma 2019, unpublished data; Williams and Foltz 2019, unpublished data). In Modest Creek in 2012 and Sturgeon Creek in 2019, surveyors noted that Chowanoke crayfish was abundant, but numbers were not provided (VDWR 2019a, unpublished data; Williams and Foltz 2019, unpublished data). Five to nine individuals were documented in Butterwood Creek, Hatcher Run, and Gravelly Run (one site each) in 2013 (Thoma 2019, unpublished data). One individual was also observed at one site in the Nottoway River and an unnamed tributary of Rocky Run. Chowanoke crayfish was noted as present, but counts not provided, at additional sites in the Nottoway River during surveys conducted for non-crayfish species (VDWR 2019a, unpublished data). Only the Mill Creek-Nottoway River HUC10, which consists of the lower Nottoway River, did not have observations in the last 10 years with: one individual observed in 2004 at one site, one individual in 2007 at another site, and one non-detect survey site in 2013 (VDWR 2019a, unpublished data; Thoma 2019, unpublished data). There may be an incidental observation within the last 10 years in the lower Nottoway River (in Mill Creek-Nottoway River HUC10), upstream of confluence with the Blackwater River, but it was undocumented (Watson 2021, pers. comm.) Experts believe it is possible for the species to be present throughout the Nottoway River, but this river is difficult to survey due to the size of the system (i.e., depth and width) (Service 2019a, p.11).

Meherrin AU – This AU has documented occurrences of Chowanoke crayfish in Beaverpond Creek, Cutawhiskie Creek, Kirbys Creek, and Potecasi Creek in North Carolina, Fountains Creek in Virginia, and the Meherrin River in both Virginia and North Carolina. All streams/rivers have had recent observations of the species since 2010. Crayfish-specific surveys in 2011 to 2013 in Virginia (Thoma 2019, unpublished data) and 2011 to 2014 in North Carolina (NCWRC 2019a, unpublished data) documented more than 10 individuals in Kirbys Creek (1 site) and Cutawhiskie Creek (1 site) and more than 30 individuals in Fountains Creek (at each of 2 sites). Potecasi Creek had nine individuals observed at one site. For the lower Meherrin River in the Tarrara Creek-Meherrin River HUC10, Chowanoke crayfish was observed at five sites: three sites had one individual each, one site had four individuals, and one site had six individuals. Only the upper Meherrin River in Virginia in the Stony Creek-Meherrin River HUC10 did not have observations in the last 15 years with the species being noted as “present” in 2002 (VDWR 2019a, unpublished data); this section of the river was not resurveyed in the last 10 years during the crayfish-specific surveys. An expert noted that the Meherrin River is a difficult river to survey, particularly below Emporia, VA, due to turbid conditions, low visibility, and lack of public access points to gain entry to the river, but he did not believe turbidity was an issue for the species (Service 2019a, p. 13). In addition, he noted that there was less survey effort in the Meherrin River in Virginia than in the Nottoway River, due to more surveys being conducted for other species, such as mussels and the Roanoke logperch.

Blackwater AU – This AU has only one waterbody with documented occurrences, which is Terrapin Swamp, a tributary to the Blackwater River in Virginia. One and four individuals were documented at the same site in 2007 and 2013, respectively (VDWR 2019a, unpublished data; Thoma 2019, unpublished data). Crayfish-specific surveys were conducted at two sites in tributaries to the Blackwater River in the same HUC10 watershed, but no Chowanoke crayfish were observed. There is also a collection record of the species from the Blackwater River (Zuni, Isle of Wight County, VA) with no specific location or collection date (Smithsonian 2019, unpublished data; record #14623).

Chowan AU – This AU has documented occurrences in the following waterbodies in North Carolina: Ahoskie Creek, Bennetts Creek, Chinkapin Swamp, Chowan River, and Wiccacon River. All streams have recent observations of the species since 2010, except Chinkapin Swamp. In 2001, five individuals were observed at one site in Chinkapin Swamp and the habitat was described as "river-like" and contained riffle, run, and slack areas. Individuals were also observed in 2000 and 2005 when specimens were collected for preservation, but numbers were not recorded (NCWRC 2019a, unpublished data; GBIF 2019, unpublished data). Targeted surveys for crayfish in 2011 and 2012 did not collect any Chowanoke crayfish (NCWRC 2019a, unpublished data). Observations noted that the habitat upstream of the bridge was not high quality and described as slack water habitat (Black 2019, pers. comm.). Crayfish-specific surveys in 2011 to 2014 in North Carolina (NCWRC 2019a, unpublished data) documented 1 to 5 individuals at each of 4 sites, more than 10 individuals at each of 2 sites, and more than 20 individuals at 1 site in Ahoskie Creek. Five individuals at 1 site and more than 10 individuals at each of 2 sites were observed in the upper Chowan River. One to two individuals were observed in the middle/lower Chowan River (at each of two sites), Bennetts Creek (one site), and Wiccacon River (one site). All HUC10 watersheds in the Chowan AU have observations in the last 10 years.

Summary ~ Chowan River Population

Although the number of records and survey effort varied between the historical and current time periods, we examined the maximum number of Chowanoke crayfish observed at a site in waterbodies between historical and current time periods to provide a general, qualitative comparison. There are 57 current records and 72 historical records total within the Chowan River basin. All waterbodies in the Chowan River population have an equal or greater number of individuals of the species observed during the current time period versus historical time period, except in Sappony Creek in the Nottoway AU. Three, 30, and 16 individuals were observed in October 2004, August 2008, and September 2013 at the Sappony Creek site, respectively. Due to the variability of the numbers over time, we could not conclude the species is declining at this site.

2.7.2 *Roanoke River Population*

The Roanoke River population occurs in North Carolina and consists of two AUs, hereafter referred to as the Middle Roanoke and Lower Roanoke (Figure 2-9). These AUs are separated by John H. Kerr Reservoir, Lake Gaston, and Roanoke Rapids Lake. Construction for the hydroelectric dam on the Roanoke River for Kerr Reservoir began in 1947 and was completed in 1953, while the dams for Lake Gaston and Roanoke Rapids were completed in 1953 and 1955, respectively (Kerr Lake Guide 2020, p. 1; Lake Gaston Guide 2020, p. 1). There have been no documented occurrences reported in the Roanoke River or reservoirs/lakes between these two AUs and we do not assume historical occurrences in these areas.

<u>Middle Roanoke AU</u> – This AU has documented occurrences in Little Grassy Creek and Grassy Creek in North Carolina and both streams have had recent observations of the species since 2010. Crayfish-specific surveys in 2011 to 2014 in North Carolina (NCWRC 2019a, unpublished data) documented 2 to 6 individuals at each of 2 sites and 32 individuals at 1 site in Grassy Creek. Six individuals were documented at two sites in Little Grassy Creek during the crayfish-specific surveys and mussel surveys (NCWRC 2019a, unpublished data).

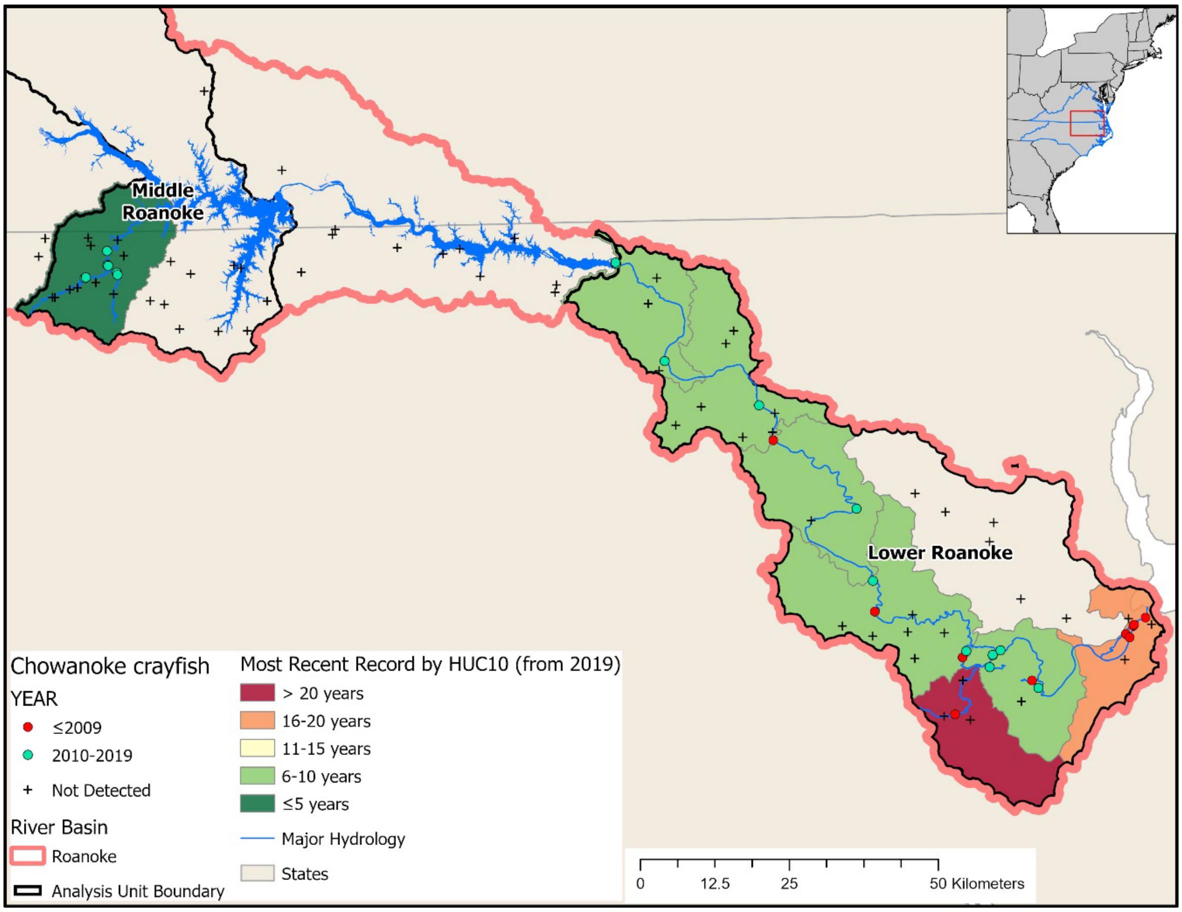


Figure 2-9. Chowanoke Crayfish Roanoke River population. Analysis units are shown by name.

<u>Lower Roanoke AU</u> – This AU has documented occurrences in the Roanoke River and multiple tributaries to this river in North Carolina, including Conine Creek, Devils Gut, Middle River, Ready Branch, and an unnamed marsh tributary. All streams have had recent observations of the species since 2010, except Ready Branch, Middle River, and the unnamed marsh tributary. Crayfish-specific surveys in the last 10 years were not conducted at the latter two sites; the species is likely still present because the surveys sampled a very small percentage of the habitat in the lower portion of the Roanoke River and there is likely suitable habitat (Black 2019, pers. comm.). When Ready Branch was re-surveyed during the crayfish-specific surveys at two sites during 2013 to 2014 (NCWRC 2019a, unpublished data), the surveyor observed no Chowanoke crayfish; however, he suspects that additional survey effort will yield the species because of presence of suitable habitat (Black 2019, pers. comm.). Negative survey results were attributed to difficulty of surveying due to water depth.

Crayfish-specific surveys in 2011 to 2014 in North Carolina (NCWRC 2019a, unpublished data) documented the following in the Roanoke River: 2 individuals at each of 2 sites, 5 to 8 at each of 4 sites, more than 10 individuals at 1 site, and more than 20 individuals at 1 site. More than 10 individuals were documented in Conine Creek (1 site) and Devil Gut (1 site). The Sweetwater Mill Creek HUC10, which consists of Ready Branch, did not have observations in more than 30 years with one individual observed each in 1949 and 1980 at one site (NCNHP 2019, unpublished data; Smithsonian 2019, unpublished data); none were detected in 2013 at the same site and 2014 at an upstream site, as described above (NCWRC 2019a, unpublished data). The Plymouth-Roanoke River HUC, which consists of the mouth of the Roanoke River and Middle River, did not have observations in the last 15 years, with observations of individuals (one to two) last made in 2000 in the Roanoke River (one site) and Middle Creek (one site) (NCWRC 2019a, unpublished data; NCNHP 2019, unpublished data). There was one non-detect survey site in 2014 in the Roanoke River and two non-detect survey sites in nearby tributaries. As noted above, an expert believes it is possible for the species to be present in the lower Roanoke River (Black 2019, pers. comm.)

Summary ~ Roanoke River Population
Although the number of records and survey effort varied between the historical and current time periods, we examined the maximum number of Chowanoke crayfish observed at a site in waterbodies between historical and current time periods to provide a general, qualitative comparison. There are 22 current records and 13 historical records total within the Roanoke River basin. All waterbodies in the Roanoke River population have an equal or greater number of individuals of the species observed during the current time period versus historical time period.

2.8 Needs of the Chowanoke Crayfish

For the purpose of this assessment, we define viability as the ability of the species to sustain populations in the wild within a biologically meaningful timeframe. Using the SSA framework, we describe the species' viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (the 3Rs) based on the species' needs.

2.8.1 *Individual and 'Population' Needs*

Habitat components that are important to the Chowanoke crayfish include small to large sized stable streams with riffles, runs, and pools with some noticeable current (i.e., not stagnant) and low levels of sedimentation; unembedded instream structure that provide shelter (e.g., rocks, boulders logs, leaf litter); and healthy riparian and adjacent upland habitat to provide adequate food sources and water quality conditions (temperature, dissolved oxygen, chemistry and siltation levels). These conditions provide individuals with sufficient food and shelter to grow, reach maturity, and reproduce. To support population viability, the Chowanoke crayfish requires healthy demographics (i.e., stable or positive growth rates), habitat connectivity and heterogeneity, and sufficient habitat quality and quantity to support healthy individuals.

The Chowanoke crayfish individual and population needs based on the best available information are summarized in Table 2-4.

Table 2-4. Summary of physical and biological features needed by Chowanoke crayfish.

Type of Resource	Resources and/or Circumstance Needs and Related Information	Citations
Instream Habitat	Unembedded coarse hard structure (boulder, cobble, and gravel), woody debris, leaf litter, undercut banks, and/or abandoned crayfish burrows for breeding, sheltering, and feeding.	Reynolds et al. 2013 pp. 200–201; Thoma 2014, pp. 25–27; VDGIF 2015, p. 26-71; NatureServe 2019, p. 4; Service 2019a, b; Foltz 2019, pers. comm.
Water Flow and Quantity	Perennial streams that are third order or greater. Sufficient water quantity (not stagnant) with noticeable current to maintain habitat and water quality.	Black and Nichols 2015, entire; Appendix A; VDGIF 2015, p. 26-71.
Water Quality	Sufficient water quality: freshwater, low levels of silt, sand, and turbidity to promote food sources and resistance to nonnative, invasive species and disease.	Thoma 2014, p. 27; VDGIF 2015, p. 26-71; Service 2019a, b.
Habitat Connectivity	Habitat connectivity for individuals to access adequate shelter, food, and space and to move to suitable habitat and climate over time.	NatureServe 2019, p. 4; Service 2019b.
Food Source	Invertebrates, periphyton, and live plant material.	Taylor et al. 1996, pp. 26–27; NatureServe 2019, p. 4; Service 2019a, b.

2.8.2 *Species Needs*

Species needs (i.e., what the species needs for viability) of the Chowanoke crayfish are described below in terms of the 3Rs. Viability is the ability to maintain populations in the wild over time. To do this, Chowanoke crayfish must have the capacity to withstand environmental and demographic stochasticity (periodic disturbances within the normal range of variation) (resiliency) and catastrophes (redundancy) and to adapt to near-term and long-term changes in its physical and biological environments (representation). In general, species viability will increase with increases in resiliency, redundancy, and representation (Smith et al. 2018, p. 306) (Table 2-5).

Resiliency

Resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions. Environmental stochasticity can vary at local and regional levels; therefore, the health of populations in any one year can vary over geographical areas (Hanski 1999, p. 372). For this reason, having populations distributed across a diversity of environmental conditions reduces the likelihood of concurrent losses of populations at local and regional scales. For the Chowanoke crayfish, we expect that environmental stochasticity primarily includes differences in precipitation (wet and dry years), prey availability, and habitat conditions (natural disturbance, embeddedness, hard substrate, water quality) throughout its range. Due to the relatively small range of the Chowanoke crayfish, these and other environmental differences could affect the species.

We consider Chowanoke crayfish resiliency as having healthy populations distributed and inter-connected across its range. As described in Section 2.8.1–Individual and 'Population' Needs, a healthy population comprises multiple, healthy, interconnected subpopulations. The greater the number of healthy populations and the greater the distribution and connectedness of those populations relative to the diversity of prey and other habitat conditions, the greater resiliency the species will possess.

Redundancy

Redundancy is a measure of the ability of a species to withstand catastrophic events and is best achieved by having multiple, widely distributed populations relative to the scale of anticipated species-relevant catastrophic events. In addition to guarding against a single or a series of catastrophic events extirpating the entire species, redundancy is important to protect against losing irreplaceable sources of adaptive diversity. To determine what the Chowanoke crayfish requires to guard against catastrophic events, we first considered what catastrophic events to which the species may be subjected (see Chapter 3). For the purposes of this SSA, we define a catastrophic event as a biotic or abiotic event that causes significant impacts at the population level such that the population cannot rebound from the effects or the population becomes highly vulnerable to normal population fluctuations or stochastic events.

For the Chowanoke crayfish, we consider severe flood and severe drought events to potentially result in catastrophic impacts to one or more populations (see Chapter 3 for details). For instance, big flood events have removed boundaries between watersheds where Chowanoke crayfish occur, which could permit nonnative crayfish species to rapidly expand their range, as well as increase siltation and suspended sediments (Service 2019c, p. 1). Floods have the potential to displace or cause mortality of individuals or populations, and can either degrade habitat or replenish habitat, depending on the scope and severity of the flood event. Some species may be adapted to periodic flooding events or not immediately show an effect but may experience an effect in the longer term (Service 2020a, p. 27). Severe drought causes a loss of habitat and prey due to the lack of flow. We did not consider sea level rise or land use modification to be potentially catastrophic events because these changes are typically more gradual that occur over the long term and are more likely to affect the representation and resiliency of the species. See Chapter 3 for additional details.

We consider multiple occupied HUC10 watersheds within each AU and multiple healthy AUs within the species' range to be important for the species' redundancy.

Representation

Representation is a function of both genetic diversity and adaptive capacity. As described in Chapter 1, genetic diversity is important because it can delineate evolutionary lineages that may harbor unique genetic variation, including adaptive traits. It can also indicate gene flow, migration, and dispersal. Ecological diversity is important because it provides the variation in phenotypes and ecological settings on which natural selection acts. In addition, the processes that drive evolution (gene flow, natural selection, mutations, and genetic drift) are required to maintain species-level representation (Crandall 2000, p. 291).

We do not have specific genetic, morphological, or ecological niche information to inform where there may be differences in the species within the Chowanoke and Roanoke River basins. However, the species occurs in headwater streams to mainstem rivers within the Piedmont province in the west to Coastal Plain province to the east, and there may be habitat, temperature, or other differences that we are not aware of. Physiographic provinces have different underlying geology and physical and chemical characteristics (e.g., topography, soil pH, elevation, hydrology) that may affect plant and animal species; the boundary between the Piedmont and Coastal Plain provinces is the transition zone from bedrock to softer sediments underlying these areas, called the Fall Line (VDCR 2021, p. 1). Therefore, we are using the species' distribution within the river basins and physiographic provinces as a surrogate for representation and infer that the species' representation needs would be best met by retaining its distribution within these geographic areas.

2.9 Summary of Description, Life History, Habitat, Distribution, and Needs

The Chowanoke crayfish is a small, freshwater, tertiary burrowing crustacean that likely burrows only during the breeding season and/or during drought conditions. The species is assumed to be an opportunistic omnivore feeding on a wide variety of items, including aquatic and terrestrial vegetation, plant detritus, insects, snails, and small aquatic vertebrates. Crayfish are primarily carnivores, gaining most of their nutrients from invertebrates, and ingest herbaceous and detrital materials only as they search for and ingest animal protein. Therefore, healthy populations of stream macroinvertebrates and the presence of healthy riparian and instream vegetation are likely important components of Chowanoke crayfish habitats.

Life history information specific to the Chowanoke crayfish is limited, but aspects of its life history and habitat requirements are presumed to be similar to those of many other stream dwelling crayfish such as use of rocky substrate, woody debris, and vegetation for shelter and often requiring habitat heterogeneity to survive the various life stages. Chowanoke crayfish prefer perennial streams and rivers with moderate to high gradient and flow and noticeable current. While they have been found in sluggish streams with sandy/silt-laden substrates, they occur there in very low numbers. They are not known to occur in stagnant water. Heavy loads of sand and silt have been found to negatively affect Chowanoke crayfish habitat by filling in interstitial spaces of rocks and cobble used for shelter. Most of the occupied streams and rivers are non-tidal and freshwater, except for near the mouth of the Roanoke River and Chowan River in North Carolina. The occurrence of Chowanoke crayfish near the river mouth with estuarine taxa suggest that they have some tolerance to infrequent low salinity conditions. To support population resiliency and viability, the Chowanoke crayfish requires healthy demographics (i.e., stable or positive growth rates), habitat connectivity and heterogeneity, and sufficient habitat quality and quantity to support healthy individuals (see Table 2-4).

There is limited genetic analysis conducted on this species, but studies thus far support that the Chowanoke crayfish is a distinct species. The limited genetic analysis suggests relatively high genetic exchange among populations within a basin, and past connectivity between the Chowan and Roanoke River basins, but with more recent isolation between the two. For the purposes of this assessment, we assume that Chowanoke crayfish populations are delineated based on the river basins that they historically occupied, which are the Chowan and Roanoke River basins (Figure 2-7).

The Chowanoke crayfish's historical range is the Chowan River basin in southeastern Virginia and northeastern North Carolina, and the Roanoke River basin in north central and northeastern North Carolina (Figure 2-7). The best available data from recent surveys suggest that

Chowanoke crayfish currently occur in the Chowan and Roanoke River basins. Based on the needs of the Chowanoke crayfish, the conditions needed for optimum resiliency, redundancy, and representation for the species to be viable are outlined in Table 2-5 and described below.

Table 2-5: Conditions needed for optimum resiliency, redundancy and representation for the Chowanoke crayfish to be viable.

3Rs	**Requisites**	**Description**
Resiliency (ability to withstand stochastic events)	Healthy populations and habitat.	Subpopulations with: • Small to large sized stable streams with riffles, runs, and pools; • Unembedded instream structure that provide shelter (e.g., rocks, boulders logs, leaf litter, undercut streambanks); • Sufficient water quality (freshwater, temperature, dissolved oxygen, chemistry, and siltation levels) to provide adequate food sources and conditions for survival and reproduction; • Sufficient water quantity with noticeable current (i.e., not stagnant) to maintain healthy habitat and water quality; • Healthy riparian and adjacent upland habitat; • Connectivity — waterways without significant barriers (e.g., large dams, reservoirs, lakes, other stream crossings).
Redundancy (ability to withstand catastrophic events)	Sufficient distribution of healthy populations	Sufficient distribution of healthy subpopulations to prevent catastrophic losses of species' adaptive capacity due to severe flood or drought events. Multiple occupied HUC10s within each AU and multiple occupied AUs within the species' range are important for the species' redundancy.
	Sufficient number of healthy populations	Sufficient number of healthy subpopulations to prevent catastrophic losses of adaptive capacity.
Representation (ability to adapt)	Sufficient capacity to adapt to new, continually changing environments.	Occupied HUC10s distributed across the range including the ecological diversity of river basins and physiographic provinces that contribute to and maintain adaptive capacity. Adequate dispersal ability for the species to migrate to suitable habitat and climate over time.

CHAPTER 3 FACTORS INFLUENCING THE SPECIES

In this chapter, we evaluate the past, current, and future influences that are affecting or could be affecting the current and future condition of the Chowanoke crayfish throughout some or all of its range. The influences are summarized in a conceptual model (Figure 3-1) and discussed in more detail in the section below.

The Chowanoke crayfish is potentially threatened by several primary influences including land use modification (e.g., development, loss of forested habitat, agricultural activities, dam, aquatic barriers), nonnative species (e.g., fish and crayfish), and effects of climate change. Current and potential future effects, along with current distribution and abundance of Chowanoke crayfish, help inform viability and therefore vulnerability to extinction. Those factors that are not known to have effects on Chowanoke crayfish populations, such as overutilization for commercial and scientific purposes, are not discussed in this SSA report.

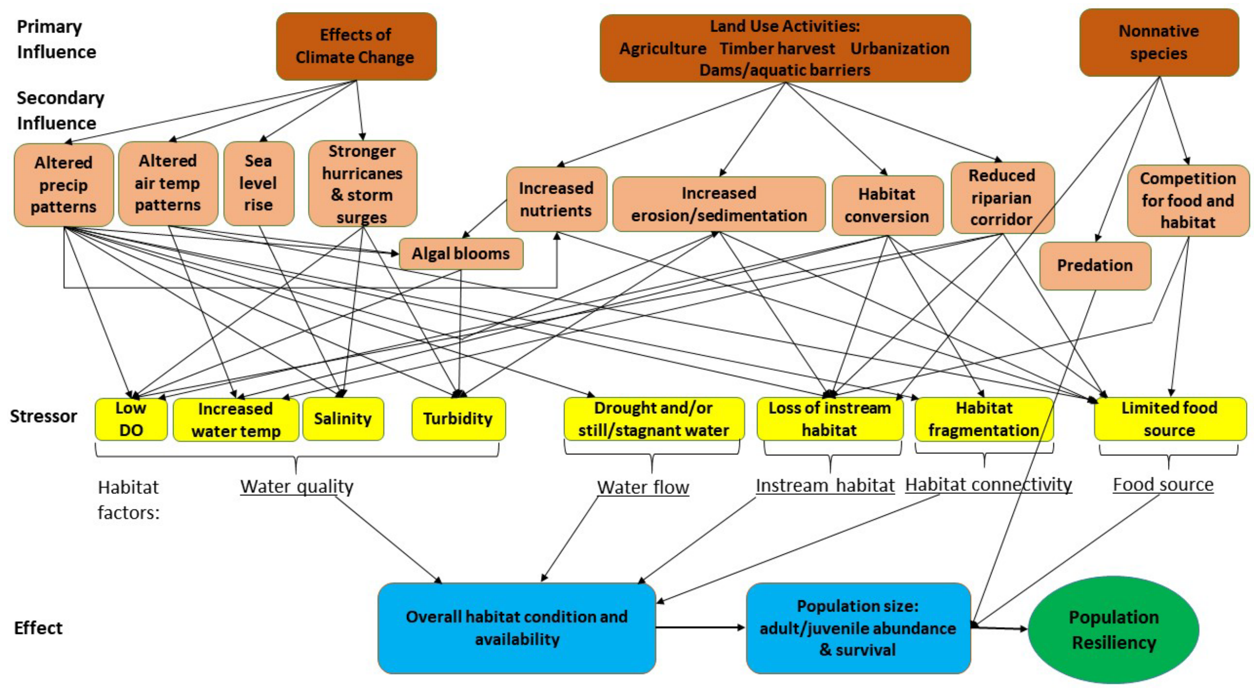


Figure 3-1. Influence diagram for the Chowanoke crayfish. The dark orange and light orange boxes represent primary and secondary influences, respectively. Yellow boxes represent stressors and the corresponding species' resource needs that have an effect on the resiliency of populations and the status of the species.

3.1 Land Use Modification

We use the term "land use modification" to refer to the alteration of the natural landscape, including (but not necessarily limited to) land conversion for development and its associated infrastructure (roads, bridges, utilities), forestry activities, and agriculture. Additionally, the regulatory mechanisms that review, and authorize or exempt these modifications are a factor we consider. The 2015 NCWAP (NCWRC, pp. 220–221) references land use modifications from natural forest to agricultural, silviculture production, and residential and commercial development as threats that continue to threaten stream integrity because of the loss of riparian buffers and related increases in sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials. Erosion and the resultant sedimentation are the largest sources of non-point source pollution in the aquatic systems. Richman et al. (2015, pp. 7–8) concluded that threatened crayfish in the United States were heavily impacted by the continued loss and degradation of habitat and pollution, and these are likely to increase extinction rates and reduce future diversification.

3.1.1 *Development and its Associated Infrastructure (roads, bridges, utilities)*

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 soil erosion and sedimentation (Giddings et al. 2009, p. 2). In general, development of the natural landscape 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). 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). The Chowanoke crayfish prefers habitats consisting of streams with rock/rubble substrates that have noticeable current (Thoma 2014, p. 25). Ultimately, when the hydrology of the stream is altered and water quantities vary widely, the physical habitat of a stream often becomes degraded from channel erosion or lower summer flows that reduce feeding, spawning, and living spaces of the various aquatic biota (Giddings et al. 2009, p. 1).

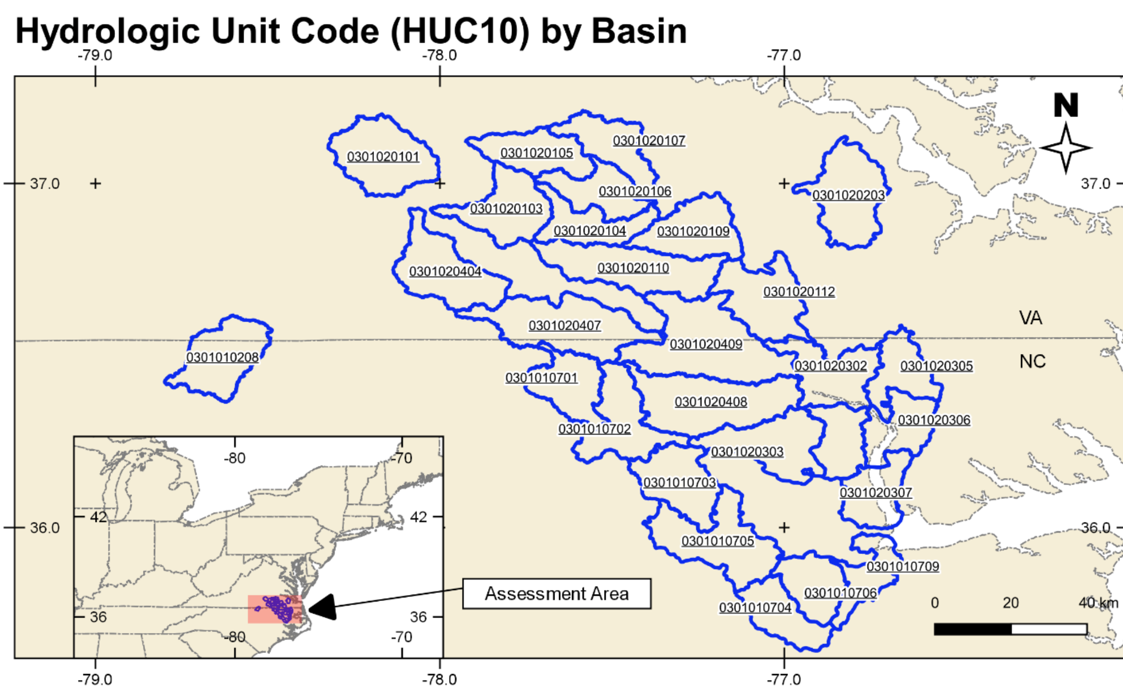


Figure 3-2. Historically and currently occupied HUC10 watershed boundaries and numbers in the range of the Chowanoke crayfish.

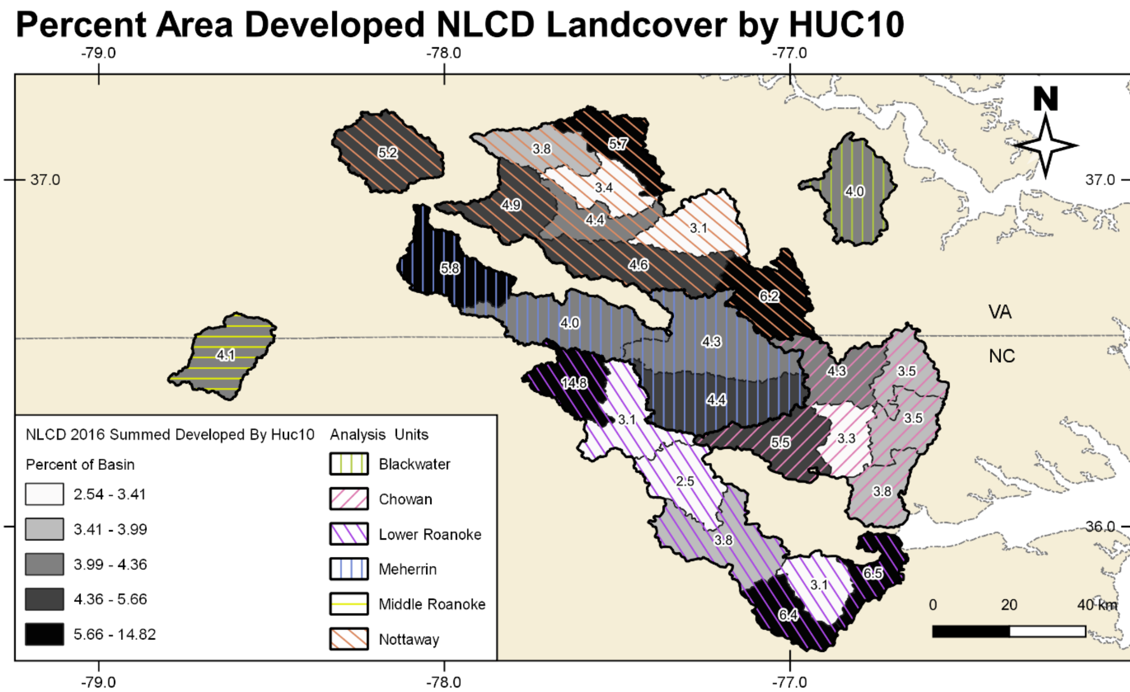


Figure 3-3. Percent of developed land cover in the HUC10 watersheds based on the 2016 National Land Cover Database (NLCD) (USGS 2019a).

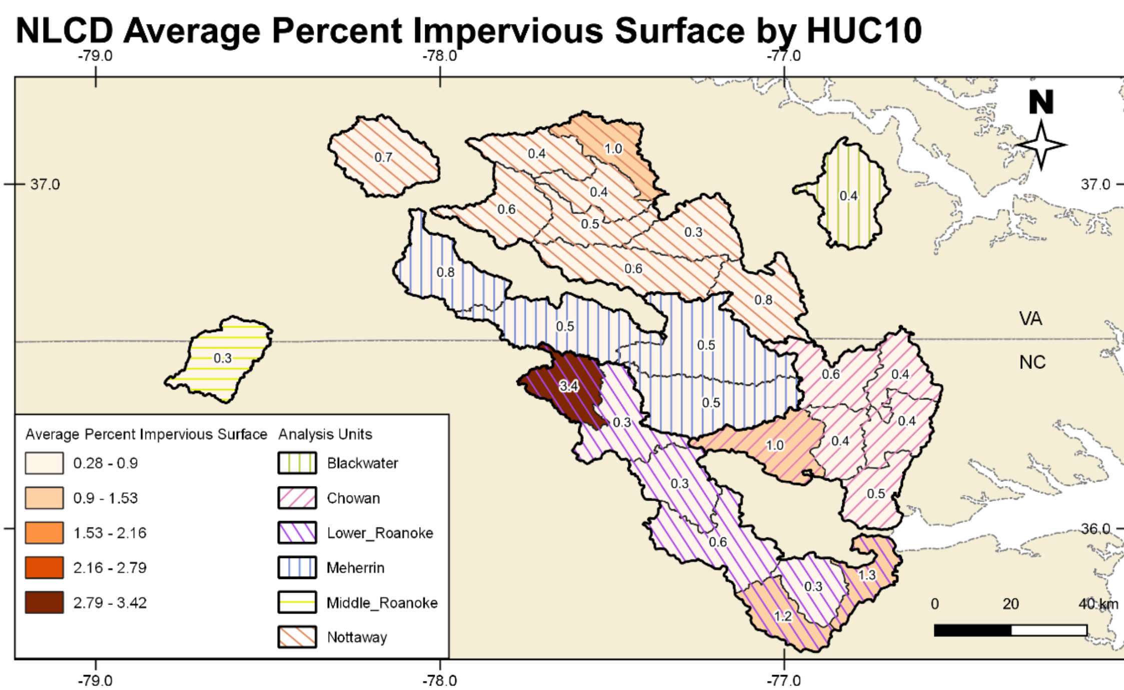


Figure 3-4. Percent of impervious surface land cover in the HUC10 watersheds based on the 2016 National Land Cover Database (NLCD) (USGS 2019b).

“Impervious surface” refers to all hard surfaces like paved roads, parking lots, roofs, and even highly compacted soils like sports fields. In more rural settings, like the agricultural and forested landscapes where the Chowanoke crayfish is known to occur, paved and highly compacted dirt roads are more prevalent than other impervious surfaces more commonly associated with urban and suburban landscapes.

Even with the low urbanization of this area to date, 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; and addition of heavy metals (especially lead), salts, organics, ozone, and nutrients to stream systems (Trombulak and Frissell 2000, p. 18). In addition, a major impact of road development is improperly constructed culverts at stream crossings. These culverts can act as barriers, causing flow through the culvert to vary significantly from the rest of the stream, or if the culvert ends up being perched - aquatic organisms have difficulty passing through them.

Utility crossings located in riparian buffer areas and their associated stream crossings (nondirectional bore) pose an additional threat to crayfish during initial construction and routine maintenance. Direct impacts from utility crossings include direct exposure or crushing of individuals, sedimentation, and flow disturbance from heavy machinery working on the banks and in the stream. The most significant cumulative impact involves the cleared rights-of-way that allow for direct runoff and increased temperature at the crossing location, and potentially provides access points for all-terrain vehicles (which destroy banks and instream habitat and cause soil compaction within trails).

Development and its associated infrastructure routinely requires multiple permits/authorizations from various local, state, and Federal agencies. Work within jurisdictional waters requires authorization from the U.S. Army Corps of Engineers (Corps) and the associated state water resource agency before any in-water work begins. Often there is associated compensatory mitigation required for the authorized impacts to reduce the overall impact to the aquatic system.

While development within most of the range of Chowanoke crayfish grew at a slow pace from 2001 to 2016 (Figure 3-5), development is anticipated to increase in the future, contributing to habitat fragmentation and forested lands being cleared for residential development and roads. One of the main drivers of change for the future is 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). The human population in the southern United States, including areas surrounding the current range of the Chowanoke crayfish, has grown 9.4 percent from 2010 to 2019 (U.S. Census 2021, entire), which is the fastest growing region in the country. This rapid growth has resulted in expanding urbanization and urban sprawl including suburban development, which fragments nonurban habitats such as forests and grasslands (Terando et al. 2014, p. 1). In turn, the increased sprawl adversely affects species and ecosystems negatively by causing water pollution and changes in local climate conditions (Terando et al. 2014, p. 1).

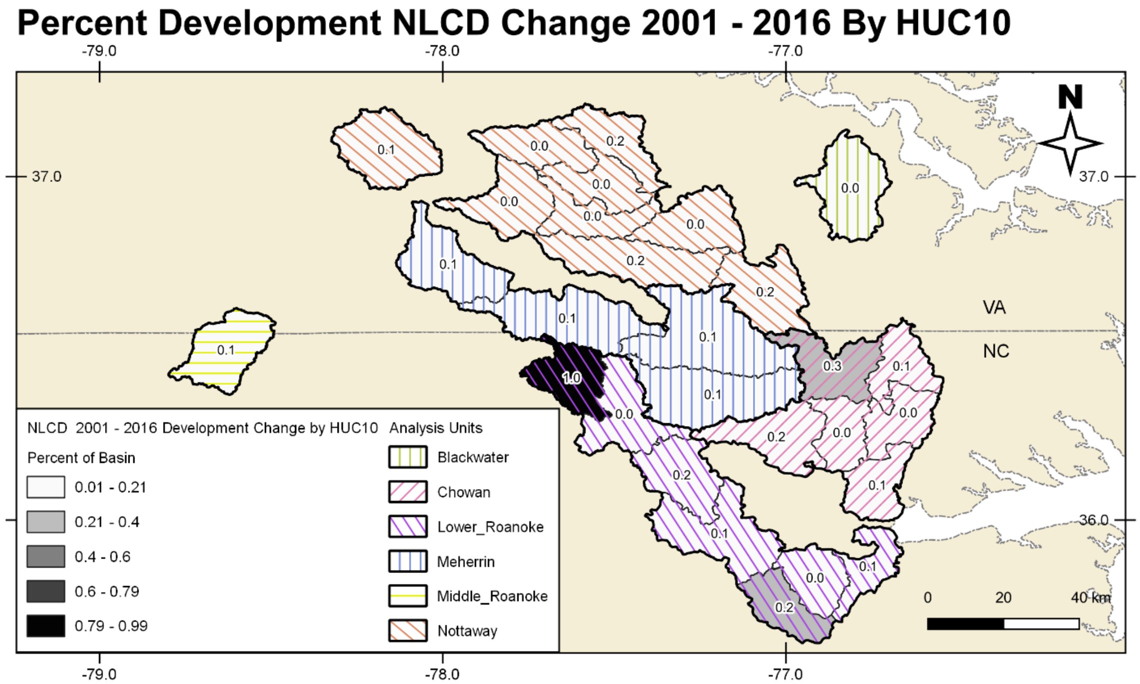


Figure 3-5. Percent difference of developed land cover in the HUC10 watersheds from 2001 to 2016, based on the National Land Cover Database (NLCD) (USGS 2019a). A positive value indicates an increase in developed land cover by 2016.

Terando et al. (2014) projected urban sprawl changes for the next 50 years for the fast-growing southeastern United States, using the SLEUTH (Slope, Land use, Excluded area, Urban area, Transportation, Hillside area) model, which simulates patterns of urban expansion that are consistent with spatial observations of past urban growth and transportation networks, including the sprawling, fragmented, "leapfrog" development that has been the dominant form of development in the Southeast (Terando et al. 2014, p. 2). The simulations point to a future in which the extent of urbanization in the Southeast is projected to increase by 101 percent to 192 percent. This projection is based on the "business-as-usual" (BAU) scenario in which the net effect of growth is in line with that which has occurred in the past (Terando et al. 2014, p. 1; Figure 3-6), and, as mentioned above, is in line with the Southeast being the fastest growing region in the country. The SLEUTH model provides scalability, uses commonly available datasets, and is adaptable to focus on patterns of suburban and exurban development (Terando et al. 2014, p. 2). The BAU scenario simulations do not consider alternative policies that could promote different urbanization patterns, however, the broad patterns of growth used do reflect recent trends in terms of the speed at which urbanization has progressed in the Southeast and in the locations that are most affected by it (Terando et al. 2014, p. 7).

As a result of modeled future growth in the watersheds and the effects of development and impervious surfaces on streamflow, water quality, and water temperature, this land cover type is considered a primary stressor.

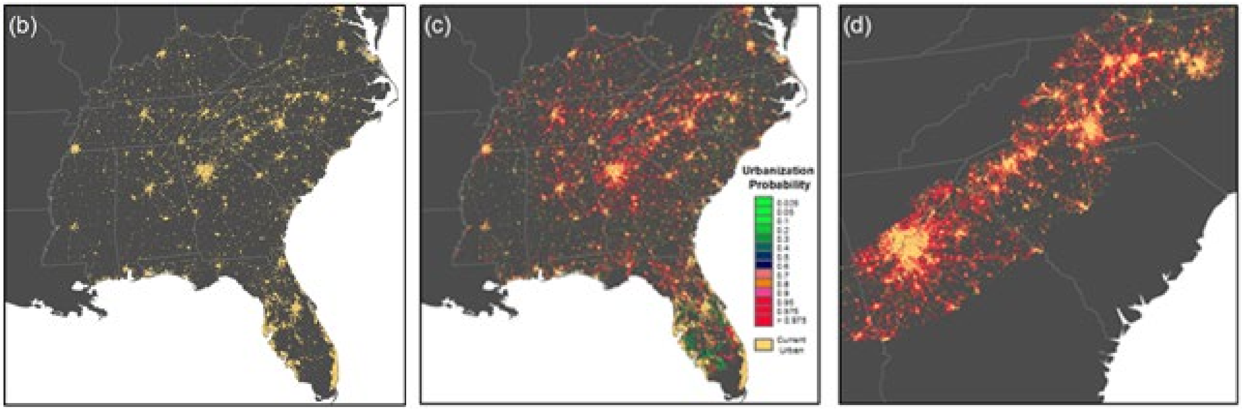


Figure 3-6. "Business-as-usual" urbanization scenario for the southeastern United States from Terando et al. (2014, p. 3) (b) is the initial urban land cover in 2009; (c) is the projected urban land cover in 2060, with the probability of urbanization indicated by color; and (d) is the projected urban land cover in the Piedmont ecoregion showing a connected urban landscape.

3.1.2 *Forested Landcover and Forestry Management*

A forested landscape provides many ideal conditions for aquatic ecosystems. If native, natural mixed hardwood forests and managed forested areas make up the active river area (Smith et al. 2008, entire), aquatic ecosystems receive the following benefits: rain is allowed to slowly infiltrate and percolate (as opposed to rapid surface runoff), a variety of food resources enter the stream via leaf litter and woody debris, banks are stabilized by tree roots, habitat is created by occasional windthrow, and riparian trees shade the stream and maintain an ideal thermal climate (Edwards et al. 2015, p. 60; Chescheir et al. 2003, p. 7).

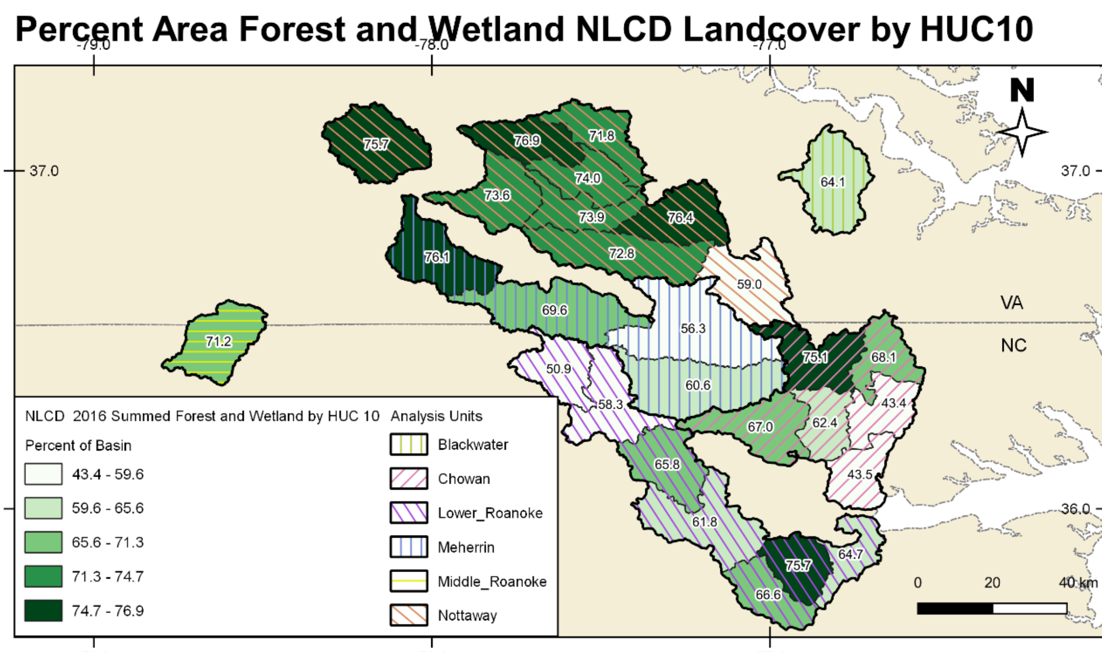


Figure 3-7. Percent of forest and wetlands land cover in the HUC10 watersheds based on the 2016 National Land Cover Database (NLCD) (USGS 2019a).

Forested active river areas (ARAs), or riparian areas, perform many functions that are essential to maintaining water quality, aquatic species survival, and biological productivity (NCWRC 2002, p. 6). 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). Specifically, forested riparian areas serve a role as: 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. 2001, p. 1475; Service 2006, p. 6). Wide, contiguous forested riparian buffers have greater and more flexible potential than other options to maintain biological integrity (May et al. 1999, p. 85; Service 2006, p. 22) and could ameliorate many ecological issues related to land use and environmental quality (Naiman et al. 1993, p. 209). The 2015 NCWAP lists the Chowanoke crayfish as a species with a potential of high threat from various biological resource use activities related to removing naturally forested areas including, large scale timber harvests that change the riparian habitat type adjacent to occupied aquatic habitat reaches, and disrupt food webs and energy and nutrient cycles (NCWRC 2015, pp. 701–703). Clearing of forested lands, in particular in the riparian area, due to urbanization also reduce instream habitat quality and biological integrity, including benthic macroinvertebrate community and large woody debris (May et al. 1997, entire). Therefore, healthy habitat conditions that support native invertebrate populations, riparian areas, and forests are likely important components of Chowanoke crayfish habitats (Momot 1995, pp. 33–63, 56).

The Chowanoke crayfish range in the Chowan and Roanoke River basins consists primarily of forested land and wetland areas, which has historically been the dominant land use type with little change over the years. If maintained in present use and managed according to North Carolina and Virginia's forestry Best Management Practices (BMPs), forested and wetlands areas will continue to provide more ecosystem services within the species range compared to other land uses such as development and agriculture. In 2016 forested and wetlands areas made up approximately 67 percent of the Chowan River basin, and 64.4 percent of the Roanoke River basin (Figure 3-7; USGS 2019a). There have been very minimal changes (less than 1 percent decrease) in total forest and wetlands land cover in the historical and currently occupied HUC10s from 2001 to 2016, with the majority of the HUC10s having a slight increase (less than 2.5 percent) in total forest and wetlands land cover by 2016 (Figure 3-8). With projected increase in population and urbanization in the southeastern United States, there may be an associated increased clearing of forested habitat.

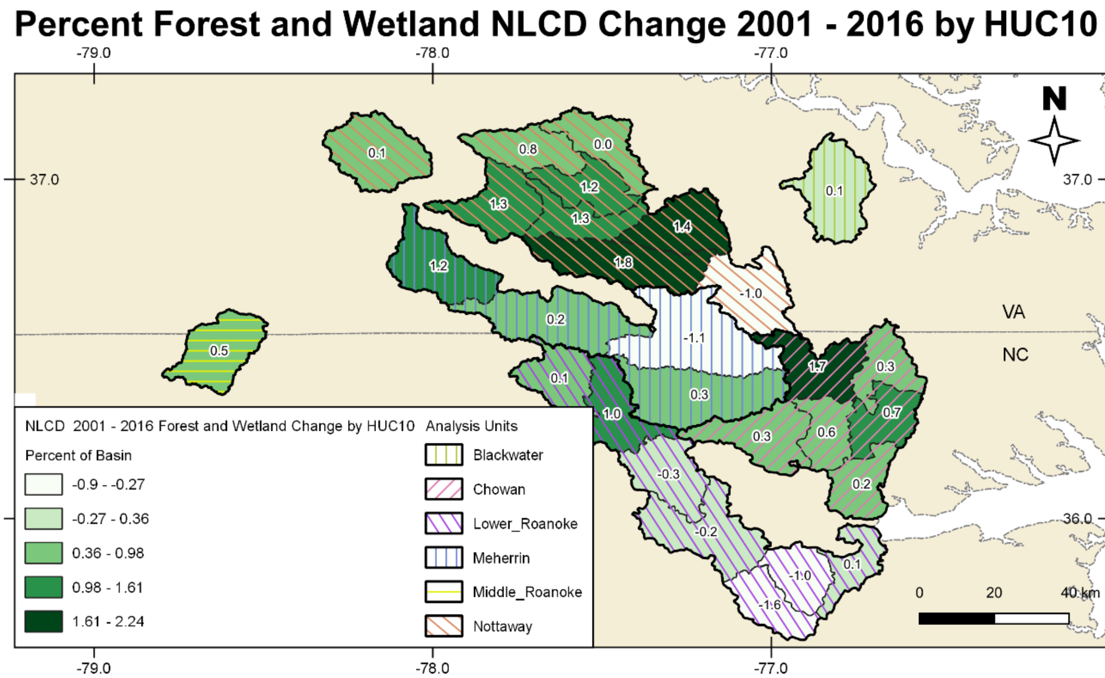


Figure 3-8. Percent difference of forest and wetlands land cover in the HUC10 watersheds from 2001 to 2016, based on the National Land Cover Database (NLCD) (USGS 2019a). A positive value indicates an increase in the land cover type by 2016.

Stream crossings and inadequately buffered clearcut areas can be important sources of sediment entering streams (Taylor et al. 1999, p. 13). Sedimentation eliminates interstitial spaces between all rock size-classes, smothering stream benthic communities and eliminating overall benthic habitat and biological diversity (Hitt and Chambers, 2014, pp. 919–924). For benthic organisms such as crayfish, the net result is elimination of habitat and increased intra- and inter-specific competition for now-limited resources (Loughman et al. 2016, pp. 4–6).

Many forestry activities are not required to obtain a Clean Water Act (CWA) 404 permit, as silviculture activities that follow the state's BMPs (e.g., harvesting for the production of fiber and forest products) are exempted (Corps 2020, entire; USEPA 2020a, p. 1). BMPs 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." Existing BMPs will be sufficient for the protection of sensitive and listed species if, and only if, they are widely implemented in watersheds where the species occurs and are implemented appropriately such that all forest management operations maintain compliance with state regulatory requirements, and that they achieve management goals related to conserving and maintaining suitable habitat for the Chowanoke crayfish. State-approved BMPs, when properly implemented, protect water quality and help conserve aquatic species, including the Chowanoke crayfish, by maintaining a forested landscape. The Chowanoke crayfish overlaps in range with the federally endangered Roanoke logperch and federally threatened yellow lance (*Elliptio lanceolata*), and would incidentally benefit from properly implemented BMPs in reaches where it shares habitat, even though it is an aquatic species currently not federally listed. However, due to the exemptions, foresters are not required to communicate with appropriate state or Federal agencies regarding their activities (e.g., do not need to obtain a permit) and therefore, opportunities for additional species-specific avoidance, minimization, and conservation measures that are part of consultation for non-exempt activities are lost (e.g., time of year restrictions, enhanced sediment and erosion control measures).

A 2018 report by the Southern Group of State Foresters (SGSF) shows that overall BMP implementation rates have increased over the last 20 years, more markedly in some states than in others. BMP implementation in Virginia was the lowest of all the southeastern states (76 percent) as recently as 2007, and increased to 94 percent by 2016 (SGSF 2018, p. 10). Data from the SGSF show North Carolina has the lowest overall implementation rate (84 percent) in the southeast, with other state implementation rates ranging 89 – 99 percent (SGSF 2018, p. 10). BMP implementation rates have increased due to forest certification programs, which require additional training, education and a working relationship with state foresters (National Council for Air and Stream Improvement, Inc. 2012, p. 4; Warrington et al. 2017, p. 1). When properly implemented, BMPs can offer a substantial improvement to water quality. However, forest management activities are not risk free for wildlife or water quality, especially when BMPs are not implemented properly or at all. Forest harvesting has been implicated in significantly impacting physical, chemical, and biological characteristics of streams and negatively affecting other aquatic species (Allan 1995, pp. 324–327; McHale et al. 2008, p.1; Osterling and Hogberg 2014, pp. 215–217). When BMPs are not properly implemented, construction of logging roads through the riparian zone have the potential to directly degrade nearby stream environments (Aust et al. 2011, p. 123). Logging roads constructed in wetlands adjacent to headwater drainages and ephemeral streams fall under silviculture exemptions, but may remain in place well after the initial forest management activity is completed due to the long rotational periods associated with ongoing forestry practices. This may potentially impact the aquatic system for years if the BMP's fail, culverts are undersized or are not maintained, causing sediment to travel downstream into sensitive instream habitats.

Virginia's most recent BMP monitoring report indicated that audits of 240 sites in 2019 resulted in findings of significant water quality risk in only four cases, and that none of them had active sedimentation during the audit visit (Virginia Department of Forestry (VDOF) 2020a, p. 3). However, they also reported that despite overall high BMP implementation rates, "three very important categories that often lead to water quality concerns, roads, crossings, and skid trails, sometimes lag behind other categories with regard to implementation percentage" (VDOF 2020a, p. 3). The most recent survey of BMP implementation in North Carolina showed that implementation rates – while averaging 84 percent statewide – varied among regions within the state, and with respect to the type of BMP being evaluated (Coats 2017, p. 8–41). The NCFS reported that BMPs were not applied or properly implemented in 4,584 opportunities in their assessments, and that 30 percent of these cases posed a risk to water quality (Coats 2017, p. 8). The NCFS also reported that 74 percent of all identified risks to water quality were associated with the lack of application or improper implementation of BMPs related to stream crossings (average implementation rate = 79 percent; range 72–83 percent), stream management zones (average implementation rate = 86 percent; range 72–91 percent), and post-harvest rehabilitation of a site (average implementation rate = 71 percent; range 53–83 percent) (Coats 2017, p. 8, 9, 18–19, 26–34). Such incidents of improperly or unused BMPs and their associated risks to water quality and habitat, as illustrated by these reports, are important to acknowledge in the context of rare, imperiled species, where any one particular localized event may result in further imperilment of a population and set back recovery of the species.

3.1.3 *Agricultural Activities*

Agricultural and farming operations, including Concentrated Animal Feeding Operations (CAFOs), can contribute to nutrient pollution of aquatic habitats when not properly managed (USEPA 2020b). In 2016, agriculture land cover including pasture, grasslands, and cultivated cropland, made up approximately 26.1 percent of the Chowan River basin, and 27.3 percent of the Roanoke River basin (Figure 3-9; USGS 2019a). In North Carolina, there are 92 Animal Operation Permits (cattle, swine, wet poultry, horse, and manure hauling) within the 9 counties containing the Chowan and Roanoke River basins (NCDEQ 2020b). Of the 92 operations in these counties, 22 are in the Chowan River basin, and 40 are in the Roanoke River basin that drain into habitat for the Chowanoke crayfish. In counties with Chowanoke crayfish records in Virginia, there are 11 permitted CAFO operations in four counties within the Chowan River basin, including seven swine, two poultry, and two dairy cattle facilities (VADEQ 2020, pers. comm.). Waste from these sites can contain high levels of nutrients (e.g., nitrogen and phosphorus) in addition to fecal coliform bacteria and any chemical compounds, such as antibiotics or hormone products used in commercial feeding operations (NCWRC 2015, p. 534).

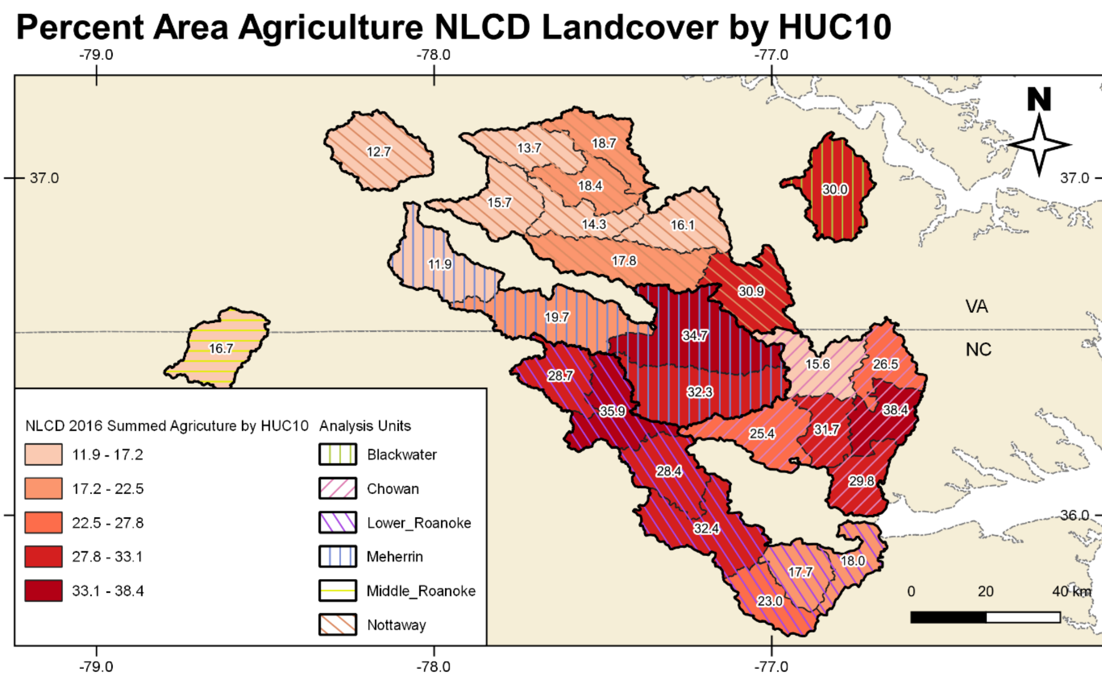


Figure 3-9. Percent of agriculture land cover in the HUC10 watersheds based on the 2016 National Land Cover Database (NCLD) (USGS 2019a).

Fertilizers applied to agricultural fields and animal manure are primary sources of nutrient (nitrogen, phosphorus, and ammonia) pollution of aquatic habitats from agricultural activities. If fertilizers are not applied properly to crops at the right time of the year and with the right application method, water quality in the stream systems can be negatively affected. Excess nutrients impact water quality when it rains or when water and soil containing nitrogen and phosphorus wash into nearby waters or leach into the water table/ground waters causing eutrophication and algal blooms (USEPA 2020b). The lack of stable streambanks from agricultural clearing and/or the lack of cover crops between rotations on farmed lands can increase the amount of sediment and nutrients that enter nearby streams by way of increased soil erosion (cover crops and other vegetation will use excess nutrients and increase soil stability). Thoma (2014, p. 27) recognized the importance of buffer strips adjacent to plowed agricultural lands as a conservation action benefitting Chowanoke crayfish to control runoff, especially runoff carrying sandy sediments.

Livestock often use streams or human-made in-line ponds as water sources, resulting in further degradation of the streambank stability, bank erosion, turbidity, nutrient input, and degradation of water quality. Livestock use of stream beds for drinking and bathing increases downstream sedimentation, and reduces water quantity available for downstream needs. The 2015 Virginia Wildlife Action Plan (VWAP) and NCWAP suggest excluding livestock from streams as a primary action to improve riparian habitats and water quality in Chowanoke crayfish watersheds (VDGIF 2015, p. 23-17; NCWRC 2015, p. 227). There is also the potential that the livestock use may physically destroy existing habitat in the stream bed for the Chowanoke crayfish as the livestock access the stream for water.

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 spray it directly onto crops. Water withdrawals for human use and irrigation can alter stream hydrology and cause stress to aquatic species that depend on specific water levels and flow rates (VDGIF 2015, p. 8-24). Excessive water withdrawal within, or upstream of sensitive aquatic stream reaches may impact flow regime in these areas during low flow months, resulting in dewatering or reduced flow in channels and requiring Chowanoke crayfish to move to a more suitable location or burrow.

Many farming, silviculture, and ranching activities are exempt from the CWA Section 404 permitting process. This includes activities such as construction and maintenance of farm ponds, irrigation ditches, and farm roads. If the activity might impact rare aquatic species, the Corps requires 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." The Chowanoke crayfish overlaps in range with the federally endangered Roanoke logperch and federally threatened yellow lance, and would incidentally benefit from properly implemented BMPs in reaches where it shares habitat, even though it is an aquatic species currently not federally listed. However, due to the exemptions, farmers are not required to communicate with appropriate state or Federal agencies regarding their activities (e.g., do not need to obtain a permit) and therefore, opportunities for additional species-specific avoidance, minimization, and conservation measures that are part of consultation for non-exempt activities are lost (e.g., time of year restrictions, enhanced sediment and erosion control measures).

Agricultural BMPs are changes in agricultural land management that can be focused on achieving multiple positive environmental outcomes. A wide variety of agricultural BMPs exist, including practices such as cover crops, conservation tillage, irrigation efficiency, contour farming, and agroforestry; these practices aim to reduce agrichemical pollution and erosion, manage nutrient and sediment runoff, and protect streams. The U.S. Department of Agriculture's Natural Resources Conservation Service (USDA-NRCS) has prepared technical guidance on conservation practices and activities that can be adapted at the state and local level, and incentives are available for local farmers to participate in programs to promote agricultural conservation practices (USDA 2020, entire).

While there are expectations and even some requirements for farmers to follow BMPs appropriate for their activity or conservation practice, there are cases where BMPs fall short of the desired results and may impact stream function if not addressed by the field technicians charged with routine monitoring of the sites (Wells 2021, pers. comm).

There has been minimal change in the total amount of agriculture land cover in the historically and currently occupied HUC10s from 2001 to 2016, with the majority of the HUC10s having a slight decrease (up to an approximately 2 percent decrease) in agriculture land cover by 2016 (Figure 3-10).

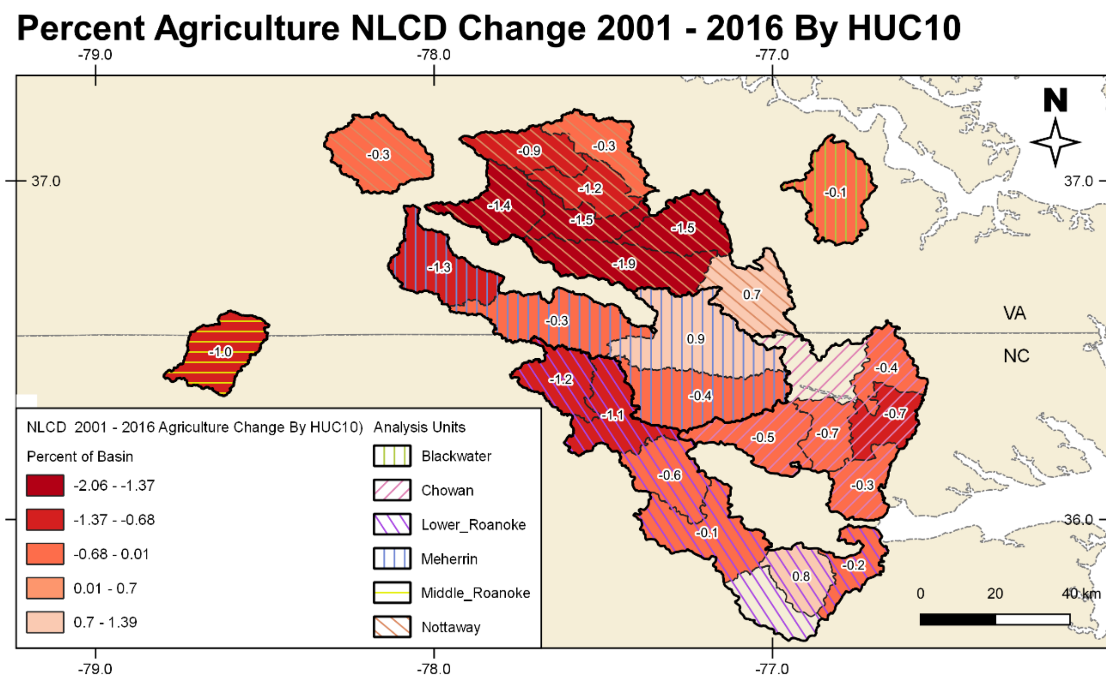


Figure 3-10. Percent difference of agriculture land cover in the HUC10 watersheds from 2001 to 2016 based on the National Land Cover Database (NLCD) (USGS 2019a). A positive value indicates an increase in the land cover type by 2016.

3.1.4 *Dams and Other Aquatic Barriers*

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 United States (Martin and Apse 2011, p. 19). Instream barriers that are human-made (e.g., dams, lowhead dams, improperly installed culverts) and natural (e.g., waterfalls, beaver dams) can have a profound impact on habitat as they can change flowing stream habitat to impounded still water systems. Moreover, stream fragmentation by dams or culverts reduces or eliminates the movement of aquatic species and their access to quality habitat for one or more life stages.

Habitat elements that are important to the Chowanoke crayfish include moderately to large sized, stable stream channels with riffles, runs, or pools that have noticeable current and low levels of sedimentation; unembedded stream substrates that have larger particle sizes and provide instream cover; and, healthy riparian and instream characteristics (e.g., adequate riparian cover to moderate temperature and sedimentation, appropriate prey resources, and sufficient water chemistry). These elements allow for individuals to have sufficient food and shelter resources to grow, reach maturity, and reproduce. Connectivity can influence population demographics and is itself influenced by the quality of instream features, water quality, and riparian conditions. For populations to be resilient, they need healthy demography (i.e., stable or positive growth rates), dispersal habitat that provides connectivity to allow for gene flow among subpopulations, and sufficient habitat quality and quantity to support healthy individuals.

The species' range includes anthropogenic and natural barriers to connectivity. Unsuitable habitat created by dams and associated reservoirs separate the Middle Roanoke from the Lower Roanoke. The reservoirs include John H. Kerr Reservoir, Lake Gaston, and Roanoke Rapids Lake. We assume that Chowanoke crayfish cannot move from Grassy Creek and Little Grassy Creek in the Middle Roanoke to the Roanoke River in the Lower Roanoke, due to multiple dams and lack of suitable habitat within the impounded areas. We conclude these factors isolate the Middle Roanoke subpopulations from the Lower Roanoke subpopulations.

Two dams in the upper portion of the Nottoway River create the Nottoway Falls Reservoir and Nottoway Reservoir. The Nottoway Falls Reservoir is located in the Little Nottoway River-Nottoway River HUC10 watershed (0301020101; see Figure 3-2) and may separate the Chowanoke crayfish in Modest Creek (a tributary to Nottoway River) from downstream occurrences in the Nottoway River. The Nottoway Reservoir is located in a HUC10 watershed with no historical or current Chowanoke crayfish occurrences; however, we assume it is a barrier to movement within the Nottoway River between the Little Nottoway River-Nottoway River HUC10 watershed and the next downriver watershed, Sturgeon Creek-Nottoway River HUC10 (03010201031; see Figure 3-2). These portions of the species' range and the impounded tributaries creating reservoirs and large lakes are no longer suitable habitat for the Chowanoke crayfish because they no longer consist of moderately sized streams with flowing conditions.

In addition to dams, culverts that are improperly designed and/or installed form barriers and prevent aquatic species' movement and dispersal. Limited information precludes our ability to quantify how many perched culverts (e.g., road related barriers that impact aquatic species) may be within the Chowanoke crayfish's range. There is also insufficient information to assess the potential effects of natural barriers and other human-made barriers, such as lowhead dams and beaver dams, on Chowanoke crayfish. Lowhead dams are noted to be common in the Chowan basin in Virginia (Watson 2021, pers. comm.). Therefore, we acknowledge that there are some unquantifiable number of natural and other human-made barriers that may impact aquatic species within the species' range, but we are unaware of the specific effects that such barriers may have on the Chowanoke crayfish. Some crayfish species have been documented to move upstream over small barriers and have been seen climbing up rock faces around waterfalls or moving overland (Kerby et al. 2005, p. 407; Puky 2014, 143); therefore, it is possible that Chowanoke crayfish have the ability to migrate past some of the natural and human-made barriers that occur within their range, however this is likely a species-specific and/or site-specific phenomenon.

As noted in Section 2.7, Gangloff et al. (in prep, pp. 8–9, 13–14, 28) conducted a genetic analysis of Chowanoke crayfish and their data suggested recent gene flow among populations within a basin, and some level of past genetic exchange between the Chowan and Roanoke River basins, but with more recent isolation between the two. However, the effects of human-made barriers on gene flow among subpopulations were not addressed in this study due to limited sample sizes and use of a single marker.

3.1.5 *Regulatory Mechanisms*

State Endangered Species Laws

Each state within the range of the Chowanoke crayfish has state-level legislation modeled after the Federal Endangered Species Act: in Virginia it is both the Virginia Endangered Species Act and the Endangered Plant and Insect Species Act, and in North Carolina it is the North Carolina Endangered Species Act. Animal species that are protected by the state laws are regulated by state wildlife agencies: the VDWR (formerly VDGIF) and the NCWRC. While the Chowanoke crayfish is not currently state listed as endangered or threatened, it may benefit from these protections in waterways shared with other listed species, such as the Roanoke logperch and yellow lance.

The state endangered species protection laws allow the state wildlife agencies to identify, document, and protect any animal species that is considered rare or in danger of extinction. In Virginia and North Carolina, illegal activities include take, transport, export, processing, selling, offering for sale, or shipping species, and the penalty for doing so is a misdemeanor crime, usually resulting in a fine of no more than $1,000 or imprisonment not to exceed a year (Pellerito 2002, entire). There are no mechanisms for recovery, consultation, or critical habitat designation other than in North Carolina where conservation plans must be developed for all state-listed species (Pellerito 2002, entire; George and Snape 2010, p. 346). In addition, nothing in the North Carolina Endangered Species Act "shall be construed to limit the rights of a landholder in the management of his lands for agriculture, forestry, development, or any other lawful purpose" (NC GS §113-332; North Carolina Legislation 1987, p. 1).

State and Federal Stream Protections and Guidance (Buffers & Permits)

A buffer is a strip of trees, plants, or grass along a stream or wetland that naturally filters out dirt and pollution from rain water runoff before it enters rivers, streams, wetlands, and marshes (Southern Environmental Law Center 2014, entire). Several state laws require setbacks or buffers, and all allow variances/waivers for those restrictions depending on the watershed and authorized activity, but the Chowan and Roanoke River basins are not subject to these protections in North Carolina and Virginia. While not a regulatory requirement, North Carolina has guidance for 200-foot riparian buffer protections for streams draining to listed aquatic species habitats (NCWRC 2002, p. 11). Virginia offers a tax credit for landowners who leave buffers when harvesting timber. The buffer needs to be 35 to 300 feet wide and remain in place for 15 years (VDOF 2020b, p. 1). The VWAP (VDGIF 2015, p. 8-30) also recommends 50- to 100-foot buffers.

Section 401 of the Federal 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, including riparian buffers in applicable watersheds.

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 to fill, culvert, bridge, or realign streams or water features are issued by the Corps under Nationwide, Regional General Permits or Individual Permits. Nationwide Permits are for "minor" impacts to streams and wetlands, and do not require a comprehensive review process. These impacts usually include stream impacts under 150 feet, and wetland fill projects up to 0.50 acres. Mitigation is usually provided for the same type of wetland or stream impacted, and is usually at a 2:1 ratio to account for uncertainty in the success of mitigation in offsetting losses and achieving the objective of "no net loss." 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 more comprehensive review 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. TMDL, or Total Maximum Daily Load, is a regulatory term from the CWA describing a plan for restoring impaired waters that identifies the maximum amount of a pollutant that a body of water can receive while still maintaining water quality standards.

Under the CWA, states are required to review their water quality standards and classifications every three years to make any modifications necessary to protect the waters of the state (NCDEQ 2020a). During this process, known as the Triennial Review, state water quality staff review current EPA guidelines, scientific data, and public comments and make recommendations for any changes of the water quality standards. In North Carolina and Virginia, the most recent triennial reviews were underway in 2020 (Higgins 2020, pers. comm.; Virginia Regulatory Town Hall 2020).

Despite existing authorities such as the CWA, pollutants continue to impair water quality throughout the current range of the Chowanoke crayfish. 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 assess effectiveness. 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.

3.1.6 *Effects of Land Use Modification on Chowanoke Crayfish*

Land use modification and the stressors associated with development, forestry activities (i.e., when BMPs are not implemented properly or lead to reduction in forested landscape), and agricultural practices within the Chowan and Roanoke River basins have the potential to negatively impact the Chowanoke crayfish directly and indirectly. Excessive pollution, sedimentation, water quality declines, riparian and instream habitat fragmentation and degradation, and reduced water quantity can directly disrupt the species' breeding, feeding and sheltering needs at varying stages of life, which indirectly affects the species' demography over time. While land use modifications vary in size, intensity, and duration, development and urban sprawl are expected to persist and increase into the future as predicted by Terando et al. (2014); therefore, we are carrying these effects forward in our current and future conditions analysis.

Dams, culverts, and reservoirs/lakes have historically impeded connectivity and created unsuitable habitat and will continue to do so in the future. We are unaware of the effects of natural and human-made barriers (e.g., culverts, lowhead dams, beaver dams) on Chowanoke crayfish. In addition, presence of invasive crayfish and the effects of sea level rise may decrease connectivity in the future; therefore, connectivity is embedded in and carried forward through our analysis of invasive species and sea level rise (see Sections 3.2.2 and 3.3 below).

3.2 Nonnative Species

3.2.1 *Nonnative Fish*

The invasive flathead catfish (*Pylodictis olivaris*), native to the Mississippi Basin, has been introduced throughout the Atlantic Slope; it was first introduced to and documented in North Carolina in the Cape Fear River in 1966 (Guier et al. 1981, pp. 1, 14). Studies on introduced flathead catfish have shown that crayfish can make up a significant portion of their diets. Pine et al. (2005, pp. 904–905) found crayfish made up 26-60 percent of frequency of occurrence of stomach contents in the 2-year study in two coastal rivers in North Carolina. Baumann and Kwak (2011, p. 1125) also found that crayfish occurred most frequently in stomach contents during a diet study in the Deep River in central North Carolina. Small flathead catfish (total length less than 300 mm) are typically invertivores feeding mainly on aquatic insects and crayfish and become more piscivorous as they mature and grow (Herndon and Waters 2000, p. 73; Pine 2003, pp. 116–123). Although flathead catfish have not been observed consuming Chowanoke crayfish because both species are not currently known to co-occur, negative impacts may be significant if habitat overlap exists. Flathead catfish have been introduced into the Roanoke Basin and have become established in all reservoirs (Kerr, Gaston, and Roanoke Rapids) along the border of North Carolina and Virginia. There is potential for habitat overlap of flathead catfish and Chowanoke crayfish within Grassy and Little Grassy creeks. These creeks flow into Kerr Reservoir, and flathead catfish can move into these creeks, although there has been no targeted effort to confirm this. To date, no flathead catfish have been observed in the Lower Roanoke River or the Chowan River, though populations have been established for several decades upstream.

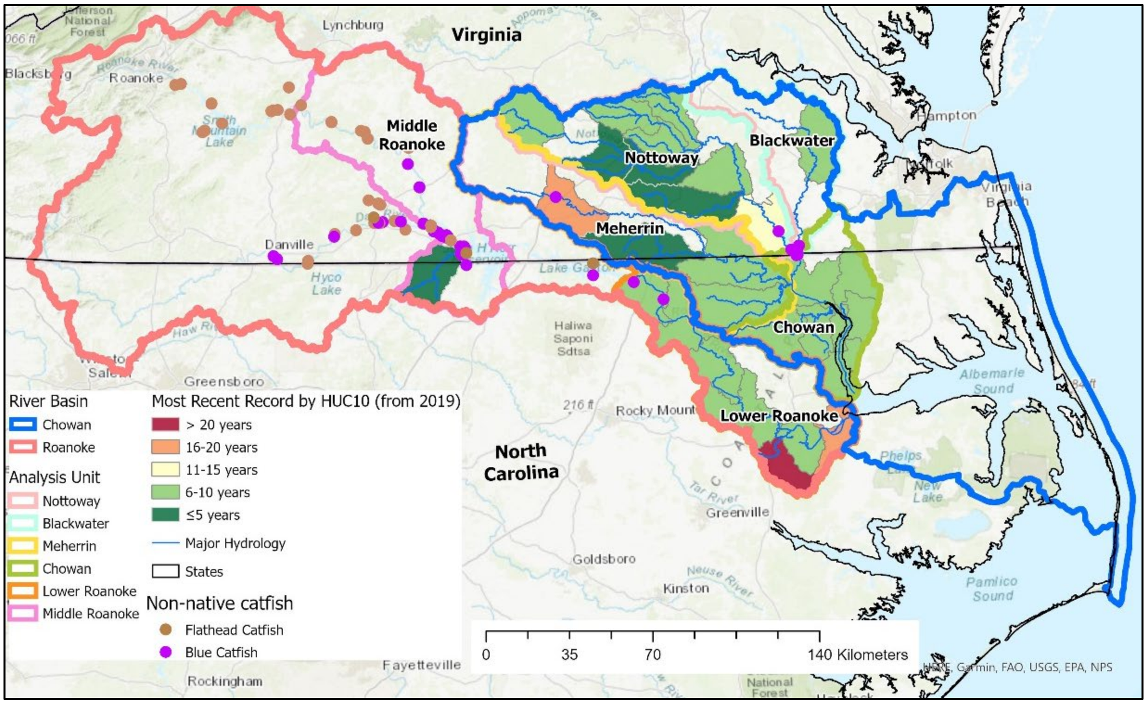


Figure 3-11. Blue catfish and flathead catfish distribution in Chowanoke crayfish river basins (distributions outside of Roanoke and Chowan basins not included on this map) (VDWR 2019b, unpublished data; NCWRC 2020a, unpublished data). Analysis units are shown by name.

The blue catfish (*Ictalurus furcatus*) were also initially introduced to the Cape Fear River in North Carolina in 1966 and are found in all of North Carolina's major coastal rivers as a result of range expansion and angler introductions (Guier et al. 1981, p. 14; Fisk et al. 2018, p. 2). They occur in the Chowan River, upper Meherrin River, and lower Nottoway River in the Chowan River basin (Figure 3-11), where Chowanoke crayfish may occur. They are also present in the Upper and Middle Roanoke River subbasins, including Kerr Reservoir, and have been collected downstream of Roanoke Rapids Reservoir (VDWR 2019b, unpublished data; NCWRC 2020a, unpublished data). While they are not considered as much of a threat as flathead catfish because they do not appear to move into tributaries as much as flathead catfish, blue catfish are a popular game fish throughout the chain of reservoirs on the Roanoke River, and there is the potential threat of an increased spread of the species through intentional or accidental introductions.

The potential expansion of flathead and blue catfish into Chowanoke crayfish streams is unknown and has not been assessed or modeled in the literature. In addition they have not been documented to be a significant threat to the Chowanoke crayfish and other crayfish species, however these nonnative catfish may pose a risk in the future.

3.2.2 *Nonnative Crayfish*

The red swamp crayfish (*Procambarus clarkii)* is native to the Gulf Coast and Mississippi River drainage to Illinois and has been introduced all over the United States including in North Carolina and Virginia (Cooper and Armstrong 2007, p. 4; Oficialdegui et al. 2020, pp. 2–3). This species was first discovered in 1996 and 1997 in North Carolina and Virginia, respectively (Cooper et al. 1998, p. 3; VDWR 2019b, unpublished data). The red swamp crayfish is expanding its range in North Carolina into the Chowanoke crayfish's range; it was first observed in 2004 in Bertie County, NC within the Roanoke Basin (Lower Roanoke AU) and in 2011 in Hertford County, NC within the Chowan Basin (Meherrin AU) (NCMNS 2011, unpublished data; NCWRC 2019b, unpublished data). The species co-occurs with the Chowanoke crayfish in two locations: the Meherrin River and Potecasi Creek, a tributary to the Meherrin River, both in the Chowan Basin (Meherrin AU) within North Carolina (Figure 3-12). This species has also been observed in the Chowan and Lower Roanoke AUs, but not at the same locations where Chowanoke crayfish have been documented (Figure 3-12).

The red swamp crayfish, a primary burrower, has been found to reduce macrophyte densities and trophic chains (Rodriguez et al. 2005, pp. 77–78; Service 2019b, pp. 4–5; Service 2019c, p. 1). They can be carriers of pathogens that impact native crayfishes (Loureiro et al. 2015, pp. 4–5), and outcompete native crayfish for food and habitat (Service 2015a, pp. 5–6). Red swamp crayfish can also negatively impact native crayfish by killing individuals (Service 2019c, p. 1; Service 2019b, p. 4). Red swamp crayfish herbivorism and predation can significantly alter habitat, result in a loss of biodiversity and, in some cases, the disappearance of some species of aquatic fauna and birds (Rodriguez et al. 2005, entire). The red swamp crayfish is known to be a global invader, by colonizing quickly and adapting to any conditions (Service 2019b, p. 4; Service 2019c, p. 1); therefore, it is possible that habitat deserts created by red swamp crayfish could act as habitat barriers and isolate Chowanoke crayfish populations within their range. While they are known to invade a wide range of freshwater habitats (Loureiro et al. 2015, p. 1; USGS 2020b, p. 4), some research suggest that red swamp crayfish prefer slow flowing, low elevation waterbodies (Cruz and Rubelo 2007, pp. 196–198) and are less likely to inhabit large, deeper, and higher flow rivers with reduced aquatic vegetation along the banks or less eutrophied conditions (Gavioli et al. 2018, pp. 546, 550). Other studies have found that introduced populations can utilize habitats that it typically is not associated with, demonstrating some degree of plasticity in habitat selection (Reynolds et al. 2013, pp. 200–201). Although the species has been found in a wide range of habitats in North Carolina, it seems to flourish in shallow, slow moving bodies of water found in floodplains and swamps in the Roanoke and Chowan basins. These studies suggest that red swamp crayfish may have different habitat preferences than Chowanoke crayfish.

The potential impacts to Chowanoke crayfish have not been assessed in the literature or observed. Red swamp crayfish have replaced some native crayfish species (i.e., the Waccamaw crayfish (*Procambarus braswelli*), a tertiary burrower) in southeastern North Carolina (Kendrick et al. 2019, p. 1; Service 2019c, p. 1; Kendrick 2021, pers. comm.). In Potecasi Creek where red swamp crayfish were detected in 2011 and overlap with Chowanoke crayfish, a survey in 2020 found both species co-occurring in the same reach in comparable numbers as in 2011 surveys (NCWRC 2019b and 2020b, unpublished data). There is debate among some crayfish experts if red swamp crayfish would likely impact Chowanoke crayfish because the former is a primary burrower, while Chowanoke crayfish is a tertiary burrower, thereby occupying different habitat niches (Thoma 2021, pers. comm.)

The virile crayfish is native to the Missouri, upper Mississippi, lower Ohio, and Great Lakes drainages but has been introduced throughout North America (Service 2015b, p. 1). Introductions have been linked to anglers using them for fishing (DiStefano et al. 2009, p. 588).

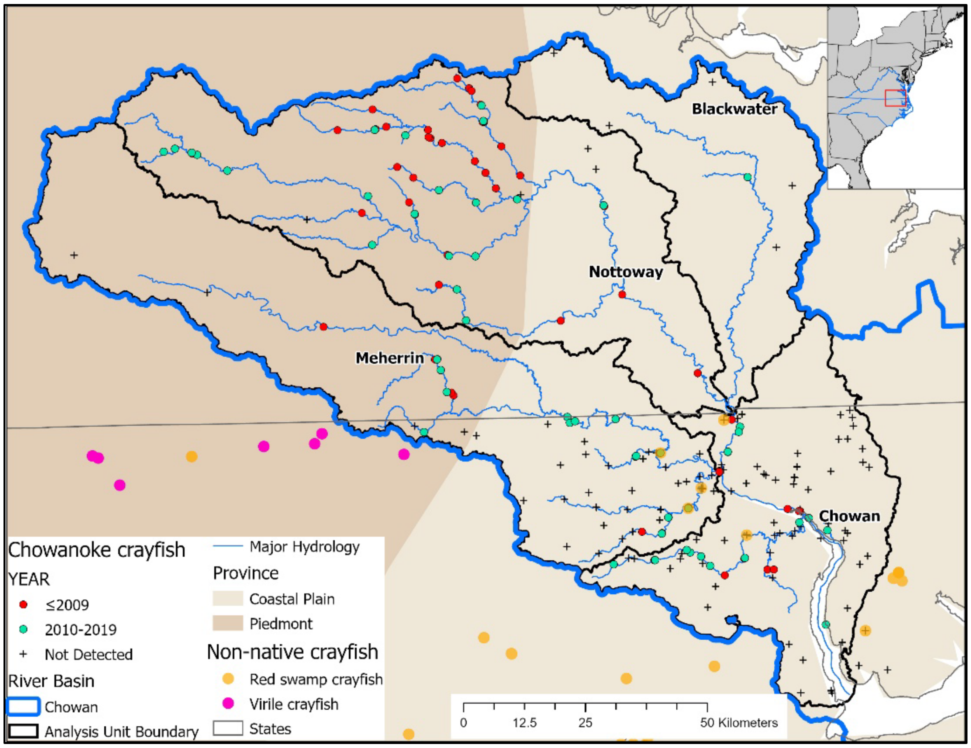
The virile crayfish is a tertiary burrower and has a similar life history as other Faxonius spp. (Service 2015b, p. 4). They are frequently found in impoundments and prefer habitats with low velocity water and depositional substrates that are made of compressed silt and detritus beds (Loughman 2013, pp. 63–66). In contrast, high-gradient streams may impede dispersal of the virile crayfish because it lacks the ability to hold position in high velocity habitats (Loughman and Welsh 2010, p. 73). Although, they have been collected in flowing, stream habitats; introduced populations typically are found in degraded streams with elevated siltation, high nutrient loads, and homogenized habitat from urbanization and other land use activities (Loughman 2010, p. 53; Loughman 2013, p. 65–66). Virile crayfish introductions have impacted other species of crayfish in Maryland and West Virginia including spiny-cheeked crayfish and Allegheny crayfish (Kilian et al. 2010, p. 20; Loughman 2010, p. 52; Loughman and Welsh 2010, p. 70). Virile crayfish are aggressive, and through competitive exclusion of refugia, native crayfish become more vulnerable to predation, which leads to population declines (Loughman 2010, p. 52). In laboratory experiments they have killed Allegheny crayfish or White River crayfish (*Procambarus acutus*) when food is present (Loughman 2010, p. 55). In contrast, native crayfish have been able to maintain populations even when nonnative crayfish are present in streams. For example in West Virginia, the native New River crayfish (*Cambarus chasmodactylus*) has maintained populations within Anthony Creek despite the presence of the virile crayfish (Loughman 2013, entire). This is likely because Anthony Creek has naturally low nutrient levels and low levels of sedimentation and has a high enough gradient that preferred habitats for the virile crayfish (depositional, sediment laden habitats with low flow conditions) are limited within the watershed.

Virile crayfish have been introduced into North Carolina dating back to 1990 in the Catawba Basin (Cooper and Armstrong 2007, p. 7) and in the Roanoke Basin in 2007 (Cooper 2010, p. 72). Established populations of virile crayfish occur in Kerr Lake and Lake Gaston and overlap in distribution with Chowanoke crayfish in Grassy Creek, a tributary that flows into Kerr Lake (Figure 3-12). Co-occurrence has mainly been documented in the transition zone between lentic (e.g., reservoirs, pools, lakes) and lotic habitats (e.g., streams or rivers with flowing waters). The impacts of virile crayfish on Chowanoke crayfish are not known or been observed. Although extensive surveys have not occurred, based on 2014 and 2019 surveys, this population has not impacted Chowanoke crayfish or other native species and has not been documented in upstream surveys (NCWRC 2019b, unpublished data). There was also a single virile crayfish record in the Roanoke Bypass reach in 2007, immediately downstream of the Roanoke Rapids Dam (NCMNS 2011, unpublished data). During crayfish surveys in 2014, no virile crayfish were found, but 35 Chowanoke crayfish were observed nearby in the Roanoke Bypass reach, suggesting lack of expansion in this area (NCWRC 2019a and 2019b, unpublished data).

There are other potential nonnative crayfish in Virginia and North Carolina, but they do not overlap in range (e.g., spiny stream crayfish (*F. cristavarius),* Ozark crayfish, and rusty crayfish) with the Chowanoke crayfish. The spiny stream crayfish and Ozark crayfish have been collected in the upper Roanoke basin in Virginia (Foltz 2021, pers. comm.; Thoma 2021, pers. comm.). The rusty crayfish has been collected in the Holston Basin in Virginia and is established in the Catawba and Broad basins in NC (NCWRC 2019b, unpublished data; Thoma 2021, pers. comm.). These nonnative crayfish rates of expansion into Chowanoke crayfish streams are unknown and has not been assessed or modeled in the literature. There is the potential threat of an increased spread of the species through intentional or accidental introductions (e.g., bait buckets). To reduce the rate of bait bucket introductions, virile and rusty crayfish are on North Carolina's prohibited species list, making it illegal to possess, propagate or sell the species (North Carolina Administrative Code 2021, p. 1). In Virginia, it is unlawful to sell any crayfish species live as bait or for personal use, except for personal consumption (Virginia Law 2021, p. 1).

3.2.3 *Effects of Nonnative Species on Chowanoke Crayfish*

Nonnative species can negatively impact native species via habitat alteration, competition, and predation, leading to native species population declines and extirpation. The red swamp crayfish, a nonnative crayfish, is present within the Lower Roanoke, Meherrin, and Chowan AUs, but only known to co-occur with the Chowanoke crayfish in Potecasi Creek and the Meherrin River in the Meherrin AU (NCWRC 2019b and 2020b, unpublished data). The virile crayfish, another nonnative crayfish, is present within the Middle and Lower Roanoke AUs, but only known to co-occur with the Chowanoke crayfish in Grassy Creek in the Middle Roanoke AU with no documented expansion (NCWRC 2019b, unpublished data). Impacts to Chowanoke crayfish by both the red swamp crayfish and virile crayfish are unknown, but negative impacts have not been observed. The red swamp crayfish and virile crayfish have been shown to replace native crayfish species in southeastern North Carolina and West Virginia/Maryland, respectively (Loughman and Welsh 2010, p. 70; Service 2019c, p. 1). Native Chowanoke crayfish populations may be able to withstand the presence of nonnative crayfish, as has apparently occurred in Potecasi Creek for at least 9 years where Chowanoke crayfish and red swamp crayfish co-occur; however, nonnative crayfish have also extirpated populations of other native crayfish, particularly in streams that are already degraded by anthropogenic nutrient inputs or high levels of sedimentation (Loughman 2013, pp. 66–67). Therefore, we included the potential effects of red swamp crayfish and virile crayfish to instream habitat in our analysis. Other nonnative crayfish are not included in our analysis due to lack of overlap in range and unknown rates of expansion. The flathead catfish has also been documented in the Roanoke and Chowan basins; however, we did not include the flathead catfish in our analysis based on the lack of data to indicate occurrence of the flathead catfish in Chowanoke crayfish streams and the unknown specific threats they may pose to Chowanoke crayfish in the future.



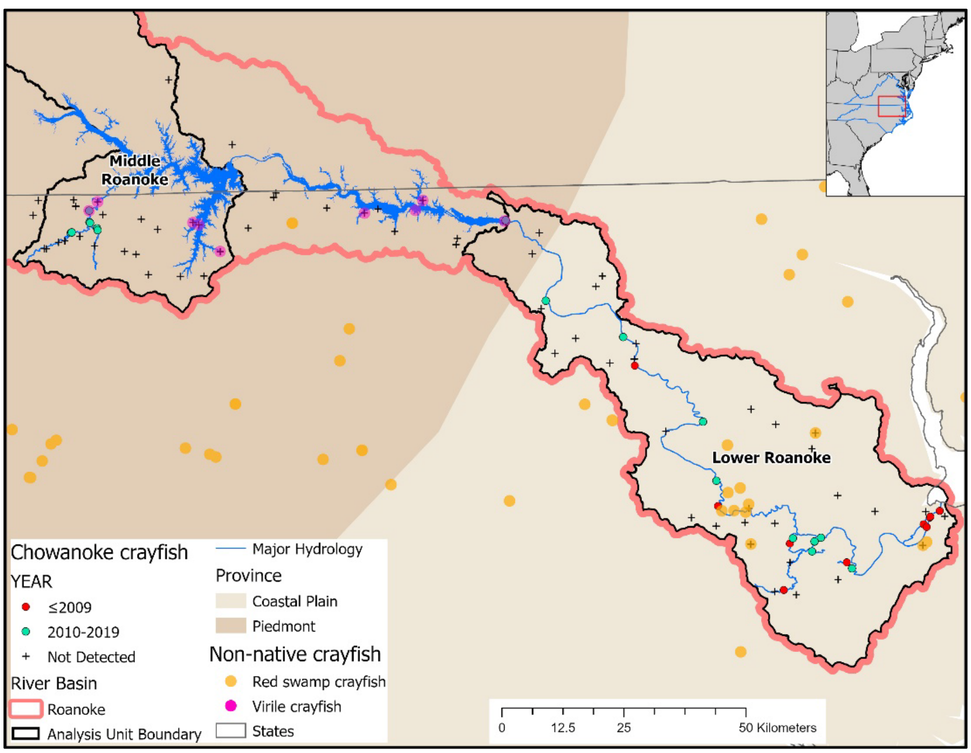


Figure 3-12 Chowanoke crayfish, red swamp crayfish, and virile crayfish occurrences in and surrounding the Chowan River (top) and Roanoke River (bottom) basins (NCMNS 2011, unpublished data; NCWRC 2019b, unpublished data; Thoma 2019, unpublished data; VDWR 2019b, unpublished data; Williams and Foltz 2019, unpublished data; Service 2020b, unpublished data). Analysis units are shown by name.

3.3 Climate Change

3.3.1 *Climate Change in North America*

Evidence of the warming of the climate system is unequivocal according to the Intergovernmental Panel on Climate Change (IPCC 2014, p. 40). Long-term climate changes observed include: widespread changes in precipitation and flood events, extreme temperature patterns, sea level rise, ocean salinity, storm surges, and aspects of extreme weather including droughts, heavy precipitation and flooding, and heat waves (IPCC 2014, pp. 2–8). These changes can have direct or indirect effects on species and their habitat. The effects may be positive, neutral, or negative and they may change over time, depending on the species and other relevant considerations, such as the effects of interactions of climate with other variables (e.g., invasive species; Service 2020a, p. 47).

The likely impacts of climate change on aquatic ecosystems include increase in water temperature and salinity due to sea level rise (SLR) that decreases habitat suitability for many aquatic species and their prey. Precipitation and runoff changes can alter the quantity and quality of aquatic habitat as well alter species composition and food web dynamics. Changes in the seasonal timing of the hydrologic regime, such as the magnitude, frequency, duration, and timing of runoff, and which can interfere with the reproduction and growth of many aquatic species and alter foraging and sheltering habitat availability (Poff et al. 2002, entire).

The ability of aquatic ecosystems to adapt to climate change is limited because the rate of change is likely too rapid to allow for genetic adaptation (Poff et al. 2002, p. 32) and the human alteration of dispersal corridors often limits migration. The adaptive capacity or resilience of aquatic ecosystems may be enhanced if society minimizes environmental stresses from pollution, habitat loss, and invasive species introductions. The following activities could help to reduce impacts and build resiliency in aquatic ecosystems: maintaining and increasing riparian forests and forested wetlands, increasing urban tree canopies, restoring damaged ecosystems and natural flow regimes, reducing nutrient loading and improving wastewater treatment, and reducing water withdrawals from rivers, lakes, and wetland ecosystems (Poff et al. 2002, pp. 32–35; Kaushal et al. 2010, pp. 465–466; Richman et al. 2015, pp. 8–9).

Since the 1950s, the North American climate trends demonstrate an increase in overall temperature and an increase in the number of heavy precipitation events (IPCC 2014, pp. 52–53; Wuebbles et al. 2017, pp. 17–21). Temperatures are expected to continue rising, and heat waves and extreme precipitation events are predicted to become more frequent, last longer, and become more intense by the mid-21st century (IPCC 2014, pp. 58–63; Wuebbles et al. 2017, pp. 17–21). The two most recent reports with climate data and predictions by U.S. Global Change Research Program (USGCRP) are the Third National Climate Assessment (NCA3; Melillo et al. 2014, entire) and the Fourth National Climate Assessment (NCA4, Volume I; Wuebbles et al. 2017, entire). The NCA4 used the World Climate Research Programme's Coupled Model Intercomparison Project, which focuses on two scenarios (Vose et al. 2017, pp. 194–199): the higher emissions (radiative forcing) scenario (Representative Concentration Pathway (RCP 8.5)) and the medium-low emissions (radiative forcing) scenario (RCP 4.5). For detailed descriptions of the scenarios, see Hayhoe et al. (2017, pp. 135–149). The USGCRP stated with very high confidence that "the observed increase in global carbon emissions over the past 15 to 20 years has been consistent with higher scenarios” such as RCP 8.5 (Wuebbles et al. 2017, pp. 152–153). It is therefore reasonable to conclude that changes from now through mid-century will also be closer to RCP 8.5 than to RCP 4.5 (Service 2020a, p. 48). Therefore we primarily use RCP 8.5 in our future analysis, but also include RCP 4.5 in one of our future scenarios (see Chapter 5) to incorporate the suite of plausible scenarios.

3.3.2 *Climate Change in Virginia and North Carolina*

As part of the NCA4, the National Oceanic and Atmospheric Administration (NOAA) prepared state climate summaries and maps with projections using simulations under the RCP 4.5 and RCP 8.5 scenarios, which predict a range of significant change based on the level of emissions (Runkle et al. 2017, entire; Frankson et al. 2019, entire). In Virginia, the state summary climate models project unprecedented warming during the 21st century, more intense droughts, and an increase in the number and intensity of extreme heat and extreme precipitation events. SLR and coastal flooding are projected to increase in frequency and severity as well (Runkle et al. 2017, entire). The North Carolina state summary climate models project unprecedented warming during the 21st century, as well as more intense droughts and heat waves. Hurricane-associated storm intensity and rainfall rates are projected to increase as the climate warms. Extreme precipitation and coastal flooding from these storms is a great hazard to the state. A large portion of the coastline is extremely vulnerable to future SLR and the associated increases in coastal flooding (Frankson et al. 2019, entire).

The NCA’s Southeast region report findings (Carter et al. 2018, entire) agree with those found by Runkle et al. (2017) and Frankson et al. (2019). Since the 1950s, the average daily minimum temperatures in the region have increased three times faster than the average daily maximum temperatures, and extreme rainfall events have increased. The reduction in the frequency and intensity of cold winter temperature extremes have allowed tropical and subtropical species to move north and replace more temperate species (Carter et al. 2018, pp. 745–746). This trend is expected to continue with warmer winters favoring invasive species (Carter et al. 2018, pp. 746, 772).

3.3.3 *Vulnerability of Crayfish to Climate Change*

The Chowanoke crayfish is rated as both highly sensitive and highly exposed to climate change (Hossain et al. 2018 and 2019, entire). A trait-based climate vulnerability assessment (TVA) protocol was used to assess the vulnerability of freshwater crayfish to climate change. Three species traits were used to identify their vulnerability to climate change (Hossain et al. 2018 and 2019, entire):

1. Inability to live in their habitats (Sensitivity),
2. High exposure to hostile environment (Exposure), and
3. Inability to adapt to changing climatic conditions (Low adaptive capacity).

The traits were scored as high or low based on ecological and biological criteria. Species that are highly sensitive to climate change are those found to be dependent on a habitat type that may become degraded/destroyed by climate change, such as habitats that may experience changes in salinity due to sea level rise or stagnation of riverine environments due to drought. Species that are highly exposed to climate change occur in areas expected to experience massive temperature or rainfall changes in the future. Species rated as having low adaptability to climate change are known to live in areas surrounded by barriers that prevent movement into favorable habitats to escape from climate change. And, finally, species that scored in all three categories as highly sensitive, lowly adaptive, and highly exposed, were identified as vulnerable to climate change overall (Hossain et al. 2018, pp. 1832–1836; Hossain et al. 2019, pp. 2–3).

Researchers were not able to assess the adaptive capacity of Chowanoke crayfish because there were no data on dispersal barriers, clutch size, or population trends, and the species was listed as data deficient in the IUCN Red List (Hossain et al. 2018, entire; Hossain 2020, unpublished data). If the species has dispersal barriers that prevent migration to new areas, or its clutch size is ≤ 56, or its population is declining, then it would be classified as lowly adaptable which in turn would designate the species as vulnerable overall to climate change (Hossain 2020, unpublished data). The finding for Chowanoke crayfish was the same in a 2019 study that tested crayfish species vulnerability using 11 individual climate model scenarios, but Chowanoke crayfish vulnerability to climate change based on adaptive capacity could not be assessed for the same reasons (Hossain et al. 2019, entire; Hossain 2020, unpublished data) identified above.

Of 574 freshwater crayfish species assessed worldwide (based on a RCP 6.0 scenario), 87 percent of the species are highly sensitive to climate change, 35 percent have a low adaptive capacity to climate change, and 57 percent are highly exposed to climate change. Fifteen percent of the species that scored in all three categories are described as being vulnerable overall to climate change. Climate change vulnerable crayfishes are concentrated in the southeastern United States (Hossain et al. 2018, pp. 1830, 1835–1841).

The 2015 NCWAP identified Chowanoke crayfish as a species of greatest conservation need and a priority species of concern that requires monitoring (NCWRC 2015, pp. 89–90, 534–537, 604–607). The NCWAP described the level of threat to Chowanoke crayfish due to biological resource use (removal of plants or animals from a particular habitat) and invasive species as high. Climate change and severe weather are identified as threats that create significant impacts to North Carolina crayfish populations in general, but the threat to Chowanoke crayfish due to climate change was not designated as high (NCWRC 2015, pp. 87–88, 702–703, 713–717, 723–730). The 2015 VWAP also identified the Chowanoke crayfish as a priority species of greatest conservation need and describes climate change as a threat due to changes in temperature and precipitation, resulting in drier more drought prone summers, as well as warmer water temperatures that could harm aquatic species (VDGIF 2015, pp. 8-23 to 8-25; 23-15 to 23-16).

3.3.4 *Assessing Future Climate Change Scenarios and Effects on Chowanoke Crayfish Habitat*

Climate model simulations project continued increases in temperature and extreme precipitation for both lower and higher scenarios (RCP 4.5 and RCP 8.5). The higher scenario tracks closely with the current consumption of fossil fuels, and by the late 21st century the temperature and precipitation increases are predicted to be much larger (double the number of heavy rainfall events) than the lower scenario (Carter et al. 2018, pp. 749–751, 762–766). Reports indicate that it is very likely that, overall, natural ecosystems will be greatly modified by the changes in winter temperatures, hurricanes, floods, and droughts (DeWan et al. 2010, entire; NCWRC 2015, pp. 222, 723–728, 879–886; VDGIF 2015, entire; Carter et al. 2018, pp. 785–787).

Empirical data on the effects of warmer water temperatures, and potentially lower dissolved oxygen (DO) levels, and the changes in precipitation on Chowanoke crayfish physiology or reproductive success are lacking; therefore, we are uncertain about the significance of increased water temperatures and changes in precipitation on the species' viability. However, direct and indirect effects of climate change are expected to continue to cause significant impacts to North Carolina crayfish populations into the future (NCWRC 2015, pp. 87–88).

Studies demonstrate that changes in water temperatures can lead to shifts in the range and distribution, and in some cases local extirpations, of multiple aquatic species (Isaak and Rieman 2013, pp. 747–749; Wiens 2016, entire). Land use changes in the 19th and 20th centuries such as clearing for agriculture, forestry, and urbanization may have contributed to increases in water temperatures (Stancil 2000, entire; Nagy et al. 2011, entire). Currently, deforested areas (i.e., urban areas, agricultural fields and pastures, and timber harvests) may contribute to elevated water temperatures in some portions of the Chowanoke crayfish range. Therefore, isolated Chowanoke crayfish populations in less forested areas of the Chowan and Roanoke River watersheds may be increasingly stressed as warming trends continue and if deforestation increases. Chowanoke crayfish populations appear to be scattered throughout the Chowan and Roanoke watersheds where there are relatively few man-made barriers and water temperatures may vary.

Warming temperatures due to the effects of climate change may also facilitate the displacement of Chowanoke crayfish by invasive species such as red swamp crayfish and flathead catfish because these species may have a greater tolerance or preference for higher water temperatures. The red swamp crayfish exhibits considerable plasticity and is tolerant of a range of salinities, pH, oxygen levels, temperatures, and pollution levels (Huner and Barr 1991 *in* Service 2015a, p. 3).

Severe drought and lower water levels may negatively affect Chowanoke crayfish by increasing water temperatures, reducing DO levels, and by reducing the amount of suitable habitat. While drought conditions may impact burrowing species more than nonburrowing species (Hossain et al. 2018, p. 1832), such as Chowanoke crayfish, drought could exacerbate the effects of invasive fish and crayfish species, such as red swamp crayfish, virile crayfish, and flathead catfish. However, due to the lack of data of the direct effects of drought on Chowanoke crayfish, we are uncertain if the species is less tolerant of drying conditions than the invasive species. Smaller-bodied crayfish are considered to be more sensitive to climate change (Hossain 2018, p. 1834). They are more susceptible to invasion and aggression by large crayfish shifting their distributions due to climate change, and it has been demonstrated that some smaller species are unable to persist with larger bodied invasive crayfish, often due to competition for food and space (Hossain 2018, pp. 1833–1834, 1840). Climate change may also increase the rate of invasiveness in freshwater crayfish species with potentially significant changes in macroinvertebrate communities (Hossain 2018, p.1840).

Extreme rain events could negatively affect Chowanoke crayfish and, while it may not be immediately evident, populations may experience longer term effects. Excessive silt and sediment from accelerated erosion fills interstitial spaces between and under rocks and logs, and potentially increases stream bottom embeddedness. Both effects would reduce suitable habitat for crayfish such as Chowanoke crayfish that use the spaces for shelter and to forage on macroinvertebrates, periphyton, and plants (Jones et al. 2011, p. 1062, 1063–1064; Reynolds et al. 2013, p. 208; Thoma 2014, p. 27). Severe flood events may also displace or cause increased mortality of individuals or populations, or lead to spread of invasive species. Within the range of the Chowanoke crayfish big flood events have removed boundaries between watersheds, which could permit invasive crayfish and fish species to rapidly expand their range:

> "During severe flooding, the stream substrate, including large rocks, can be mobilized. When this happens, crayfish individuals using the mobilized substrate as refugia would be dislodged and potentially injured or killed during the flood event. Though it seems unlikely that an extreme flood event would extirpate an entire subpopulation, such an event could substantially reduce the health of affected subpopulations, increasing their vulnerability to other stressors. In addition, flood events create higher stream flow and flow velocity, which can increase erosion of unstable stream banks and degrade habitat due to sedimentation. The higher stream flow and flow velocity can also accelerate the downstream expansion of invading crayfish, particularly of juveniles (DiStefano 2017 pers. comm.)." (Service 2018, p. 26).

Warming temperatures and changes in precipitation may promote increased eutrophication and associated harmful algal blooms (Ho and Michalak 2020, p. 992). The effects of eutrophication and algal blooms include potentially released toxins by some genera of blue-green algae (or cyanobacteria) and depleted oxygen (e.g., hypoxia and anoxia) in bottom waters when organic matter sinks and degrades; both effects may reduce suitable habitat and harm aquatic organisms, as documented for fish (Paerl et al. 2001, pp. 76, 102-103). Some studies have documented other crayfish species consuming the toxic algae and bioaccumulating the toxins, but effects are uncertain, ranging from none to mortality and need additional studies (Liras et al. 1998, p. 233; Vasconcelos et al. 2001, p. 1461; Clearwater et al. 2012, p. 487). Within the range of Chowanoke crayfish, algal blooms have been observed in the Chowan River, NC and Lake Gaston, VA (NCDEQ 2021, entire; Virginia Department of Health 2021, p. 1), but effects to Chowanoke crayfish have not been documented and are unknown.

Global sea level is projected to increase at an accelerated rate under both RCP 4.5 and 8.5 with different scenarios of projected global mean sea level (GMSL) rise of 0.3 m (Low) up to 2.5 m (Extreme) (Sweet et al. 2017, pp. 21–22). Table 3-1 provides the probabilities of exceeding the different GMSL rise scenarios in 2100; however, the probabilities of the Intermediate-High, High, and Extreme scenarios may be significantly higher than presented in this table due to the large uncertainty and improved understanding of the effects of ice sheets on SLR (Sweet et al. 2017, pp. 21). Bamber et al. (2019, entire) takes into account the potential effects of and uncertainty due to the ice sheets on SLR and provides estimates of GMSL rise under a low (+2°C) and high temperature scenario (+5°C). Although the high temperature scenario is slightly warmer than the RCP 8.5 temperature 2100 projections (mean of +4.5°C and median of +4.3°C) and the low temperature scenario is slightly cooler than the RCP 4.5 temperate 2100 projections (mean +1.9°C and median of +2.4°C), they are roughly comparable and provide an improved estimate of SLR (Bamber et al. 2019, p. 11197). As shown in Table 3-2, under the high temperature scenario, GMSL rise is predicted to increase up to 1.74 m and 2.38 m for the upper range estimate for the "likely" range (17th–83rd percentile) and "credible" range (5th–95th percentile) of the probability distribution, respectively (Sweet et al. 2017, pp. 4–5; Bamber et al. 2019, p. 11199). Under the low temperature scenario, GMSL rise is predicted to increase up to 0.98 m and 1.26 m for the upper range estimate for the "likely" range and "credible" range of the probability distribution, respectively. Therefore, we use Intermediate-High and High GMSL rise scenarios for RCP 8.5 and Intermediate GMSL rise scenario for RCP 4.5, adjusted to Regional Sea Level Rise projected at Duck, NC (Sweet et al. 2017, entire), in our future scenarios (see Chapter 5) to incorporate the suite of plausible scenarios.

Table 3-1. Probability of exceeding Global Mean Sea Level (GMSL; median value) rise scenarios in 2100 based upon Kopp et al. (2014 in Sweet et al. 2017, p. 22). Table adapted from Table 4 in Sweet et al. (2017, p. 22).

GMSL Rise Scenario	RCP4.5	RCP8.5
Low (0.3 m)	98%	100%
Intermediate-Low (0.5 m)	73%	96%
Intermediate (1.0 m)	3%	17%
Intermediate-High (1.5 m)	0.5%	1.3%
High (2.0 m)	0.1%	0.3%
Extreme (2.5 m)	0.05%	0.1%

Table 3-2. Total GMSL rise projections in 2100 for low (+2°C) and high (+5°C temperature increase) temperature, incorporating ice sheet contributions (Table adapted from Table 2 in Bamber et al. 2019, p. 11199).

	Total GMSL Rise Projection (m)			
Scenario	**50% (Median)**	**17–83% (Likely Range)**	**5–95% (Credible Range)**	**1–99%**
2100 Low	0.69	0.49–0.98	0.36–1.26	0.21–1.63
2100 High	1.11	0.79–1.74	0.62–2.38	0.43–3.29

As described in an IPCC special report (Oppenheimer et al. 2019, p. 4–72), six main concerns of SLR for low-lying coastal regions, such as the Coastal Plain area of the Chowanoke crayfish's range, are: "(i) permanent submergence of land by mean sea levels or mean high tides; (ii) more frequent or intense flooding; (iii) enhanced erosion; (iv) loss and change of ecosystems; (v) salinization of soils, ground and surface water; and (vi) impeded drainage." These effects could reduce the amount of suitable instream habitat and reduce water quality for Chowanoke crayfish by increasing salinity conditions of groundwater and surface waters and loss of adjacent riparian forests and freshwater wetlands due to the increasing intrusion of saline water (Oppenheimer et al. 2019, p. 4–76; Smart et al. 2020, p. 1). While Chowanoke crayfish may be moderately tolerant of infrequent low salinity conditions, none have been observed in areas with frequent higher salinity conditions (see Section 2.5- Habitat). SLR and associated coastal flooding events may increasingly expose the species to salinity and affect some populations by causing them to move upstream.

3.3.5 *Effects of Climate Change on Chowanoke Crayfish*

Uncertainty exists as to the extent of the effects of climate change currently affecting Chowanoke crayfish because specific temperature and salinity tolerances are unknown for the species. Chowanoke crayfish appear to be distributed throughout much of their range and are potentially present in a variety of habitat conditions in the Chowan and Roanoke River basins. Connectivity in not known to be widely impaired within most subbasins, and therefore opportunities for dispersal in response to the effects of climate change may be available. Based on the best available science, rising sea level that increases salinity and reduces the suitability and amount of habitat available; more frequent and severe precipitation events that cause excessive erosion and sedimentation and degradation of instream habitat; severe flooding that facilitates the dispersal of invasive species; and higher temperatures with more frequent and severe heat waves and drought conditions that increase the expansion rate of invasive species will continue to alter habitat within the range of the Chowanoke crayfish. Therefore, these stressors and the synergistic effects of climate change will likely continue to act as an ongoing stressor to the Chowanoke crayfish.

3.4 Other Possible Stressors

3.4.1 *Disease*

Two pathogens that could have an effect on Chowanoke crayfish are "Crayfish Plague" (*Aphanomyces astaci*) and "Porcelain Disease" (*Thelohabia contejeani*). These infectious agents can cause mortality in individuals and affect populations of North American crayfish species.

Crayfish plague is a water mold that can infect the exoskeleton cuticle of freshwater crayfish, and in some crayfish species it penetrates the cuticle to the underlying connective tissue and blood vessels, eventually leading to death (World Organization for Animal Health 2009, p. 64). Native North American crayfish species appear to have a low susceptibility to crayfish plague, and infection is usually limited to the cuticle (World Organization for Animal Health 2009, p. 65). Although infected North American individuals may not exhibit any clinical symptoms, they can survive as lifelong carriers of the pathogen (World Organization for Animal Health 2009, p. 64). Several crayfish species in the genera *Faxonella* and *Faxonius* [*Orconectes*], including the spiny cheek crayfish, were found to have a low susceptibility to crayfish plague (Svoboda et al. 2017, p. 128). Crayfish plague has not been documented in the range of Chowanoke crayfish and if it was, it is unlikely to be a significant threat to Chowanoke crayfish.

Porcelain disease is caused by a microsporidian that is swallowed by the crayfish and causes paralysis and eventually death. In North Carolina, porcelain disease was first documented in 2012 in the Broad River basin but was observed anecdotally before that. To date Porcelain disease has not been found in the Chowan or Roanoke River basins (Fisk 2020b, pers. comm.). The closest occurrence of Porcelain disease is in the western portion of the Yadkin-Pee Dee Basin. Where it has been observed in these seven river basins, it was not widespread and was found in only one to a few individuals. In general, Porcelain disease does not appear to be affecting crayfish abundance or crayfish at the population level (Fisk 2020b, pers. comm.). Surveys of crayfish diseases have not been conducted in Virginia.

3.4.2 *Effects of Disease on Chowanoke Crayfish*

Crayfish plague and Porcelain disease may pose a threat to Chowanoke crayfish in individuals that are stressed, but neither disease has been documented in the range of the species; therefore, based on the best available information they do not appear to affect the Chowanoke crayfish at the watershed or species level.

3.5 Synergistic Effects

The Chowanoke crayfish is exposed to a variety of stressors that can interact to affect the species synergistically, meaning that the effects of two or more stressors are more harmful than the effects of each stressor acting alone. Synergistic effects of multiple stressors have been observed to be more harmful than one stressor alone in many wildlife species (Sih et al. 2004, entire; Coors and DeMeetser 2008, pp. 1822–1826; Goulson et al. 2015, entire). Several significant interacting stressors can act in combination to cause shifts and declines in native aquatic communities through the introduction of invasive species, habitat loss, disease, and changing climate (Martinez 2012, pp. 226–230; Kernan 2015, pp. 326–330).

For example, as noted above, crayfish can be more susceptible to disease when they are subjected to other environmental stressors such as temperature and water quality changes. An increase in water temperature can occur from an increase in air temperature. Increasing water temperatures and changes in precipitation can affect crayfish movement and the quality of instream habitat, as well as the salinity levels in the lower watershed due to sea level rise. As described in earlier sections above, water quality can also be negatively affected by an increase in precipitation and flood events. In addition, these stressors reduce the quality of instream habitat for the benthic community and prey resource for Chowanoke crayfish. Further, as described above, the range expansion of invasive species (crayfish and catfish) as the habitat becomes more suitable for invasive species from increasing temperatures and as more frequent flood events increase the spread of these species, can lead to an increase in competition with and predation of Chowanoke crayfish.

3.6 Conservation Actions

We are aware of few conservation measures currently being implemented that target or benefit Chowanoke crayfish specifically.

The Chowanoke crayfish is listed as a species of high conservation need in North Carolina and Virginia. In North Carolina this classification considers the Chowanoke crayfish a priority for state wildlife grant funds, and much of the Chowanoke crayfish's range in North Carolina has been designated as Tier 1 (highest priority) for consideration for conservation (NCWRC 2015, pp. 32–33, 703–704). In Virginia the species is listed as Tier-III, or high conservation need and assigned a Conservation Opportunity Ranking of "C," which signifies that managers have not identified any specific conservation opportunities for the species (VDGIF 2015, pp. 2-1 to 2-2, 8–40). The VDCR-DNH moved the species recently from the Rare Animal List to the Animal Watchlist; the latter list contain species that are "decidedly uncommon in Virginia but not scarce enough to merit inclusion on the Rare Animal List" (Roble 2021, pp. 5, 55).

Chowanoke crayfish have a negative response to fine bedload sediments, which eliminates its preferred habitat of rocks and cobble (Thoma 2014, p. 27). Because they utilize hard substrate for shelter, Thoma (2014, p. 27) recommended as a management strategy to add rocks that are cobble sized and flat shaped around bridges, but not limestone boulders that are rounded or square shaped. Therefore, the species could benefit from the implementation of erosion and sediment control BMPs, as well as enhancement, maintenance, and restoration of aquatic and riparian habitats (Thoma 2014, p. 27; VDGIF 2015, pp. 26-71, 8–23). Best management practices are available for agriculture, urban development, forestry, and onsite waste disposal systems (VDCR 2020, entire). The USDA-NRCS has also prepared national technical guidance on conservation practices and activities that can be adapted at the local level, and incentives are available for local farmers to participate in programs to promote agricultural conservation practices (USDA 2020, entire).

Within the range of the Chowanoke crayfish, there have been on-the-ground conservation and restoration actions, which are anticipated to continue into the future. The Corps requires compensatory mitigation for wetland and stream impacts that cannot be avoided or minimized onsite when a project is authorized. These impacts are mostly mitigated for in the form of mitigation banks or through sites that the state's in-lieu fee program restores within the watersheds where the impacts occur. Within the Roanoke and Chowan River basins in North Carolina and Virginia there have been projects located upstream of Chowanoke crayfish occurrence records. The Nature Conservancy also administers an in-lieu fee compensatory mitigation fund, named the Virginia Aquatic Resources Trust Fund, which restores and preserves wetlands and streams in Virginia and has priority conservation areas within the Chowan River basin where Chowanoke crayfish occur (The Nature Conservancy 2009, pp. 30–36). In North Carolina and Virginia, there are protected lands adjacent to waterbodies in the Chowanoke crayfish range that are managed by state agencies (NCWRC, VDWR, VDCR), USDA-NRCS Conservation Reserve Program lands, and some properties managed by private land trusts in the area that will benefit habitat protection and riparian corridors.

The Service's Roanoke River National Wildlife Refuge (RRNWR) is within the Chowanoke crayfish's range in the Lower Roanoke subbasin and manages land that borders the lower Roanoke River in multiple locations. Although the Chowanoke crayfish is not included, the RRNWR's Habitat Management Plan identifies other aquatic species and management and monitoring efforts for those species that could also benefit the Chowanoke crayfish, including restoring and enhancing floodplain forest, supporting habitat with sufficient submerged woody debris and detritus for feeding, sheltering, and breeding, and increasing access to spawning sites by removing impediments (Service 2013, pp. 46, 47, 68).

3.7 Summary of Influencing Factors

The primary metrics used to assess the Chowanoke crayfish's viability currently and in the future are (1) habitat quality (i.e., quality of instream breeding, feeding, and sheltering features) and (2) population demographics (i.e., its abundance and distribution). Habitat quality metrics are sufficient water quality and quantity, sufficient unembedded moderately-sized instream structure and undercut banks for shelter, healthy riparian and upland areas, and connectivity. While we have evaluated multiple influencing factors on habitat quality and population demographics, the primary current and future threats to the species are land use modifications (i.e., through sedimentation and loss of riparian habitat), nonnative red swamp crayfish and virile crayfish, and the effects of climate change (increased severe flood and drought events, increased temperatures, and sea level rise).

Land use modification associated with development, forestry activities, and agricultural practices vary in size, intensity, and duration within the Chowan and Roanoke River basins. Excessive pollution, sedimentation, water quality declines, riparian and instream habitat fragmentation and degradation, and reduced water quantity can directly disrupt the species' breeding, feeding, and sheltering needs at varying stages of life and therefore directly and indirectly affects the species' demography over time. While land use modifications vary in size, intensity, and duration, development and urban sprawl are expected to persist and increase into the future as predicted by Terando et al. (2014); therefore, we carried these effects forward in our current and future conditions analysis.

Nonnative species can negatively impact native species through habitat degradation, competition, and predation and lead to population declines and extirpation. Red swamp crayfish have been documented in the Roanoke and Chowan River basins and virile crayfish in the Roanoke River basin. As their range expands it is unknown what the impacts will be on Chowanoke crayfish; however, the negative impacts of red swamp crayfish and virile crayfish on other native crayfish and their habitat have been documented. Therefore, nonnative crayfish will be considered in the future condition analysis.

While it is unknown to what extent climate change are currently affecting the species, based on the best available science, it is likely that the following effects will continue to alter habitat within the range of the Chowanoke crayfish: rising sea level that increase salinity; more frequent and severe precipitation events that cause excessive sedimentation and degradation of instream habitat; severe flooding that facilitates the dispersal of invasive species and degrades instream habitat; and higher temperatures with more frequent and severe heat waves and drought conditions that increase the expansion rate of invasive species. Climate change may also have synergistic, deleterious effects in the future such as increased water temperature compounding the effects of competition from invasive crayfish species. Therefore, these stressors and the synergistic effects of climate change will likely continue to act as ongoing threats to the Chowanoke crayfish.

CHAPTER 4 ANALYSIS OF CURRENT CONDITION

4.1 Analysis Units

As previously described, Chowanoke crayfish populations were delineated at the river basin level, while AUs were defined at a finer geographic scale, which were one or more HUC10 watersheds within a HUC8 subbasin that encompass historically or currently documented occupied habitat (see Section 2.7). Because the river basin level was determined to be too coarse of a scale at which to estimate the condition of factors influencing current condition, AUs were used to evaluate the condition metrics.

As described in Chapter 3, there are multiple factors that can influence the Chowanoke crayfish at the individual, population/watershed, or species level (see Figure 3-1). The primary influences to the Chowanoke crayfish's viability are (1) population demographics, (2) instream habitat, (3) water quality, (4) water quantity (i.e., flowing water), and (5) salinity. The current condition is a qualitative estimate based on the analysis of two population factors (AU occupancy, approximate abundance) and four habitat factors (instream habitat, water quality, water quantity/flow, salinity). We also evaluated two additional condition metrics (reproduction/recruitment, habitat connectivity), but did not provide condition scoring for these factors due to insufficient information to adequately assess these factors rangewide. See the sections below and Table 4-1 for a summary of the parameters we use to assess the Chowanoke crayfish's current condition, and Appendix B for more details.

4.2 Analytical Metrics

4.2.1 *Condition Metrics (included in the condition scoring)*

4.2.1.1 Analysis Unit Occupancy Decline

The known historical and current distribution of the species within HUC10 watersheds was used to document AU occupancy. Chowanoke crayfish presence was compiled from historical (1935–2009) and current (2010-2019) survey data from state agency databases, museum online databases, and crayfish experts/surveyors (see Sections 2-6 and 2-7 and Appendix A). See Appendix B for more detailed information.

4.2.1.2 Approximate Abundance

For most surveys, surveyors recorded the number of live individuals observed at a location, but quantitative measures of density or level of effort were not available. For some surveys, Chowanoke crayfish abundance was recorded as a qualitative approximation (e.g., abundant, present) or observed incidentally as part of a mussel survey (i.e., therefore not actively collected but observed). In addition, collection methods varied, such as trapping, electroshocking, or seine-netting; therefore, the level of effort is not consistent and difficult to compare the abundances between sites or at the same site if surveyed more than once. Thus, we used the cumulative record of the total number of live individuals observed within an AU to provide an approximate estimate of abundance within AUs. See Appendix B for more detailed information.

Table 4-1: Population and habitat factors used to create condition categories.

	Population Factors		Habitat Factors			
Condition Category	**Analysis Unit Occupancy Decline**	**Approximate Abundance**	**Instream Habitat/Water Quality[1]**	**Water Quality[1]**	**Salinity**	**Water Quantity/Flow**
High	≤30% decline	>100 individuals total observed in past 10 years; and large numbers (10+) of individuals seen during targeted surveys at 3 or more sites (past 10 years)	Predominantly natural (>70% forested/wetlands) active river area	<6% impervious surfaces in HUC10 watersheds	<1 ppt at any site	Optimal flowing water conditions; no known flow issues; infrequent low flow/drought periods
Moderate	31-50% decline	51-100 individuals total observed in past 10 years; and large numbers (10+) of individuals seen during targeted surveys at 2 sites (past 10 years)	20-70% forested/wetlands active river area	6-15% impervious surfaces in HUC10 watersheds	1 to 7 ppt at any site	Moderate flowing water conditions; moderate flow issues, including 3 to 4 consecutive years of drought or moderately flashy flow
Low	51-70% decline	2-50 individuals observed in past 10 years	<20% forested/wetlands active river area	>15% impervious surfaces in HUC10 watersheds	>7 ppt at any site	Low flowing water condition- either frequently inundated or dry; severe flow issues; more than 4 consecutive years of drought; flashy flow regime
Very Low	>70% decline	1 individual observed in past 10 years	Instream habitat/water quality unable to support species survival	Water quality unable to support species survival	Salinity conditions do not support species survival	Flow conditions do not support species survival
Ø	Total Loss	Total Loss	N/A	N/A	N/A	N/A

[1] The forested/wetlands active river area is an indicator of both instream habitat and water quality, while impervious surfaces in HUC10 watersheds is an additional indicator of water quality.

4.2.1.3 Instream Habitat/Water Quality

As described in Section 2.5, optimal habitat for the Chowanoke crayfish is predominantly rocky substrate, woody debris, and vegetation for shelter. They find shelter in interstitial spaces between rocks and woody debris, beneath undercut stream banks, in leaf litter, under dense, emergent vegetation (Service 2019a, pp. 1–3; Service 2019b, p. 1). They have also been observed to find shelter under unnatural habitat. The specific instream habitat data to inform a rangewide analysis of this factor is not available; therefore, we used percent forested/wetlands in the riparian area as a surrogate. Riparian condition strongly influences the composition and stability of substrates that crayfish 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 runoff, resulting in less suitable instream habitat for crayfish as compared to habitat with forested corridors (Allan et al. 1997, p. 156). For this assessment, we considered the streamside riparian condition, as delineated by the ARA (Smith et al. 2008, entire) as an indicator of instream 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).

Specific physical and chemical water quality parameters (e.g., DO, pH, temperature) for the Chowanoke crayfish were not available rangewide; therefore, we also used the streamside riparian condition in the ARA as an indicator of water quality, including water temperature and DO. As described in Section 3.1.1, forested areas, including forested wetlands, within the ARA provide numerous habitat and water quality benefits including filtering and slowing of runoff, providing a variety of food resources via leaf litter and woody debris, stabilizing banks, and creating habitat by occasional windthrow, and shading the stream and maintaining an ideal thermal climate (Edwards et al. 2015, p. 60; Gilliam 1994, p. 1). See Appendix B for more detailed information.

4.2.1.4 Water Quality

As an additional indicator of water quality condition, we assessed the percent impervious surfaces in the watershed. Suitable habitat for crayfish includes streams that have stable thermal regimes, low salinity, and limited chemical pollution. Section 3.1.1 provides a summary of the effects of development and impervious surfaces on streamflow, water quality, and water temperature. Although agriculture land cover is also an indicator of water quality condition, it has a strong, negative correlation with forest and wetlands land cover and would be double counting if also included as a metric. See Appendix B for more detailed information.

4.2.1.5 Salinity

Chowanoke crayfish prefer freshwater habitats, and their occurrence near the river mouth with estuarine taxa in the Chowan and Roanoke Rivers suggest that they may have some tolerance to infrequent low salinity conditions (see Section 2.5). With sea level rise and lower river discharge due to drought, salt water intrusion may increase in frequency and duration, reducing available suitable habitat and food sources, and crayfish can become stressed because they exert significant energy to move upstream to fresher waters. We used the salinity data from USGS monitoring stations to assess exposure of Chowanoke crayfish populations to salinity. See Appendix B for more detailed information.

4.2.1.6 Water Quantity/Flow

Optimal habitats for Chowanoke crayfish are perennial streams with continuous, year-round flow and noticeable current (Service 2019a, p. 1–3; see Section 2.5). While they have been found in sluggish streams with sandy/silt-laden substrates, they occur there in very low numbers (Thoma 2014, p. 25, VDGIF 2015, p. 26-71). They are not known to occur in stagnant water (Service 2019a, pp. 1–3). Crayfish are mobile, and other crayfish have been documented to move upstream over small barriers and have been seen climbing up rock faces around waterfalls or moving overland (Kerby et al. 2005, p. 407; Service 2019a, p. 5). Although we do not have specific information about the Chowanoke crayfish's ability to move around barriers and overland, we anticipate they are able to some unknown extent.

While crayfish 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; global climate change). Even during naturally occurring low flow events, crayfish may become stressed if they exert significant energy to migrate into deeper, flowing waters or they may succumb to desiccation or predation. 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 Chowanoke crayfish populations were subject to droughts during low flow times of the year (late summer, early fall), we compiled a series of U.S. Drought Monitor graphics during the first week of September during years 2010 to 2019, the same time period for current occurrences (Figures 4-1 and 4-2). These data were used to identify times that crayfish were exposed to consecutive droughts and likely reduced flow conditions. See Appendix B for more detailed information.

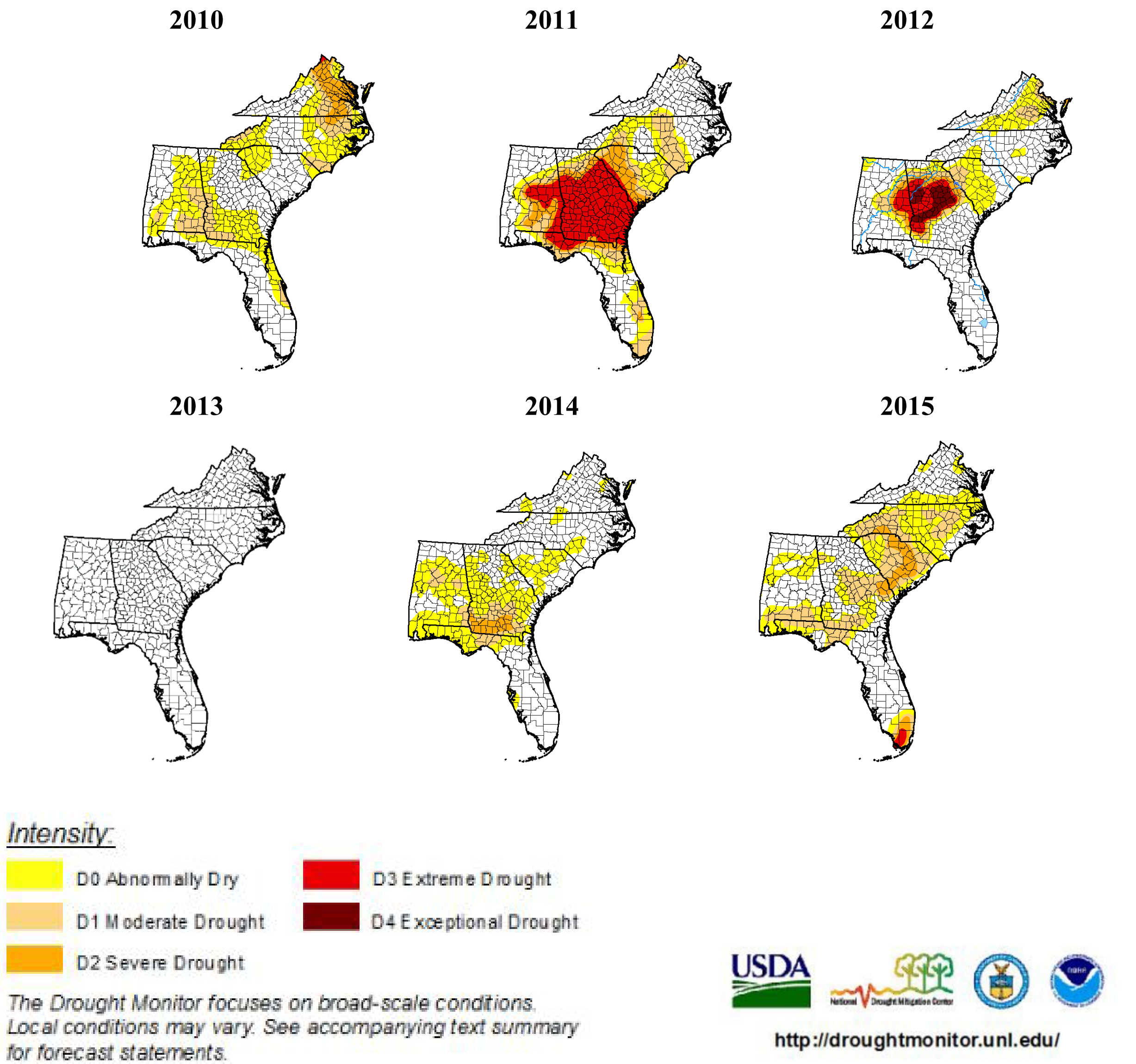


Figure 4-1. U.S. Drought Monitor Southeast annual image for 1st week in September from 2010 to 2015 (Figures from U.S. Drought Monitor 2020, unpublished data).

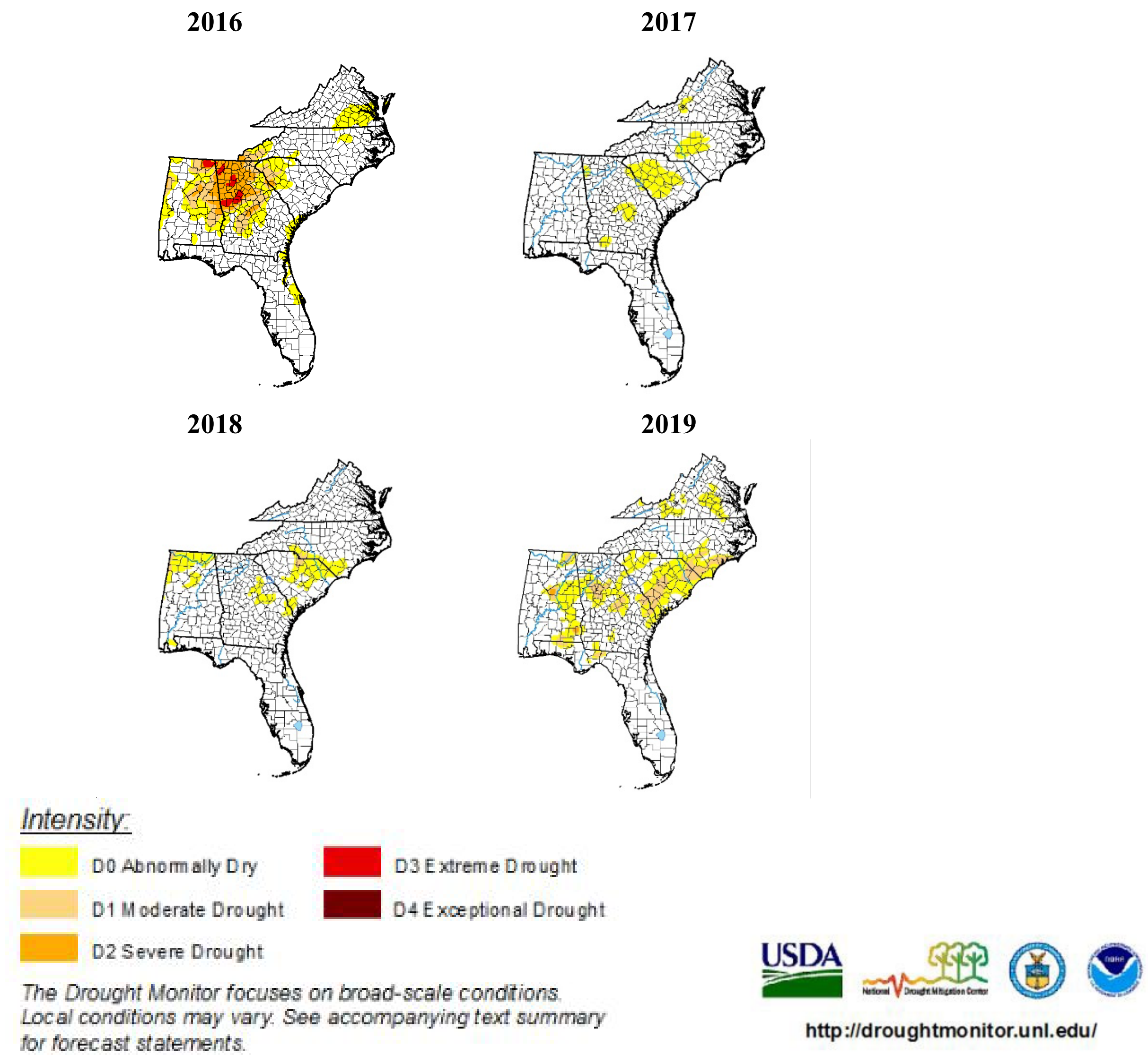


Figure 4-2. U.S. Drought Monitor Southeast annual image for 1st week in September from 2016 to 2019. (Figures from U.S. Drought Monitor 2020, unpublished data).

4.2.2 *Condition Metrics (not included in condition scoring)*

4.2.2.1 Reproduction and Recruitment

While measures of population size reflect past influences on the crayfish resiliency, reproduction and recruitment are important to ascertaining where the population may be headed. For example, observations of juveniles and gravid females would indicate reproduction and recruitment is occurring. Survey data varied on the type of information reported (e.g., providing details on number of female and male juveniles to only indicating yes that there is reproduction/ recruitment) and some did not provide any notations about reproduction/recruitment (Table 4-2); thus, there is insufficient data to adequately assess the condition of the species' reproduction and recruitment across its range. However, evidence of reproduction (gravid females and/or juveniles observed) has been documented in all of the AUs in the last 10 years).

Table 4-2. Summary of recent (2010–2019) reproduction/recruitment data for Chowanoke crayfish.

Population	Analysis Units	Number of HUC10s with Recent Reproduction/ Recruitment	Number of Records with Evidence of Recent Reproduction/ Recruitment	Total Number of Recent Records with Any Notations
Chowan				
	Nottoway	6	10	14
	Meherrin	2	4	13
	Blackwater	1	1	1
	Chowan	3	6	16
Roanoke				
	Middle Roanoke	1	2	6
	Lower Roanoke	2	2	10

4.2.2.2 Habitat Connectivity

As discussed in Section 3.1.4, reservoirs/lakes and dams have historically impeded connectivity and will continue to do so in the future. Specifically, in the Roanoke population, the Middle Roanoke AU subpopulation is isolated from the Lower Roanoke AU subpopulation due to John H. Kerr Reservoir, Lake Gaston, and Roanoke Rapids Lake. In the Chowan population, Chowanoke crayfish in Modest Creek is separated from the Nottoway River due to Nottoway Falls Reservoir. Subpopulations in Little Nottoway River-Nottoway River HUC10 watershed (0301020101) and Sturgeon Creek-Nottoway River HUC10 (03010201031; see Figure 3-2) are separated by the Nottoway Reservoir. These portions of the species' range and the impounded tributaries creating reservoirs and large lakes are not suitable habitat for the Chowanoke crayfish because they do not consist of moderately sized streams with riffles, runs, or pools that have noticeable current.

We are unable to quantify other barriers (e.g., stream crossings, lowhead dams, beaver dams) or determine their specific effects on the Chowanoke crayfish; therefore, we did not provide condition scoring for this factor.

4.3 Current Condition

We assessed the current condition of the Chowanoke crayfish using six metrics, as described above and with additional detail in Appendix B. These are derived from a combination of GIS analyses, survey data, land cover data, NOAA drought index data, and USGS monitoring station salinity data. Each of these metrics correlate to one of the Chowanoke crayfish's needs, specifically for breeding (abundance, number of occupied HUC10s), feeding (instream habitat, water quality, water quantity, salinity), and sheltering (instream habitat, water quality, water quantity, salinity). Overall population condition rankings and habitat condition rankings were determined by combining the two population factors and four habitat factors, respectively. Table 4-3 and Figure 4-3 provide a summary of the current condition of the Chowanoke crayfish within each AU and population. See Appendix B for detailed information about the scoring and weighting of the factors.

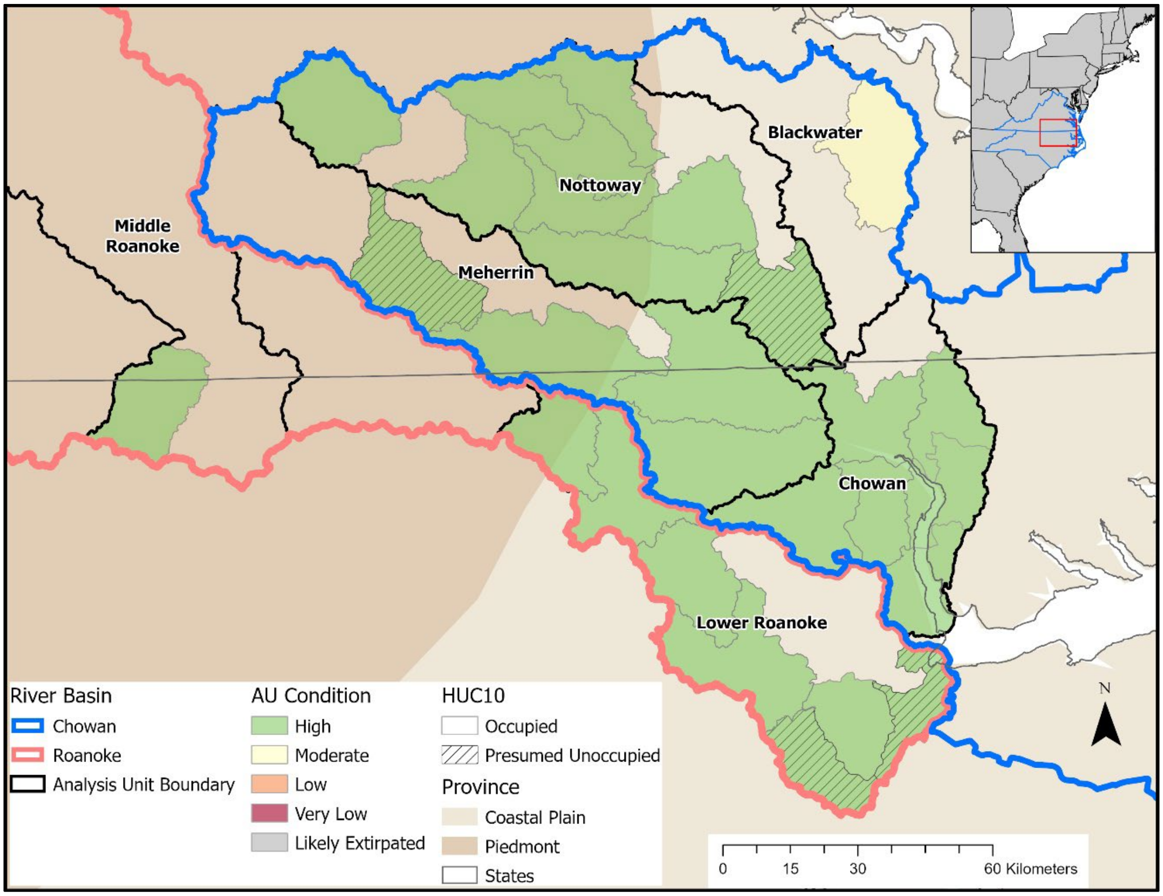


Figure 4-3. Current condition of the Chowanoke crayfish by AU. AUs are shown by name.

Table 4-3. Current condition of Chowanoke crayfish populations. See Table 4-1 for condition categories. Data for categorization are found in Appendix B.

		Population Factors			Habitat Factors					
Population	**Analysis Unit**	**Analysis Unit Occupancy**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Current Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**
	Nottoway	High	High	High	High	High	High	High	High	High
	Meherrin	High	High	High	High	High	High	High	High	High
	Blackwater	High	Low	Moderate	High	High	High	High	High	Moderate
	Chowan	High	High	High	Moderate	High	Moderate	High	Moderate	High
Roanoke		**High**	**Moderate**	**High**	**High**	**High**	**Moderate**	**High**	**High**	**High**
	Middle Roanoke	High	Moderate	High	High	High	High	High	High	High
	Lower Roanoke	High	Moderate	High	High	High	Moderate	High	High	High

4.3.1 *Species Resiliency*

Given its small range, the Chowanoke crayfish is inherently vulnerable to environmental variation and stochastic events (e.g., flooding or drought) that could impact individual subpopulations, depending on the severity of the event. Healthy subpopulations as assessed by the current condition evaluation of AUs is an indicator of resiliency. The species currently occupies all six AUs or subbasins that it historically occupied, with their overall population condition designated as moderate in one AU and high in five AUs (Table 4-3 and Figure 4-3). The current habitat quality/condition of the Chowanoke crayfish AUs is primarily high, with the exception of one AU, which is in moderate condition. When combining the population and habitat conditions, the overall current condition of the AUs is also primarily high (5 of 6 AUs) and moderate (1 of 6 AUs), which provide primarily high resiliency to environmental stochasticity. Scaling up from the AU to the population level, both the Chowan and Roanoke populations are estimated to have high resiliency.

4.3.2 *Species Redundancy*

Redundancy reduces the risk that a large area of the species' range will be negatively affected by a natural or anthropogenic catastrophic event at a given point in time. An adequate number of sites within each AU and basin would ensure that, if severe flooding (e.g., hurricane) or drought makes portions of the range unsuitable, the species will still be maintained. It is unknown whether the Chowanoke crayfish historically occurred throughout the Chowan and Roanoke River basins; it is historically known from six AUs based on occurrence data, and that is assumed to be its range. Chowanoke crayfish redundancy is evaluated through reviewing the number of occupied HUC10s and high/moderate condition AUs across its range. Since 2010, the species has been observed in all 4 AUs in the Chowan River basin and both AUs in the Roanoke River basin in a total of 24 HUC10 watersheds out of 28 that were historically occupied (Table 4-4 and Figure 4-4). The occupied HUC10s are evenly distributed within AUs and both basins.

Table 4-4. Historical (2009 and earlier) and current (2010–2019) occurrence of Chowanoke crayfish populations.

		Number of Occupied AUs		Number of Occupied HUC10s				
Population (River Basin)	**Analysis Unit**	**Historical**	**Current**	**Historical**	**Current**	**HUC10 % decline**	**Number of Current Records**	**Number of Currently Occupied Streams/ Rivers**
Chowan		**4**	**4**	**20**	**18**	**10**	**57**	**22**
	Nottoway			9	8	11	22	11
	Meherrin			4	3	25	17	6
	Blackwater			1	1	0	1	1
	Chowan			6	6	0	17	4
Roanoke		**2**	**2**	**8**	**6**	**25**	**22**	**5**
	Middle Roanoke			1	1	0	10	2
	Lower Roanoke			7	5	29	12	3

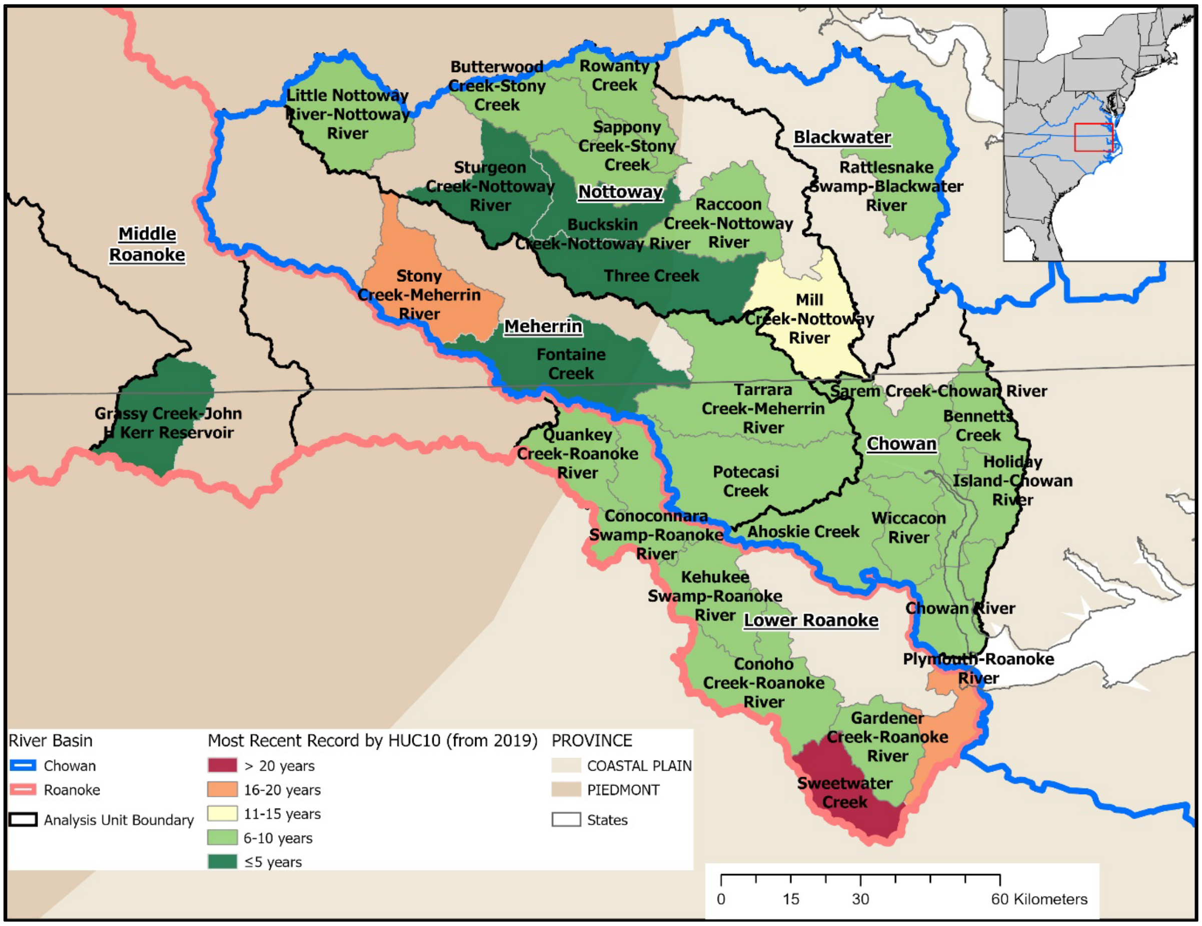


Figure 4-4. Distribution of Chowanoke crayfish historically (most recent record greater than 10 years) and currently (most recent record less than or equal to 10 years) occupied HUC10 watersheds. Analysis units (underline) and HUC10 watersheds (no underline) are labeled.

There are a total of 27 streams and rivers with Chowanoke crayfish occurrences since 2010 within the Chowan and Roanoke River basins. Seven streams have not had observations since 2010; however, the majority of them were not resurveyed since 2010 during the crayfish-specific surveys or survey effort was limited; experts believe that the species is likely still present in most of the streams because habitat has not changed significantly and the species is fairly tolerant of minor disturbances (see Sections 2.7.1 and 2.7.2). The four HUC10s where they have not been observed since 2010 are Mill Creek-Nottoway River, Stony Creek-Meherrin River, Plymouth-Roanoke River, and Sweetwater Creek (Table 4-4, Figure 4-4). Two of the AUs (Blackwater, Middle Roanoke) each have one occupied HUC10 watershed with one to two occupied streams and may be more susceptible to a catastrophic event.

4.3.3 *Species Representation*

The range of the Chowanoke crayfish is restricted to two river basins, and its limited range makes it vulnerable to anthropogenic disturbances and environmental perturbations throughout its range (Taylor et al. 1996, p. 27). Although Chowanoke crayfish prefer stream habitat with rocky substrate and flowing water, they have been observed in a variety of other habitat types in low numbers, with the exception of stagnant water where they have not been observed. There is no genetic information available to evaluate genetic diversity. As described in Section 2.7—Current Range and Distribution and Section 2.8.2—Species Needs—Representation, we are using the species' distribution within the basins and physiographic provinces as surrogates for representation, assessing the Chowanoke crayfish across its range from western streams and rivers in the Piedmont province to streams and larger rivers in eastern portions of basins in the Coastal Plain province.

The Chowanoke crayfish remains distributed within the river basins throughout its historical western to eastern extent and in both physiographic provinces, which serve as surrogates for their potential adaptive capacity. The species currently occupies 18 of the 20 historically occupied HUC10s in the Chowan basin, representing a 10-percent decline in HUC10s occupied (Table 4-4). In the Roanoke basin, the Chowanoke crayfish currently occupies 6 of the 8 historically occupied HUC10s, representing a 25-percent decline in HUC10s occupied. In the Piedmont province Chowanoke crayfish exhibit a 9-percent decline in HUC10s occupied (from 11 to 10 HUC10s occupied). In the Coastal Plain province Chowanoke crayfish exhibit an 18-percent decline in HUC10s occupied (from 17 to 14 HUC10s occupied).

4.4 Summary of Current Condition

The current condition of Chowanoke crayfish was assessed using six demographic and habitat metrics as described above and in Appendix B: occupancy, abundance, instream habitat quality, water quality, water quantity, and salinity. These are derived from a combination of survey data, habitat data, and GIS analyses. These metrics correlate to the needs of the Chowanoke crayfish to breed (abundance and number of sites), feed (habitat quality), and find shelter (habitat quality). Table 4-5 provides a summary of the metrics and current condition evaluated in terms of the 3Rs. All six of the AUs are healthy with moderate or high current condition (Resiliency) and are distributed throughout both physiographic provinces and river basins (Representation). The species currently occurs in 24 out of the 28 historically occupied HUC10 watersheds and 6 out of 6 AUs (Redundancy).

Table 4-5. Current Condition and the 3Rs

3Rs	Requisites	Description	Current Condition
Resiliency (ability to withstand stochastic events)	Healthy populations and habitat.	Subpopulations with: • Small to large sized stable streams with riffles, runs, and pools; • Unembedded instream structure that provide shelter; • Sufficient water quality (freshwater, temperature, dissolved oxygen, chemistry, and siltation levels) to provide adequate food sources and conditions for survival and reproduction; • Sufficient water quantity with noticeable current (i.e., not stagnant) to maintain healthy habitat and water quality; • Healthy riparian and adjacent upland habitat; • Connectivity — waterways without significant barriers.	AUs were defined at one or more HUC10 watersheds within a HUC8 subbasin that encompass historically or currently documented occupied habitat. Each AU with high or moderate current condition is thought to currently have adequate habitat and healthy subpopulations, thus has high or moderate resiliency. • 6 of 6 AUs (100%) are known to be extant. • AU status: – 5 of 6 AUs (83%) high condition – 1 of 6 AUs (17%) moderate condition
Redundancy (ability to withstand catastrophic events)	Sufficient distribution of healthy populations.	Sufficient distribution of healthy subpopulations to prevent catastrophic losses of species' adaptive capacity due to severe flood or drought events. Multiple occupied HUC10s within each AU and multiple occupied AUs within the species' range are important for the species' redundancy.	• Healthy AUs (moderate or high condition) evenly distributed within both basins and across the range. • Occupied HUC10s evenly distributed within AUs and both basins.
	Sufficient number of healthy populations.	Sufficient number of healthy subpopulations to prevent catastrophic losses of adaptive capacity.	• 6 of 6 AUs (100%) are moderate or high condition. • 24 of 28 HUC10 watersheds (86%) currently occupied.
Representation (ability to adapt)	Sufficient capacity to adapt to new, continually changing environments.	Occupied HUC10s distributed across the range, including the ecological diversity of river basins and physiographic provinces that contribute to and maintain adaptive capacity. Adequate dispersal ability for the species to migrate to suitable habitat and climate over time.	Connected, occupied HUC10s found in both river basins (populations) and physiographic provinces. **River basin:** • Chowan – 18 of 20 HUC10s (90%) occupied. • Roanoke – 6 of 8 HUC10s (75%) occupied. **Physiographic province:** • Piedmont – 10 of 11 HUC10s (91%) occupied. • Coastal Plain – 14 of 17 HUC10s (82%) occupied.

CHAPTER 5 FUTURE CONDITIONS

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 biological status of the species in terms of its resiliency, representation, and redundancy (the 3Rs). In this chapter, we predict the species' future conditions based on the 3Rs given a range of plausible future scenarios. We used the Chowanoke crayfish demographic and habitat information to project how the watersheds will respond to the primary factors likely to influence the species' condition in the future. Our analysis predicts three future scenarios, which are representative examples from the potential range of plausible scenarios, and that describe how these stressors to the species may drive changes from current conditions.

5.1 Future Scenarios

Predictions of Chowanoke crayfish's resiliency, redundancy, and representation were forecast out to 50 years, which represents approximately 14 Chowanoke crayfish life cycles. Fifty years is also a period that allows us to reasonably predict the potential effects of the various stressors within the range of the species. The 50-year timeframe is predicted in 10- to 20-year increments from 2020 (2030, 2050, and 2070). We chose 10 years for the immediate future because the SLEUTH projections for the Southeast and SLR models are based on 10-year increments starting with 2010 and 2000, respectively (Belyea and Terando et al. 2012, unpublished data; Sweet et al. 2017, entire; NOAA 2020a, 2020b, 2020c, unpublished data); however, we chose 20-year increments thereafter because a 10-year increment is too fine a scale to reasonably predict changes for Chowanoke crayfish in the long term. These timeframes are supported by approximately 10 to 20 years of Chowanoke crayfish persistence data, which we deem biologically reasonable to use as a surrogate to project forward a similar amount of time; available land cover data (percent forest cover and impervious surface) that serves as a surrogate for instream habitat and water quality, salinity (SLR), and water quantity (drought) data, nonnative crayfish data, and climate data (50 years) to predict potential significant effects of stressors (up to 50 years); and other potential, but plausible, conservation actions. A summary of the three scenarios are presented in Table 5-1 and the detailed narratives, below.

5.1.1 *Scenario 1: Continuation of Current Trends*

The first future scenario evaluates the continuation of current trends based on the effects of moderate level of land use changes and climate change on the 3Rs of the Chowanoke crayfish. This scenario includes the effects resulting from a plausible, **moderate increase in development** (affecting percent impervious surface and forest/wetlands land cover), according to the SLEUTH urban change analysis as described in Section 3.1 Land Use Modification, and without implementation of any additional watershed restoration or enhancement measures. This scenario also assumes that the Chowanoke crayfish is not sensitive to air and water temperature changes resulting from a changing climate, but that the climate change scenario **RCP 8.5** trajectory is met with an **intermediate-high level increase in SLR** and associated increase in salinity (based on Regional Sea Level Rise scenario of Intermediate High projected at Duck, NC, within the "likely" range of estimates: 17–83th percentile of the probability distribution (Sweet et al. 2017, entire; NOAA 2020a, b, and c, unpublished data)), as described in Section 3.3—Effects of

Climate Change (Figures 5-1 and 5-2). Changes in precipitation (drought and flood events) projected under the RCP 8.5 climate scenario will increase **moderately** in frequency and intensity. We assume that the Chowanoke crayfish is insensitive to the red swamp crayfish's negative effects on instream habitat because of this nonnative species' preference for swampy, slow-flowing habitats (i.e., not the Chowanoke crayfish's preferred habitat). Lastly, we assume that the virile crayfish will not expand into Chowanoke crayfish habitat because of this nonnative species' preference for lentic habitats (e.g., reservoirs, pools, lakes) (Loughman 2010, p. 53; Loughman 2013, p. 65–66). See Appendix C for more detailed information.

5.1.2 *Scenario 2: Increase in Rates of Land Use Changes and Climate Change Effects*

The second future scenario evaluated is based on the effects of high level increase in land use changes and climate change on the 3Rs. This scenario includes the effects resulting from a plausible, **maximum increase in development** (affecting percent impervious surface and forest/wetlands land cover), according to the SLUETH urban change analysis as described in Section 3.1 Land Use Modification, and without implementation of any additional watershed restoration or enhancement measures. This scenario assumes that the Chowanoke crayfish is sensitive to air and water temperature changes resulting from a changing climate and that the climate change scenario **RCP 8.5** trajectory is met with the **high level increase in SLR** and associated increase in salinity (based on Regional Sea Level Rise scenario of High projected at Duck, NC, within the "credible" range of estimates: 5–95th percentile of the probability distribution (Sweet et al. 2017, entire; NOAA 2020a, b, and c, unpublished data)), as described in Section 3.3—Effects of Climate Change (Figure 5-1 and 5-2). Changes in precipitation (drought and flood events) projected under the RCP 8.5 climate scenario will **increase greatly** in frequency and intensity. There would be a **high dispersal of red swamp crayfish** and **moderate dispersal of virile crayfish** into the range of the Chowanoke crayfish due to the effects of climate change for this scenario and we assume that the Chowanoke crayfish is sensitive to the red swamp crayfish and virile crayfish's negative effects on instream habitat because they will spread to the Chowanoke crayfish's preferred habitat. See Appendix C for more detailed information.

5.1.3 *Scenario 3: Continuation Plus Conservation*

The third future scenario evaluates the continuation of current trends based on the effects of moderate level of land use changes and climate change, but assumes that conservation measures will be implemented to minimize their impacts. This scenario includes the effects resulting from a plausible, **moderate increase in development** (affecting percent impervious surface and forest/wetlands land cover), according to the SLEUTH urban change analysis as described in Section 3.1 Land Use Modification, but with implementation of additional watershed restoration or enhancement measures. This scenario also assumes that the Chowanoke crayfish is not sensitive to air and water temperature changes resulting from a changing climate, that climate change scenario **RCP 4.5** is met with an **intermediate level increase in SLR** (based on Regional Sea Rise scenario of Intermediate projected at Duck, NC, within both the "likely" and "credible" range of estimates (Sweet et al. 2017, entire; NOAA 2020a, b, and c, unpublished data)), as described in Section 3.3—Effects of Climate Change (Figure 5-1 and 5-2). Changes in precipitation (drought and flood events) projected under the RCP 4.5 climate scenario will increase **moderately** in frequency and intensity. We assume that the Chowanoke crayfish is insensitive to the red swamp crayfish's negative effects on instream habitat because of this nonnative species' preference for swampy, slow-flowing habitats (i.e., not the Chowanoke crayfish's preferred habitat). Lastly, we assume that the virile crayfish will not expand into Chowanoke crayfish habitat because of this nonnative species' preference for lentic habitats (e.g., reservoirs, pools, lakes) (Loughman 2010, p. 53; Loughman 2013, p. 65–66). See Appendix C for more detailed information.

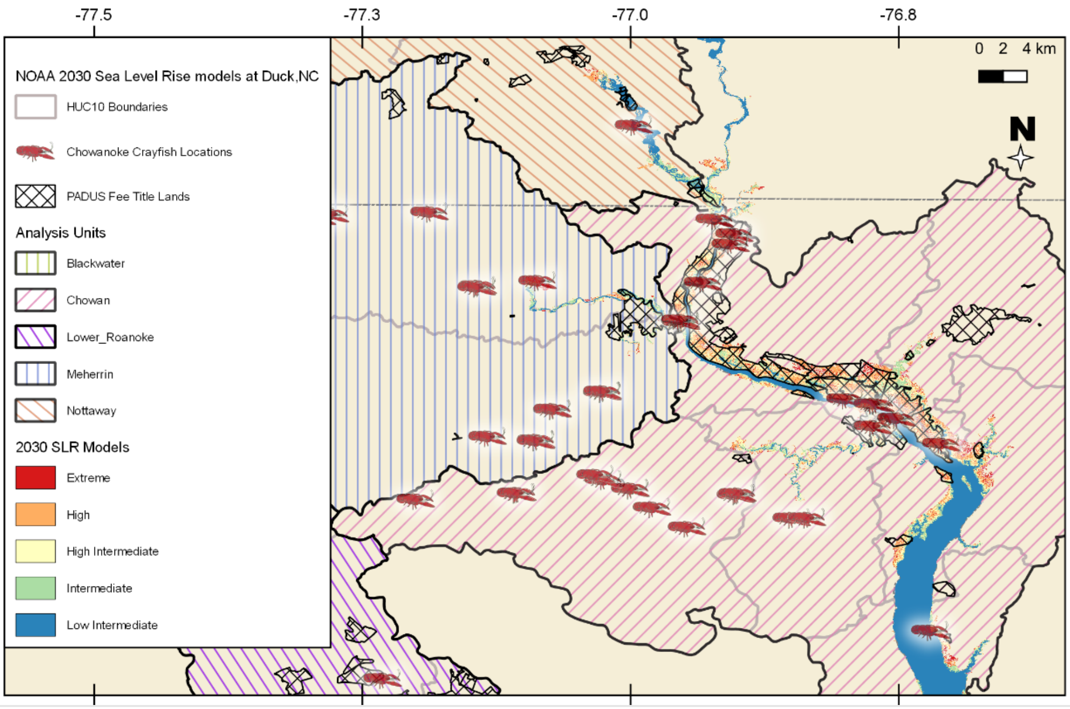
Table 5-1. Summary of Future Scenario influencing factors[1] as compared to current condition.

Influencing Factor	**Scenario 1**	**Scenario 2**	**Scenario 3**
Habitat Factors			
Instream Habitat/ Water Quality (%forested/ wetlands)	↓ (due to moderate increase in urbanization)	↓↓ (due to maximum increase in urbanization)	↓ (due to moderate increase in urbanization)
Water Quality (% impervious surface)	↓ (due to moderate increase in urbanization)	↓↓ (due to maximum) increase in urbanization)	↓ (due to moderate increase in urbanization)
Water Quantity/Flow (drought)	↓	↓↓	↓
Salinity (SLR)	↑↑ (Intermediate High)	↑↑↑ (High)	↑ (Intermediate)
Climate Projection	RCP 8.5	RCP 8.5	RCP 4.5
Climate Effects	↑ air temperature and variation in precipitation and flooding	↑↑ air temperature and variation in precipitation and flooding	↑ air temperature and variation in precipitation and flooding
Red swamp crayfish and virile crayfish's effects on instream habitat	Same	↑	Same
Conservation Actions			
Conservation Actions (habitat enhancement and restoration, non-native species control, etc.)	Same	Same	↑
Population Factors			
Distribution (AU Occupancy Decline)	↓	↓	Same
Demography (Approximate Abundance) [2]	Same	↓	Same

[1] Influencing Factor Rate of Change Compared to Current Condition: some increase (↑), greater increase (↑↑), greatest increase (↑↑↑), some decrease (↓), greater decrease (↓↓), no change in rate (Same).

[2] Approximate abundance remains the same, except decreases due to overall low habitat quality condition or crayfish condition becomes very low. See Appendix C for additional information.

NOAA Sea Level Rise Projections 2030 Chowan River with Protected Lands



NOAA Sea Level Rise Projections 2050 Chowan River with Protected Lands

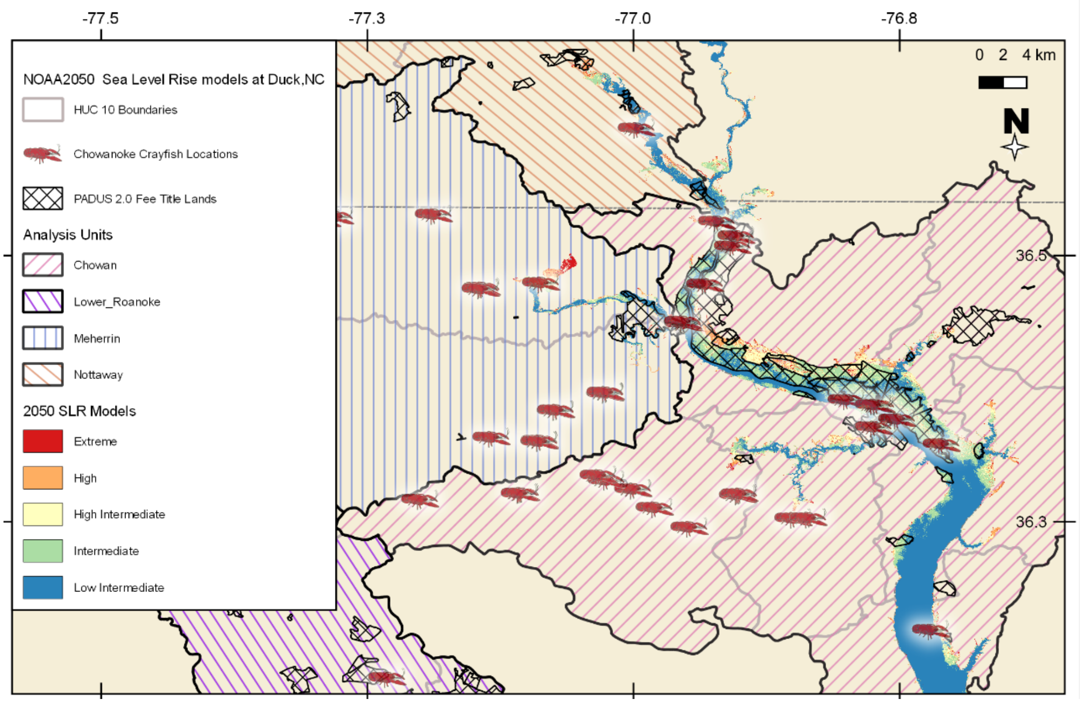


Figure 5-1a. Sea level rise (SLR) projections in the Chowan River basin for 2030 and 2050. The maps show areas that will be progressively inundated based on the regional SLR projections of: Low Intermediate, Intermediate, High Intermediate, High, Extreme (Sweet et al. 2017; NOAA 2020a, 2020b, 2020c). For example, to assess areas that will be inundated by High Intermediate (yellow), also include the lower areas that will be inundated by Low Intermediate (green) and Intermediate (blue).

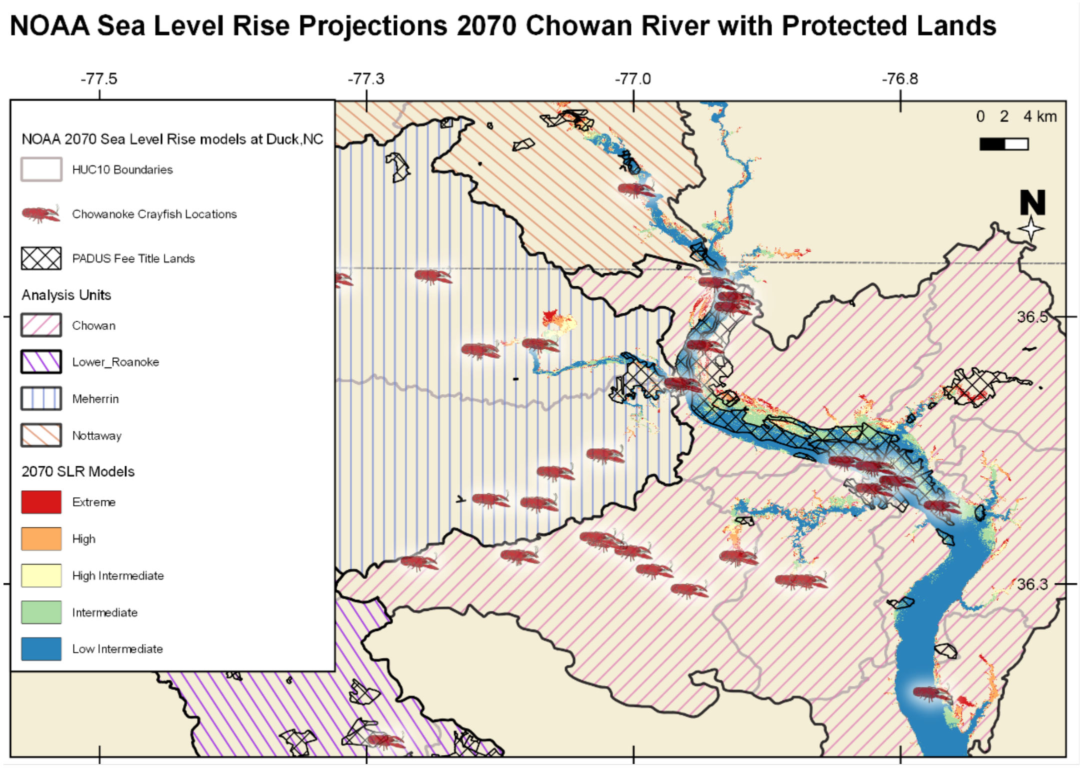
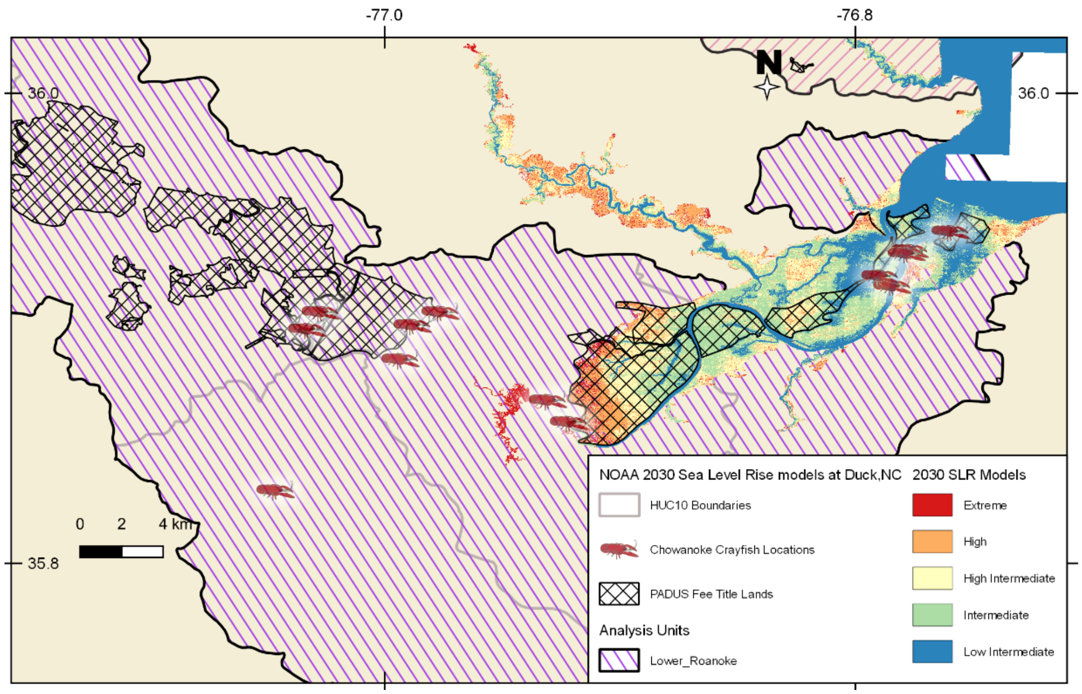


Figure 5-1b. Sea level rise (SLR) projections in the Chowan River basin for 2070. The maps show areas that will be progressively inundated based on the regional SLR projections of: Low Intermediate, Intermediate, High Intermediate, High, Extreme (Sweet et al. 2017; NOAA 2020a, 2020b, 2020c). For example, to assess areas that will be inundated by High Intermediate (yellow), also include the lower areas that will be inundated by Low Intermediate (green) and Intermediate (blue).

NOAA Sea Level Rise Projections 2030 Lower Roanoke River with Protected Lands



NOAA Sea Level Rise Projections 2050 Lower Roanoke River with Protected Lands

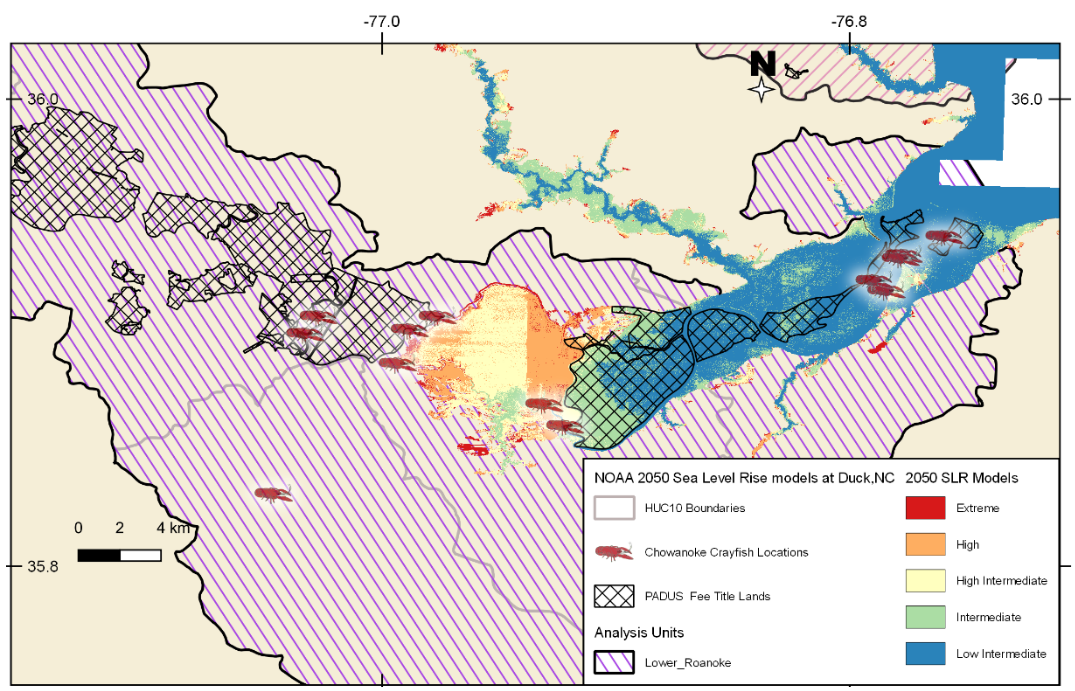


Figure 5-2a. Sea level rise (SLR) projections in the Roanoke River basin for 2030 and 2050. The maps show areas that will be progressively inundated based on the regional SLR projections of: Low Intermediate, Intermediate, High Intermediate, High, Extreme (Sweet et al. 2017; NOAA 2020a, 2020b, 2020c). For example, to assess areas that will be inundated by High Intermediate (yellow), also include the lower areas that will be inundated by Low Intermediate (green) and Intermediate (blue).

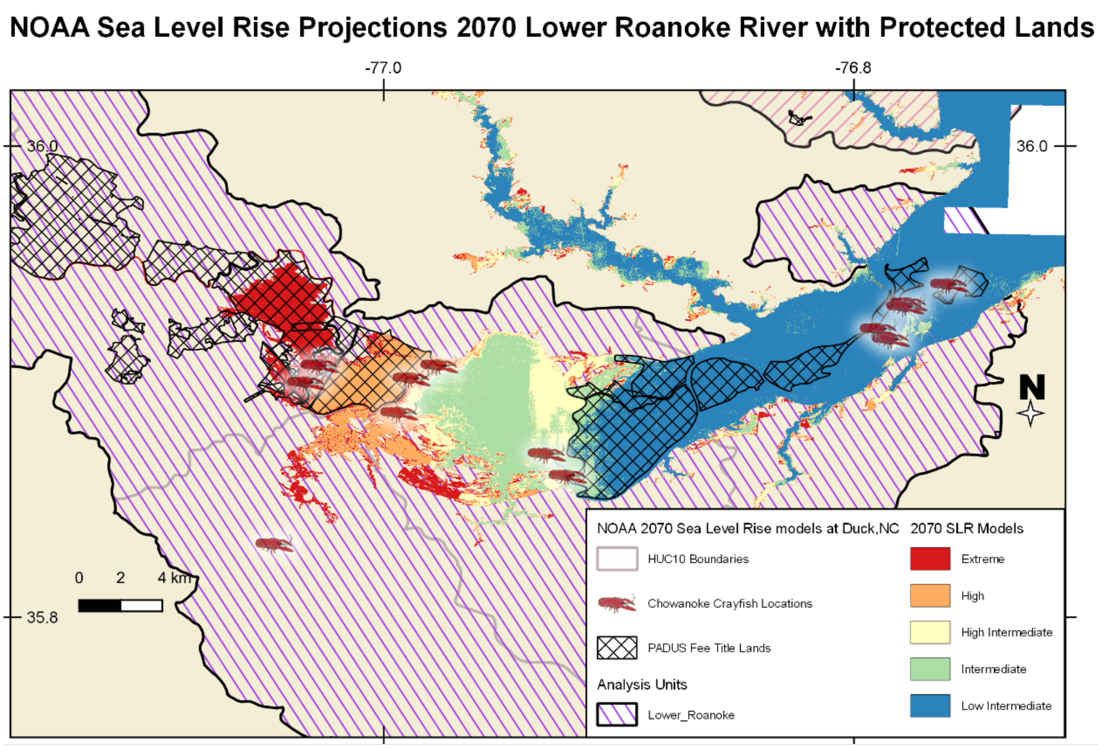


Figure 5-2b. Sea level rise (SLR) projections in the Roanoke River basin for 2070. The maps show areas that will be progressively inundated based on the regional SLR projections of: Low Intermediate, Intermediate, High Intermediate, High, Extreme (Sweet et al. 2017; NOAA 2020a, 2020b, 2020c). For example, to assess areas that will be inundated by High Intermediate (yellow), also include the lower areas that will be inundated by Low Intermediate (green) and Intermediate (blue).

5.2 Future Conditions

The future conditions for each scenario are described below and summarized in Table 5-2.

5.2.1 *Scenario 1*

5.2.1.1 Resiliency

At the end of 50 years, we predict the species will continue to occupy all six AUs. Two AUs will have moderate population condition, and four will have high population condition (Table 5-3). The habitat quality condition of two AUs will decrease from high to moderate, while three AUs will continue to have high habitat quality condition. When combining the population and habitat conditions, the overall condition of the AUs is predicted to be half high (3 of 6 AUs) and half moderate (3 of 6 AUs) (Figure 5-3 and Table 5-3). The Chowan AU and Lower Roanoke AU resiliency will decrease to moderate, mainly due to projected moderate increase in inundation of higher salinity waters and associated loss of suitable habitat in the lower portions of these AUs caused by SLR and moderate decline in water quantity. However, instream habitat and water quality are projected to remain high for most of the AUs due to the watersheds continuing to have a high percentage of forested/wetland ARAs and a low percentage of impervious surfaces. Although urbanization rates are projected to increase by 2070, the areas that will be affected in the Chowanoke crayfish range remain relatively small and will cause minimal habitat degradation. Based on an evaluation of occupied areas upstream of stream and river reaches degraded by inundation and associated habitat loss, there will likely be sufficient suitable habitat for the Chowanoke crayfish to migrate, with no impact to overall approximate abundance. Appendix D provides population and habitat condition tables for 2030 and 2050, and Table 5-4 provides a comparison of overall current and future conditions.

5.2.1.2 Redundancy

At the end of 50 years, we predict the Chowanoke crayfish will continue to be observed in all six AUs in the Chowan and Roanoke River basins with more AUs with moderate condition in the eastern and southern portions of the range (Figure 5-3 and Table 5-3). A total of 21 HUC10 watersheds out of 28 that were historically occupied are predicted to be occupied (Figure 5-3). We assumed that HUC10 watersheds that are considered currently unoccupied will remain so in the future, but that three additional HUC10s will become unoccupied due to projected significant loss of habitat in two HUC10 watersheds in the Chowan AU and one HUC10 watershed in the Lower Roanoke AU caused by moderate increase in inundation of higher salinity waters, as described above. The occupied HUC10s will be unevenly distributed within the Chowan and Lower Roanoke AUs and both basins.

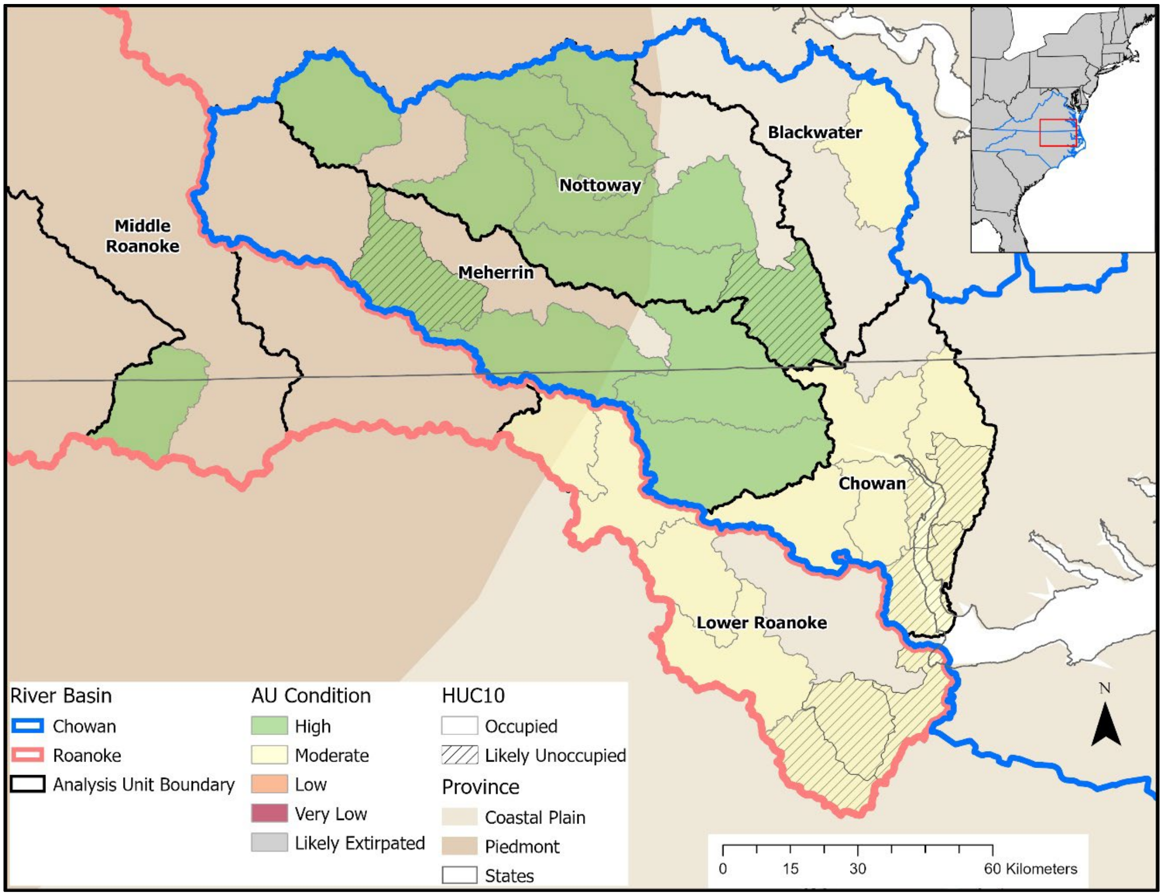


Figure 5-3. Future condition by AU for Scenario 1. AUs are shown by name.

5.2.1.3 Representation

At the end of 50 years, we predict that the Chowanoke crayfish will have reduced representation in the Coastal Plain region and the eastern portions of both the Chowan and Roanoke River basins. This is due to the projected significant loss of habitat in two HUC10 watersheds in the Chowan AU and one HUC10 watershed in the Lower Roanoke AU, as described above, in addition to the AUs that are currently unoccupied. Therefore, the species is predicted to occupy 16 of the 20 historically occupied HUC10s in the Chowan basin (20-percent decline) (Figure 5-3). In the Roanoke basin, the Chowanoke crayfish is predicted to occupy 5 of the 8 historically occupied HUC10s (37.5-percent decline).

In the Piedmont province, the Chowanoke crayfish is predicted to continue to occupy 10 of the 11 historically occupied HUC10s (Figure 5-3). In the Coastal Plain province, the Chowanoke crayfish is predicted to occupy 11 of the 17 historically occupied HUC10s, a 35-percent decline in HUC10s occupied.

5.2.2 *Scenario 2*

5.2.2.1 Resiliency

At the end of 50 years, we predict the species will continue to occupy five of the six AUs, with the Middle Roanoke AU likely extirpated. Three AUs will have moderate population condition, and two will have high population condition (Table 5-3). The habitat quality condition of four AUs will decrease to moderate and two AU to low, mainly due to projected low water quantity condition and moderate to very low instream habitat condition, and partially due to moderate/low salinity conditions. When combining the population and habitat conditions for the five extant AUs, the overall condition of the AUs is predicted to be 33 percent high (2 of 6 AUs) and 50 percent moderate (3 of 6 AUs) (Figure 5-4 and Table 5-3). The Chowan AU and Lower Roanoke AU resiliency will decrease to moderate, mainly due to projected greater increase in inundation of higher salinity waters and associated loss of suitable habitat in the lower portions of these AUs caused by SLR, moderate/low instream habitat condition, and low water quantity condition. The red swamp crayfish is projected to increase in numbers and distribution in all the AUs, which contributes to a decrease in instream habitat condition for all AUs, even though the watersheds will continue to have a high percentage of forested/wetland ARAs. The virile crayfish is projected to increase in numbers and distribution in the Roanoke River basin, where it currently is known to occur, but the Middle Roanoke AU will experience greater expansion of virile crayfish because its streams have lower stream order (fourth and fifth order) and the Chowanoke crayfish subpopulation is isolated in Grassy and Little Grassy Creeks in a single HUC10 watershed. In the Middle Roanoke AU, Chowanoke crayfish will likely become displaced and extirpated by virile crayfish, which reduced most instream habitat for shelter and food and caused loss of HUC10 occupancy. Although urbanization rates are predicted to increase by 2070, the areas that will be affected in the Chowanoke crayfish range remain relatively small (e.g., the highest average percentage impervious surfaces is predicted to be 8.7 percent in the Nottoway AU) and will contribute minimal habitat degradation. Therefore, instream habitat/water quality is projected to remain moderate for the majority of the AUs. Based on an evaluation of occupied areas upstream of stream and river reaches degraded by inundation and associated habitat loss, there will likely be sufficient suitable habitat for the Chowanoke crayfish to migrate, with no impact to overall approximate abundance for all the AUs, except the Chowan AU and Middle Roanoke AU. For the Chowan AU, the low overall habitat condition is predicted to cause the Chowanoke crayfish's approximate abundance to decrease from high to moderate. Appendix D provides population and habitat condition tables for 2030 and 2050, and Table 5-4 provides a comparison of overall current and future conditions.

5.2.2.2 Redundancy

At the end of 50 years, we predict the Chowanoke crayfish will be observed in five of six AUs in the Chowan and Roanoke River basins with one AU in the southwestern portion of the range likely extirpated and more AUs with moderate condition in the eastern and southern portions of the range (Figure 5-4 and Table 5-3). A total of 19 HUC10 watersheds out of 28 that were historically occupied are predicted to remain occupied (Figure 5-4). We assumed that HUC10 watersheds that are considered currently unoccupied will remain so in the future, but four additional HUC10s will become unoccupied due to projected significant loss of habitat in three HUC10 watersheds in the Chowan AU and one HUC10 watershed in the Lower Roanoke AU caused by greater increase in inundation of higher salinity waters, as described above. One additional HUC10 will become unoccupied in the Middle Roanoke AU due to virile crayfish increasing and expanding to levels that will displace the Chowanoke crayfish via competition by reducing most of the healthy instream habitat used for shelter and food. The occupied HUC10s will be unevenly distributed within the Chowan and Lower Roanoke AUs and both basins.

5.2.2.3 Representation

At the end of 50 years, we predict that the Chowanoke crayfish will have reduced representation in both the Piedmont and Coastal Plain regions and the southwestern and eastern portions of both the Chowan and Roanoke River basins. As described above, this is due to the projected significant loss of habitat in three HUC10 watersheds in the Chowan AU and one HUC10 watershed in the Lower Roanoke AU and the only HUC10 watershed in the Middle Roanoke AU, as described above, in addition to the AUs that are currently unoccupied. Therefore, the species is predicted to occupy 15 of the 20 historically occupied HUC10s in the Chowan basin (25-percent decline) (Figure 5-4). In the Roanoke basin, the Chowanoke crayfish is predicted to occupy 4 of the 8 historically occupied HUC10s (50-percent decline). In the Piedmont province, the Chowanoke crayfish is predicted to occupy 9 of the 11 historically occupied HUC10s, an 18-percent decline (Figure 5-4). In the Coastal Plain province, the Chowanoke crayfish is predicted to occupy 10 of the 17 historically occupied HUC10s, a 41-percent decline.

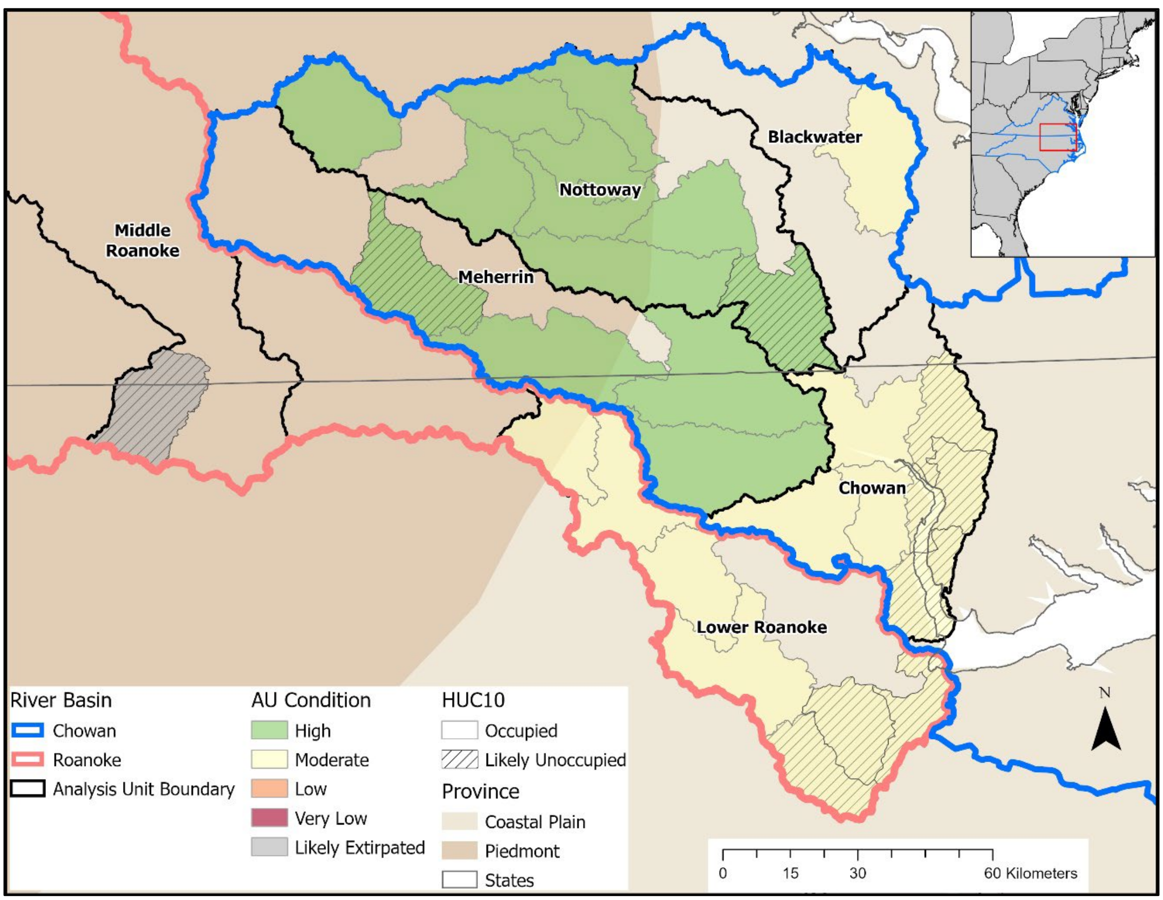


Figure 5-4. Future condition by AU for Scenario 2. AUs are shown by name.

5.2.3 *Scenario 3*

5.2.3.1 Resiliency

At the end of 50 years, we predict the species will continue to occupy all six AUs. One AU will have moderate population condition, and five will have high population condition (Table 5-3). The habitat quality condition of one AU will decrease from high to moderate, while four AUs will continue to have high habitat quality condition. When combining the population and habitat conditions, the overall condition of the AUs is predicted to not change, with 83 percent high (5 of 6 AUs) and 17 percent moderate (1 of 6 AUs) (Figure 5-5 and Table 5-3). With an intermediate level increase in SLR, there will be some increase in inundation of higher salinity waters in the Chowan AU and Lower Roanoke AU; however, it is not anticipated that salinity levels become high enough to cause a significant loss of suitable, occupied habitat. Instream habitat and water quality is projected to remain high for most of the AUs due to the watersheds continuing to have a high percentage of forested/wetland ARAs and a low percentage of impervious surfaces. Conservation actions will also contribute to protecting and maintaining high quality habitat for the Chowanoke crayfish. Appendix D provides population and habitat condition tables for 2030 and 2050, and Table 5-4 provides a comparison of overall current and future conditions.

5.2.3.2 Redundancy

At the end of 50 years, we predict the Chowanoke crayfish will continue to be observed in all 6 AUs in the Chowan and Roanoke River basins with continued high condition AUs distributed across the range (Figure 5-5 and Table 5-3). A total of 24 HUC10 watersheds out of 28 that were historically occupied are predicted to be occupied (Figure 5-5). We assumed that HUC10 watersheds that are considered currently unoccupied will remain so in the future. The occupied HUC10s will be evenly distributed within AUs and both basins.

5.2.3.3 Representation

At the end of 50 years, we predict that the Chowanoke crayfish will continue to have good representation in both basins and physiographic provinces. The species is predicted to continue occupying 18 of the 20 historically occupied HUC10s in the Chowan basin and 5 of the 8 historically occupied HUC10s in the Roanoke basin, with no change in the percentage decline from current condition. The species is predicted to continue occupying 10 of the 11 historically occupied HUC10s in the Piedmont province and 14 of the 17 historically occupied HUC10s in the Coastal Plain province, with no change in the percentage decline from current condition (Figure 5-5).

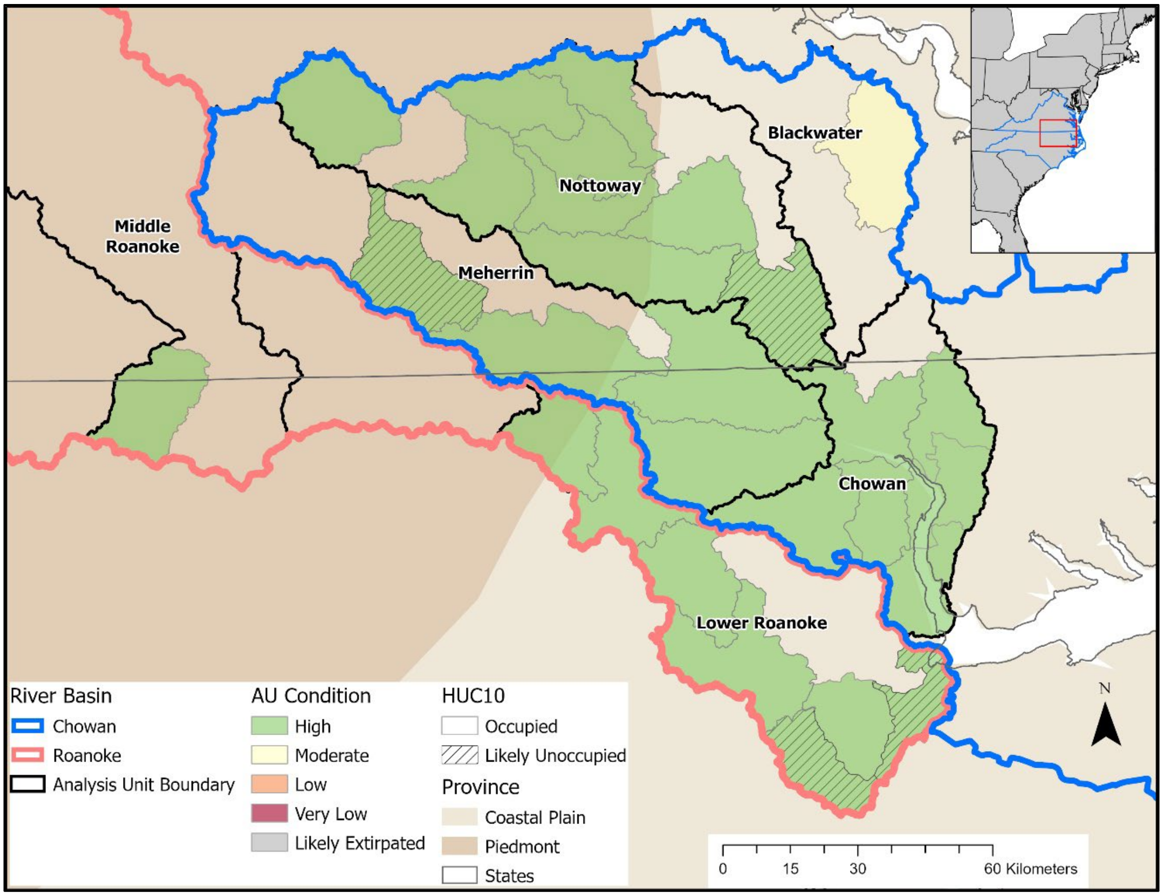


Figure 5-5. Future condition by AU for Scenario 3. AUs are shown by name.

Table 5-2: Current and Future Conditions and the 3 Rs

3Rs	Requisites	Current Condition	Future Condition in 50 years
Resiliency (ability to withstand stochastic events)	Healthy populations and habitat.	AUs were defined at one or more HUC10 watersheds within a HUC8 subbasin that encompass historically or currently documented occupied habitat. Each AU with high or moderate current condition is thought to currently have adequate habitat and healthy subpopulations, thus has high or moderate resiliency. • 6 of 6 AUs (100%) are known to be extant. • AU status: – 5 of 6 AUs (83%) high condition – 1 of 6 AUs (17%) moderate condition	Scenario 1: • 6 of 6 AUs (100%) extant • 3 of 6 AUs (50%) high condition • 3 of 6 AUs (50%) moderate condition Scenario 2: • 2 of 6 AUs (33%) high condition • 3 of 6 AUs (50%) moderate condition • 1 of 6 AUs (17%) likely extirpated Scenario 3: • 6 of 6 AUs (100%) extant • 5 of 6 AUs (83%) high condition • 1 of 6 AUs (17%) moderate condition
Redundancy (ability to withstand catastrophic events)	Sufficient distribution of healthy populations	• Healthy AUs (moderate or high condition) evenly distributed within both basins and across the range. • Occupied HUC10s evenly distributed within AUs and both basins.	Scenario 1: • More AUs with moderate condition in the eastern and southern portions of the range. • Occupied HUC10s will be unevenly distributed within the Chowan and Lower Roanoke AUs and both basins. Scenario 2: • More AUs with moderate condition in the eastern and southern portions of the range. High condition AUs will occur in the middle/northern portion of range. 1 AU in southwest likely extirpated. • Occupied HUC10s will be unevenly distributed within the Chowan and Lower Roanoke AUs and both basins; no occupied HUC10 in the Middle Roanoke AU. Scenario 3: • Healthy AUs evenly distributed across the range • Occupied HUC10s will be evenly distributed within AUs and both basins.
	Sufficient number of healthy populations	• 6 of 6 AUs (100%) are healthy (moderate or high condition). • 24 of 28 HUC10 watersheds (86%) currently occupied.	Scenario 1: • 6 of 6 AUs (100%) moderate or high condition. • 21 of 28 HUC10 watersheds (75%) occupied. Scenario 2: • 5 of 6 AUs (83%) moderate or high condition; 1 AU likely extirpated. • 19 of 28 HUC10 watersheds (68%) occupied. Scenario 3: • 6 of 6 AUs (100%) moderate or high condition. • 24 of 28 HUC10 watersheds (86%) occupied.

3Rs	Requisites	Current Condition	Future Condition in 50 years
Representation (ability to adapt)	Sufficient capacity to adapt to new, continually changing environments.	Connected, occupied HUC10s found in both river basins (populations) and physiographic provinces. **River basin:** • Chowan – 18 of 20 HUC10s (90%) occupied. • Roanoke – 6 of 8 HUC10s (75%) occupied. **Physiographic province:** • Piedmont – 10 of 11 HUC10s (91%) occupied. • Coastal Plain – 14 of 17 HUC10s (82%) occupied.	Scenario 1: **River basin:** • Chowan – 16 of 20 HUC10s (80%) occupied. • Roanoke – 5 of 8 HUC10s (63%) occupied. **Physiographic province:** • Piedmont – HUC10 occupancy unchanged. • Coastal Plain – 11 of 17 HUC10s (65%) occupied. Scenario 2: **River basin:** • Chowan – 15 of 20 HUC10s (75%) occupied. • Roanoke – 4 of 8 HUC10s (50%) occupied. **Physiographic province:** • Piedmont – 9 of 11 HUC10s (82%) occupied. • Coastal Plain – 10 of 17 HUC10s (59%) occupied. Scenario 3: **River basin:** • Chowan – HUC10 occupancy unchanged. • Roanoke – HUC occupancy unchanged. **Physiographic province:** • Piedmont – HUC10 occupancy unchanged. • Coastal Plain – HUC10 occupancy unchanged.

Table 5-3. Current condition and future condition in 2070 of Chowanoke crayfish populations for Scenarios 1, 2, and 3.

Current		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy Decline**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**
	Nottoway	High	High	High	High	High	High	High	High	High
	Meherrin	High	High	High	High	High	High	High	High	High
	Blackwater	High	Low	Moderate	High	High	High	High	High	Moderate
	Chowan	High	High	High	Moderate	High	Moderate	High	Moderate	High
Roanoke		**High**	**Moderate**	**High**	**High**	**High**	**Moderate**	**High**	**High**	**High**
	Middle Roanoke	High	Moderate	High	High	High	High	High	High	High
	Lower Roanoke	High	Moderate	High	High	High	Moderate	High	High	High

Scenario 1: 2070		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**Moderate**	**Moderate**	**Moderate**	**High**
	Nottoway	High	High	High	High	Moderate	Moderate	Moderate	Moderate	High
	Meherrin	High	High	High	High	High	Moderate	Moderate	High	High
	Blackwater	High	Low	Moderate	High	High	High	Moderate	High	Moderate
	Chowan	Moderate	High	High	Moderate	High	Low	Moderate	Moderate	Moderate
Roanoke		**Moderate**	**Moderate**	**Moderate**	**High**	**High**	**Low**	**Moderate**	**High**	**Moderate**
	Middle Roanoke	High	Moderate	High	High	High	High	Moderate	High	High
	Lower Roanoke	Moderate	Moderate	Moderate	High	High	Low	Moderate	Moderate	Moderate

Scenario 2: 2070		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**Moderate**	**High**	**Moderate**	**Low**	**Moderate**	**Moderate**
	Nottoway	High	High	High	Moderate	Moderate	Moderate	Low	Moderate	High
	Meherrin	High	High	High	Moderate	High	Moderate	Low	Moderate	High
	Blackwater	High	Low	Moderate	Moderate	High	High	Low	Moderate	Moderate
	Chowan	Moderate	Moderate	Moderate	Low	High	Low	Low	Low	Moderate
Roanoke		**Moderate**	**Moderate**	**Moderate**	**Moderate**	**High**	**Low**	**Low**	**Moderate**	**Moderate**
	Middle Roanoke	ø	ø	ø	Very Low	High	High	Low	Low	Likely Extirpated
	Lower Roanoke	Moderate	Moderate	Moderate	Moderate	High	Low	Low	Moderate	Moderate

Scenario 3: 2070		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**Moderate**	**Moderate**	**Moderate**	**High**
	Nottoway	High	High	High	High	Moderate	Moderate	Moderate	Moderate	High
	Meherrin	High	High	High	High	High	Moderate	Moderate	High	High
	Blackwater	High	Low	Moderate	High	High	High	Moderate	High	Moderate
	Chowan	High	High	High	Moderate	High	Moderate	Moderate	Moderate	High
Roanoke		**High**	**Moderate**	**High**	**High**	**High**	**Moderate**	**Moderate**	**High**	**High**
	Middle Roanoke	High	Moderate	High	High	High	High	Moderate	High	High
	Lower Roanoke	High	Moderate	High	High	High	Moderate	Moderate	High	High

Table 5-4. Overall Current Condition vs. Overall Future Conditions for Scenarios 1, 2, and 3 for 2030, 2050, and 2070.

Scenario 1

Population	Analysis Units	Current Condition	2030	2050	2070
Chowan		**High**	**High**	**High**	**High**
	Nottoway	High	High	High	High
	Meherrin	High	High	High	High
	Blackwater	Moderate	Moderate	Moderate	Moderate
	Chowan	High	High	High	Moderate
Roanoke		**High**	**High**	**High**	**Moderate**
	Middle Roanoke	High	High	High	High
	Lower Roanoke	High	High	High	Moderate

Scenario 2

Population	Analysis Units	Current Condition	2030	2050	2070
Chowan		**High**	**High**	**High**	**Moderate**
	Nottoway	High	High	High	High
	Meherrin	High	High	High	High
	Blackwater	Moderate	Moderate	Moderate	Moderate
	Chowan	High	High	High	Moderate
Roanoke		**High**	**High**	**Moderate**	**Moderate**
	Middle Roanoke	High	High	Moderate	Likely Extirpated
	Lower Roanoke	High	High	Moderate	Moderate

Scenario 3

Population	Analysis Units	Current Condition	2030	2050	2070
Chowan		**High**	**High**	**High**	**High**
	Nottoway	High	High	High	High
	Meherrin	High	High	High	High
	Blackwater	Moderate	Moderate	Moderate	Moderate
	Chowan	High	High	High	High
Roanoke		**High**	**High**	**High**	**High**
	Middle Roanoke	High	High	High	High
	Lower Roanoke	High	High	High	High

5.3 Summary of Species Viability

This assessment describes the viability of the Chowanoke crayfish in terms of resiliency, redundancy, and representation by using the best commercial and scientific information available. We used these parameters to describe current and potential future conditions regarding the species' viability. To address the uncertainty associated with potential future threats and how they will affect the species' resource needs, we assessed potential future conditions using three plausible scenarios. These scenarios were based on the primary threats and positive influences on the species across its range, allowing us to predict potential changes in population and habitat parameters.

5.3.1 *Resiliency*

Species-level resiliency for the Chowanoke crayfish is evaluated through the number of healthy subpopulations through the species' range. Currently, the condition of each AU is high or moderate and is thought to have adequate habitat and healthy subpopulations. The species occupies six of six historically occupied AUs within its range and most of the AUs (83 percent) are designated as high condition, which provide high resiliency to environmental stochasticity.

In future Scenarios 1 and 3, the six AUs are predicted to remain extant and maintain high or moderate condition. Scenario 2 is predicted to have the Middle Roanoke AU be likely extirpated and has the lowest percentage of high condition AUs (2 of 6 AUs, 33 percent), but the other three AUs are predicted to be in moderate condition, thus maintaining resiliency for five subpopulations.

The dominant drivers for the decrease in resiliency for some of the AUs are (1) SLR and the associated loss of suitable habitat due to increases in inundation of higher salinity waters and associated significant loss of suitable habitat in the Chowan AU and Lower Roanoke AU, (2) decreases in water quality/flow due to increased drought from climate change, (3) decreases in instream habitat due to increasing number and distribution of nonnative red swamp crayfish into the Chowanoke crayfish's range caused by climate change effects (e.g., warmer temperatures, increased floods, SLR), and (4) loss of most of the instream habitat due to increasing number and distribution of nonnative virile crayfish into the Middle Roanoke AU caused by its proximity to Kerr Reservoir (source of virile crayfish) and climate change effects (e.g., increased flood, droughts).

5.3.2 *Redundancy*

Species redundancy for the Chowanoke crayfish is achieved through multiple, widely distributed healthy subpopulations and occupied HUC10 watersheds throughout its range. The species is currently known from 24 occupied HUC10 watersheds distributed evenly in six healthy AUs throughout the Chowan and Roanoke River basins.

Under Scenarios 1 and 3 through 50 years, the species is predicted to maintain populations in moderate or high conditions in all six AUs; however, there will be a greater number of AUs with moderate condition occurring in the eastern and southern portions of the range for Scenario 1.

Under Scenario 2, the species is predicted to be likely extirpated in the Middle Roanoke AU in the southwestern portion of the range. Under Scenarios 1 and 2, the number of occupied HUC10s decreases slightly to 21 and 19 HUC10s, respectively (75-percent and 68-percent occupied, respectively), with the majority of HUC10s becoming unoccupied in the southeastern portions of Chowan AU and Lower Roanoke AU due to the projected greater increase in inundation of higher salinity waters and associated significant loss of suitable habitat. Even with the loss of these HUC10s, except for the only HUC10 in the Middle Roanoke AU, there will likely be sufficient suitable and connected upstream habitat for the Chowanoke crayfish to migrate. Therefore, under all scenarios through 50 years there will be redundancy both at the subpopulation and species level, which will help the species maintain populations in the event of catastrophic events such as extreme flooding or drought.

5.3.3 *Representation*

The range of the Chowanoke crayfish is currently restricted to two river basins; therefore, it has inherently limited representation. Because we have limited information on the species' genetic, morphological, or ecological niche, which are the typical measures of species representation, we used the species' distribution within the basins and two physiographic provinces as surrogates for potential adaptive capacity. The species retains its representation by maintaining healthy subpopulations and occupied HUC10s across its range. The Chowanoke crayfish is currently distributed within both river basins throughout its historical western to eastern extent and in both physiographic provinces. Some of the representation of the Chowanoke crayfish has been lost in the Chowan and Roanoke River basins, with a 10-percent and 25-percent decline in HUC10s occupied, respectively. In the Piedmont and Coastal Plain provinces, a majority of the representation has been retained, with a 9-percent and 18-percent decline in HUC10s occupied, respectively.

In future Scenarios 1 and 3, both basins and provinces will maintain all their AUs with high and moderate condition. For Scenario 2, one AU will become likely extirpated in the Roanoke basin and Piedmont province and a greater number of the AUs will become moderate condition (50 percent of the AUs will be moderate condition for both the Chowan and Roanoke basins). For all the future scenarios, the Chowan basin and Piedmont province maintains relatively high HUC10 occupancy, 75-90 percent and 82-91 percent, respectively. For Scenarios 1 and 2, the Coastal Plain province portions of both basins will have reduced HUC10 occupancy, as low as 59 percent for Scenario 2, due to projected a greater increase in inundation of higher salinity waters and associated significant loss of suitable habitat. In addition for these two scenarios, the Roanoke basin will have reduced HUC10 occupancy, as low as 50 percent for Scenario 2 due to the salinity stressor in the east as well effects of virile crayfish in the west. With the range contracting in the western and eastern portions of the Roanoke basin and the eastern portion of the Coastal Plain province under Scenario 2, the species' representation is predicted to be reduced, and the Chowanoke crayfish may not be as adaptive to changing conditions after the 50-year period.

5.3.4 *Summary*

The Chowanoke crayfish faces a variety of stressors from declines in water quality, reduction of stream flow, riparian habitat loss, and deterioration of instream habitats. The primary threats affecting the Chowanoke crayfish are land use modification, climate change, and nonnative crayfish, therefore these factors were included in our assessment of the future condition of the Chowanoke crayfish. When resiliency is very low, populations become more vulnerable to extirpation, in turn, resulting in concurrent losses in representation and redundancy. The results of the future analysis describe a range of possible future conditions for the Chowanoke crayfish populations and AUs (Table 5-5). Based on current and projected habitat conditions and population factors for two future scenarios (1 and 3), estimates of current and future resiliency for Chowanoke crayfish are high to moderate in all the AUs and Chowan and Roanoke populations, as are estimates for redundancy and representation at the end of 50 years. For Scenario 2, the Middle Roanoke AU in the Roanoke population is predicted to be likely extirpated, but the other five AUs in the Chowan and Roanoke populations will be in moderate or high condition, thus maintaining resiliency for five (83 percent) subpopulations. Redundancy is predicted to be reduced, but still at a moderate level across the range, with 68 percent of the HUC10 watersheds occupied. Representation in the Roanoke population and Coastal Plain province will decline, with the range contracting in the southwestern and eastern portions of the range. Under Scenario 2, the Chowanoke crayfish may not be as adaptive to changing conditions after the 50-year period.

Table 5-5. Summary of current and future scenario overall conditions (resiliency).

			Future Scenarios of Overall Conditions		
Population	**Analysis Units**	**Current**	**#1: Continuation of Current Trends**	**#2: Increase in Rates of Land Use Changes and Climate Change Effects**	**#3: Continuation Plus Conservation**
Chowan		**High**	**High**	**Moderate**	**High**
	Nottoway	High	High	High	High
	Meherrin	High	High	High	High
	Blackwater	Moderate	Moderate	Moderate	Moderate
	Chowan	High	Moderate	Moderate	High
Roanoke		**High**	**Moderate**	**Moderate**	**High**
	Middle Roanoke	High	High	**Likely Extirpated**	High
	Lower Roanoke	High	Moderate	Moderate	High

CHAPTER 6 KEY UNCERTAINTIES

Inherently, projecting future scenarios and the species' response to those scenarios requires us to make plausible assumptions. Our analyses are predicated on multiple assumptions, which could lead to over and underestimates of the Chowanoke crayfish's viability. Below, we identify the key sources of uncertainty and indicate the likely effect of our assumptions on the viability assessment. The uncertainty associated with determining species' status and trends underpins all of our analyses, and thus warrants further explanation.

Table 6-1. Key assumptions encountered in the analysis and the impact on our viability assessment. "Overestimates" means the species' viability is optimistic; "Underestimates" means the species' viability is pessimistic; "Either" means the effect could lead to an over or underestimate of viability.

Number	Assumption	Effect on Viability Assessment
1	Crayfish survey results from two time periods are not comparable. Therefore, changes in populations/trends may not be apparent.	Either
2	Due to the relatively limited amount of historical data, the historical range is assumed to include current occurrences.	Either
3	We assume that Chowanoke crayfish populations are delineated based on the river basins they historically occupied (Chowan and Roanoke River basins). HUC6 boundaries provide geographic separation of land based on surface water drainage and we refer to these as 'populations.'	Either
4	If Chowanoke crayfish were not observed and documented in a HUC10 since 2010, it was considered to be not currently occupied, even if the stream was not resurveyed since 2010, there is additional information to indicate that habitat conditions have not changed significantly, or believed to have been observed, but not documented (i.e., personal communication).	Underestimates
5	We only assume historical presence of Chowanoke crayfish in a HUC10 based on documented occurrences within its boundaries. Therefore, we do not assume historical presence in HUC10 or HUC8 watersheds that are adjacent to or between occupied watersheds.	Either
6	Life history and species/habitat needs information specific to Chowanoke crayfish is limited. Their life history is presumed to be similar to many other stream dwelling crayfish, Family Cambaridae, and *Faxonius* spp.	Either
7	Chowanoke crayfish sensitivity/tolerance to temperature, sedimentation, disease, non-native species, and/or other factors influencing the species is not known. There is known within genus variation in species sensitivity in other Family Cambaridae and *Faxonius* spp. crayfish.	Either
8	Landcover metrics (% forested/wetlands and % impervious surface in watershed) are assumed to represent and be an indicator of water quality and instream habitat condition.	Either
9	Presence of nonnative species are assumed to be the same as previously surveyed. It is possible that nonnatives may have continued to spread throughout the watersheds.	Overestimates
10	Red swamp crayfish's effects on Chowanoke crayfish are unknown, but we assume its effects will primarily be on instream habitat.	Either
11	The direct effects of climate change spatially and temporally are unknown, especially when considering the effect on overall suitable habitat relative to the species' water temperature and salinity preferences and synergistic effects (e.g., effects of increased drought/storms and SLR on salinity).	Either
12	For future scenarios, HUC10 watersheds that are not currently occupied continue to be unoccupied in all future scenarios, even when habitat conditions are projected to remain in moderate or high condition.	Underestimates

Number	Assumption	Effect on Viability Assessment
13	For future scenarios, we assume there is suitable habitat for Chowanoke crayfish to migrate upstream in response to sea level rise, based on the presence of occupied habitat.	Overestimates

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APPENDIX A: SUMMARY OF OCCURRENCE DATA COMPILATION AND REVIEW PROCESS

Datafiles sources

State natural resource agencies in Virginia and North Carolina and researchers provided occurrence records of Chowanoke crayfish (CC) (*Faxonius virginiensis*) (Table A-1). Records from online databases were also obtained, using both current and previous scientific names (Table A-1).

Table A-1. Chowanoke crayfish datafile information

Datafile Source	Date Received or Accessed from Website	Datafile Provider or Website	Description
Virginia Department of Wildlife Resources (VDWR), B.T. Watson's aquatics database	6/13/2019	Brian T. Watson, VDWR	Records of Chowanoke crayfish in Virginia, which included all records from VDWR HQ collections database and most records from Smithsonian Institution.
R. Thoma Chowanoke crayfish records	5/29/2019	Roger Thoma, Midwest Biodiversity Institute	Records of Chowanoke crayfish in Virginia, which included observations from Thoma (2014, 2019).
North Carolina Wildlife Resources Commission (NCWRC)	3/26/2019	Sarah McRae, U.S. Fish and Wildlife	Records of Chowanoke crayfish in North Carolina
Global Biodiversity Information Facility (GBIF)	3/22/2019, 9/12/2019	https://www.gbif.org	Records of Chowanoke crayfish in Virginia and North Carolina, which included records from multiple sources, including NC Museum of Natural Sciences, Smithsonian Institution, NatureServe Network.
Virginia Department of Conservation and Recreation, Division of Natural Heritage (VDCR-DNH)	6/13/2019	David Boyd, VDCR-DNH	Records of Chowanoke crayfish in Virginia
North Carolina Natural Heritage Program (NCNHP)	4/17/2019	Judith Ratcliffe, NCNHP	Records of Chowanoke crayfish in North Carolina
Smithsonian Institution	3/22/2019, 9/12/2019	http://collections.si.edu/	Records of Chowanoke crayfish
B. Williams and David Foltz Chowanoke crayfish records	12/2/2019	Bronwyn Williams, North Carolina Museum of Natural Sciences (NCMNS)	Records of Chowanoke crayfish in Virginia

Review of individual datafiles

Each of the datafiles were imported to ArcGIS for an initial review of location information. If the latitude/longitude location information placed it in an area outside of Virginia and North Carolina or far from other CC occurrences, the record was further reviewed and compared to site description information included with the record. Data provider was contacted to verify and/or correct location information.

Reorganization and compilation of datafiles

For each of the datafiles, except Smithsonian, column headings in the excel spreadsheets were organized, renamed, and combined so that each of the datafiles had the same column headings and provided similar information under specific column headings. Some columns also removed if they provided information not relevant to analysis (i.e., USGS quad). Year was added as a new column heading, based on date. Some datafiles provided less information (e.g., no habitat or stream substrate information), therefore have many columns that are blank.

The Smithsonian datafile was compared to the other datafiles, and all records except one were included in VDWR, NCNHP, and VDCR-DHP datafiles. Only one record was not included (#14623, Blackwater River, Zuni, Isle of Wight county, VA) in the other datafiles, but it was not added to the compiled datafile because it did not provide specific information to determine exact location, however, this record will be discussed in the SSA.

The NCWRC datafile provided records for each individual CC observed (e.g., each row represented one CC observation), while the other datafiles provided one record by location and date when one or more CC were observed (e.g., each row provided total number of CC observed, number of females, number of juveniles). Therefore, multiple records of CC observed on the same date and location were combined into one record and the number of CC observed by gender and age were calculated.

All the datafiles were then compiled together into one excel spreadsheet and sorted by date. Records were then compared to determine if they were replicates (e.g., same date, location, etc) and then merged into one record. The sources of each record are noted in the "Database_source" column heading.

Review and check of combined datafile

The combined datafile was imported into ArcGIS and missing information was filled in based on location of datapoints (e.g., waterway, state, physiographic province, watershed). Stream order was determined based on U.S. Geological Survey (USGS) National Hydrography Dataset Plus High (NHDPlus) Resolution GIS files (USGS 2018). Several waterbody names were also revised to match NHDPlus naming convention based on location of occurrence point (e.g., Falls Creek was revised to Nottoway River; Chinkapin Creek to Chinkapin Swamp).

APPENDIX B: CURRENT CONDITION METHODOLOGY

The Chowanoke crayfish condition metrics of population and habitat factors (described in Chapter 4) are derived from multiple data sources, as summarized in Table B-1 and described below. We sorted the population and habitat factors into five categories (high, moderate, low, very low, and extirpated (ø)) based on an assessment of the data to facilitate summarizing the current condition of each of the Chowanoke crayfish analysis units (AUs) (Table B-2). AUs were defined as one or more HUC10 watersheds within a HUC8 subbasin that encompass historically or currently documented occupied habitat.

To summarize the current condition of the Chowanoke crayfish by population (i.e., Roanoke or Chowan basin based on HUC6 boundaries) for each metric, we assigned numbers to each category ranking for each AU (High = 3; Moderate = 2; Low = 1; Very Low = 0) and calculated an average score, weighted by the area of each AU.

For example, the Roanoke population's average score for a condition metric was calculated using the following equation:

$$\frac{(\text{M. Roanoke AU area} * \text{M. Roanoke AU score}) + (\text{L. Roanoke AU area} * \text{L. Roanoke AU score})}{\text{M. Roanoke AU area} + \text{L. Roanoke AU area}}$$

M: Middle; L: Lower

The average score was converted to qualitative condition rankings, as summarized in Table B-3.

Table B-1. Condition metric data and data sources.

Condition Metric	**Data Description**	**Data Source**
Analysis Unit Occupancy Decline	Chowanoke crayfish occurrence data	See Appendix A
Approximate Abundance	Chowanoke crayfish occurrence data	See Appendix A
Instream Habitat/Water Quality	Forest and wetlands land cover data	2016 National Land Cover Database (USGS 2019a, unpublished data)
Water Quality	Impervious surfaces land cover data	2016 National Land Cover Database (USGS 2019b, unpublished data)
Salinity	Salinity data	Coastal Salinity Index (USGS 2020a, unpublished data)
Water Quantity/Flow	U.S. Drought Monitor maps	U.S. Drought Monitor Southeast annual images (U.S. Drought Monitor 2020, unpublished data)

Table B-2. Population and habitat factors used to create condition categories.

	Population Factors		Habitat Factors			
Condition Category	**Analysis Unit Occupancy Decline**	**Approximate Abundance**	**Instream Habitat/Water Quality[1]**	**Water Quality[1]**	**Salinity**	**Water Quantity/Flow**
High	≤30% decline	>100 individuals total observed in past 10 years; and large numbers (10+) of individuals seen during targeted surveys at 3 or more sites (past 10 years)	Predominantly natural (>70% forested/wetlands) active river area	<6% impervious surfaces in HUC10 watersheds	<1 ppt at any site	Optimal flowing water conditions; no known flow issues; infrequent low flow/drought periods
Moderate	31-50% decline	51-100 individuals total observed in past 10 years; and large numbers (10+) of individuals seen during targeted surveys at 2 sites (past 10 years)	20-70% forested/wetlands active river area	6-15% impervious surfaces in HUC10 watersheds	1 to 7 ppt at any site	Moderate flowing water conditions; moderate flow issues, including 3 to 4 years of consecutive drought or moderately flashy flow
Low	51-70% decline	2-50 individuals observed in past 10 years	<20% forested/wetlands active river area	>15% impervious surfaces in HUC10 watersheds	>7 ppt at any site	Low flowing water condition- either frequently inundated or dry; severe flow issues; more than 4 consecutive years of drought; flashy flow regime
Very Low	>70% decline	1 individual observed in past 10 years	Instream habitat/water quality unable to support species survival	Water quality unable to support species survival	Salinity conditions do not support species survival	Flow conditions do not support species survival
Ø	Total Loss	Total Loss	N/A	N/A	N/A	N/A

[1] The forested/wetlands active river area is an indicator of both instream habitat and water quality, while impervious surfaces in HUC10 watersheds is an additional indicator of water quality.

Table B-3. Condition ranking by average score.

Condition Ranking	Average Score
High	2.5-3
Moderate	1.5-2.4
Low	0.5-1.4
Very Low	<0.5

Analysis Unit Occupancy and Approximate Abundance

To determine the known historical and current distribution and approximate abundance of the species within AUs (boundaries based on HUC8 watershed) and HUC10 watersheds, Chowanoke crayfish presence was compiled from historical and current survey data and converted to a shapefile in ArcGIS Pro (see Sections 2-6 and 2-7 and Appendix A). Historical data was collected from 2009 and earlier; current data were collected from 2010 through 2019. Shapefiles for hydrology lines and watershed boundaries for HUC6, HUC8, and HUC10 were obtained from the USGS National Hydrography Dataset Plus High Resolution (NHDPlus) for 4-digit Hydrologic Unit – 0301 (USGS 2018, unpublished data). Using ArcGIS's Spatial Join tool, each occurrence record had its intersecting watershed (HUC 6, HUC8, and HUC10) information attributed to the record. Tables B-4 and B-5 provide the results and associated condition ranking.

Table B-4. Analysis unit (AU) occupancy metric data and condition by AU and population.

Population	Analysis Unit (AU)	AU Area (km^2)	Historically Occupied HUC10s	Currently Occupied HUC10s (2010-2019)	HUC10 % decline	AU Occupancy Decline Condition
Chowan		**8,625**	**20**	**18**	**10**	**High**
	Nottoway	3,567	9	8	11	High
	Meherrin	2,558	4	3	25	High
	Blackwater	485	1	1	0	High
	Chowan	2,015	6	6	0	High
Roanoke		**2,980**	**8**	**6**	**25**	**High**
	Middle Roanoke	413	1	1	0	High
	Lower Roanoke	2,567	7	5	29	High

Table B-5. Approximate abundance metric data and condition by AU and population, based on current records (2010-2019).

Population (HUC6)	Analysis Unit	Total # of Live Individuals	Number of Current Records	Maximum Number Observed at One Site	Year Last Seen	Approximate Abundance Condition
Chowan		**570**	**57**			**High**
	Nottoway	323	22	100	2019	High
	Meherrin	129	17	35	2014	High
	Blackwater	4	1	4	2013	Low
	Chowan	114	17	24	2014	High
Roanoke		**144**	**22**			**Moderate**
	Middle Roanoke	55	10	32	2018	Moderate
	Lower Roanoke	89	12	24	2014	Moderate

Instream Habitat/Water Quality

GIS analyses were used to determine the land cover percentages for each HUC10 watershed (all historically and currently occupied) and active river area (ARA) using the most recent land cover dataset (Table B-1). ARA raster dataset were provided by The Nature Conservancy (Smith et al. 2008, entire). Percent forested/wetlands included the following land cover types: deciduous forest, evergreen forest, mixed forest, shrub/scrub, woody wetlands, emergent herbaceous wetlands. The average percentage of forested/wetlands in the ARA in each AU was calculated from the percentage of forested/wetland in the ARA by all historically or currently occupied HUC10s within the AU. Similarly the average percentage of impervious surfaces in each AU was calculated from the percentage of impervious surfaces by all historically or currently occupied HUC10s within the AU. Table B-6 provides the results and associated condition category. Agriculture land cover is not included as a metric because it has a strong, negative relationship to forest and wetlands land cover in the HUC10 watersheds (Figure B-1).

Table B-6. Instream habitat/water quality and water quality metric data and condition by AU and population.

Population	Analysis Unit (AU)	Area of ARA within AU (km^2)	AU Area (km^2)	Average % Forested/Wetlands in ARA	Instream Habitat/ Water Quality Condition	Average Watershed % Impervious Surfaces	Water Quality Condition
Chowan		2,699	8,625		High		High
	Nottoway	1,028	3,567	84	High	0.6	High
	Meherrin	770	2,558	82	High	0.6	High
	Blackwater	122	485	82	High	0.4	High
	Chowan	779	2,015	69	Moderate	0.5	High
Roanoke		1,350	2,980		High		High
	Middle Roanoke	120	413	74	High	0.3	High
	Lower Roanoke	1,229	2,567	78	High	1.1	High

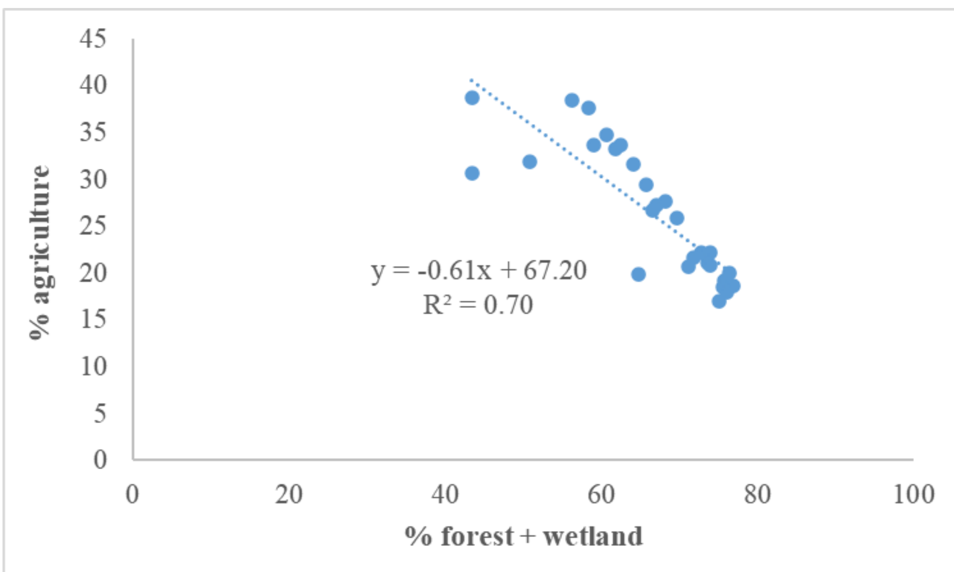

Figure B-1. Relationship between % agriculture and % forest/wetlands land covers in the HUC10 watersheds based on 2016 NLCD (USGS 2019a).

Salinity

We utilized the salinity data from U.S. Geological Survey (USGS) monitoring station inside the mouth of the Roanoke River (Station Number 0208114150). Monthly average salinity data inside the mouth of the Roanoke River from November 1997 to March 2020 indicate that this site is predominantly tidal freshwater (salinity less than or equal to 0.5 parts per thousand (ppt); Figure B-2) (USGS 2020a, unpublished data). More than 85 percent of the monthly average salinity data was less than or equal to 0.5 ppt, however there were periods of up to 3.5 ppt prior to 2010 and up to 2.5 ppt from 2010-2019. We assumed that the mouth and lower portion of the Chowan

River would be exposed to similar salinity conditions as the lower Roanoke River, due to its close proximity. Brown et al. (2015) measured salinity from April 2012 through September 2013 in a 16-km section of the lower Chowan River and its tributaries, including the Wiccacon River, and typically observed values between 0 and 0.1 ppt throughout the area, with peak salinity of 1.5 ppt observed in the main stem for an unspecified period of time during summer 2012. Approximately 27 km upstream of the Roanoke River station is another USGS monitoring station in the Roanoke River (Station Number 02081094; Roanoke River at Jamesville, NC) and the one-month average salinity was consistently less than 0.1 ppt from 2010-2019 (USGS 2020a, unpublished data; Figure B-3). We do not have information to indicate there is tidal influence in the other AUs, therefore we assumed their salinity would be less than 1 ppt. Table B-7 provides the results and associated condition ranking.

Table B-7. Salinity and water quantity/flow metric data and condition by AU and population.

Population	Analysis Unit	Salinity (ppt) (2010-2019)	Salinity Condition	Drought Years (2010-2019)	Water Quantity Condition
Chowan			**High**		**High**
	Nottoway	<1	High	2010, 2012, 2015-2016, 2019	High
	Meherrin	<1	High	2010, 2015-2016, 2019	High
	Blackwater	<1	High	2010, 2015-2016	High
	Chowan	1-2.5 periodically inside the mouth of Chowan River	Moderate	2010, 2015	High
Roanoke			**Moderate**		**High**
	Middle Roanoke	<1	High	2010, 2015	High
	Lower Roanoke	1-2.5 periodically inside the mouth of Roanoke River	Moderate	2010, 2015	High

Water Quantity/Flow

USGS has stream gauges/monitoring stations in both the Chowan and Roanoke basin, however they mostly occur in higher stream-order rivers (e.g., Nottoway River, Meherrin River, Roanoke River) and not in lower stream-order streams that may be more susceptible to drought and low flow conditions. Therefore, to assess potential flow conditions, we compiled a series of US Drought Monitor graphics from the Southeast during the low flow time of year, which is generally during the first week of September, from 2010 to 2019 (Figures B-2 and B-3). We assumed multiple years of drought, at any of the level (e.g., D0 to D4), would be an indicator of moderate streamflow issues to cause stress to Chowanoke crayfish. Table B-7 provides the results and associated condition ranking.

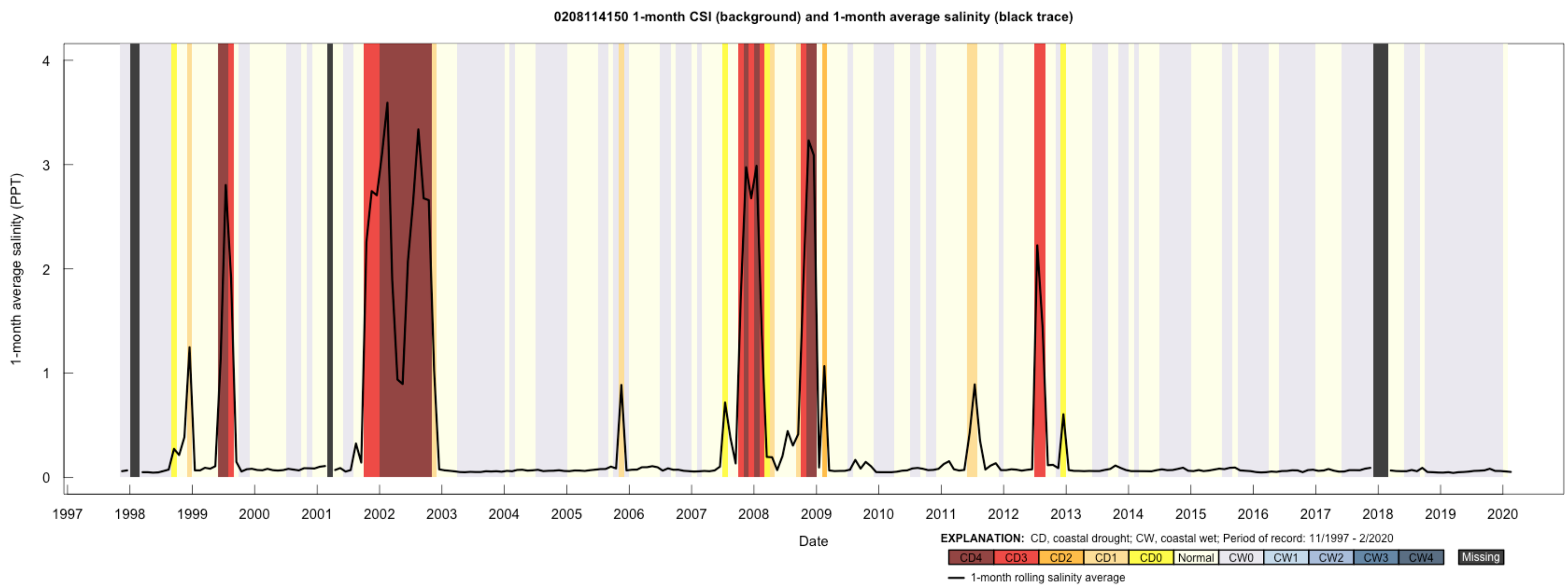

Figure B-2. Monthly average Coastal Salinity Index (CSI) and salinity at USGS monitoring station 0208114150, Roanoke River at NC 45, which is upstream of the mouth of the Roanoke River. Coastal Salinity Index positive (light yellow to blue) and negative (bright yellow to red) represent increasingly fresh and saline conditions, respectively (Figure from USGS 2020a, unpublished data).

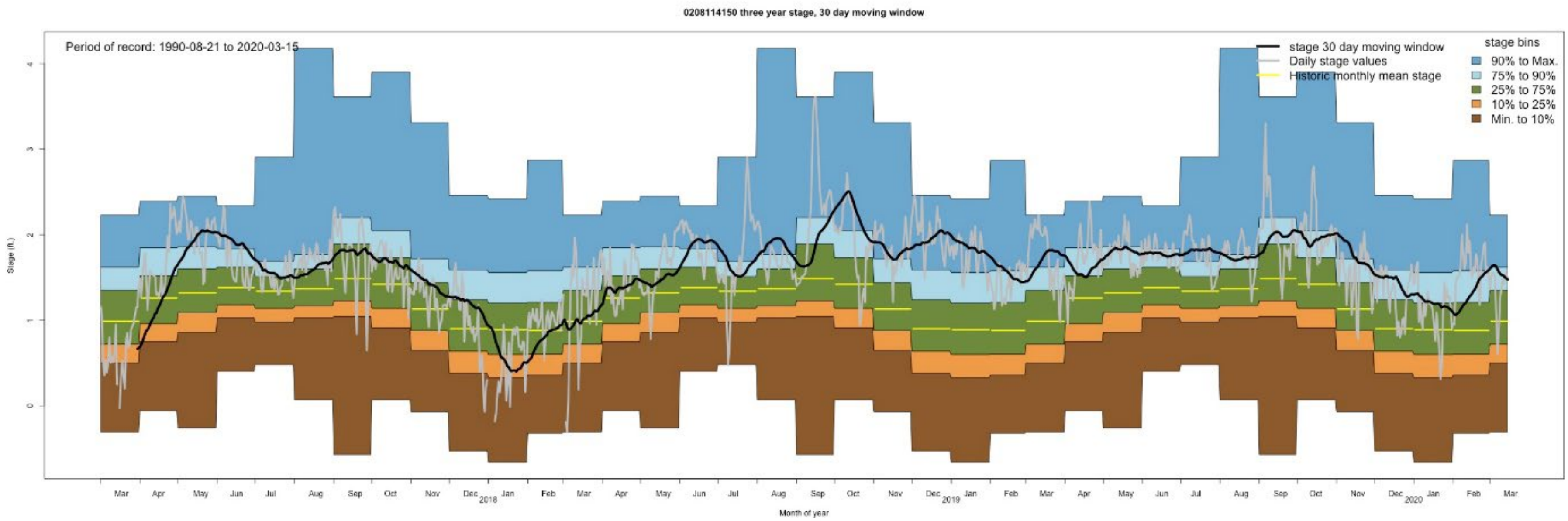

Figure B-3. Daily values, 30-day moving window, and historic monthly mean stage height at USGS monitoring station 0208114150, Roanoke River at NC 45, which is inside the mouth of the Roanoke River (Figure from USGS 2020a, unpublished data).

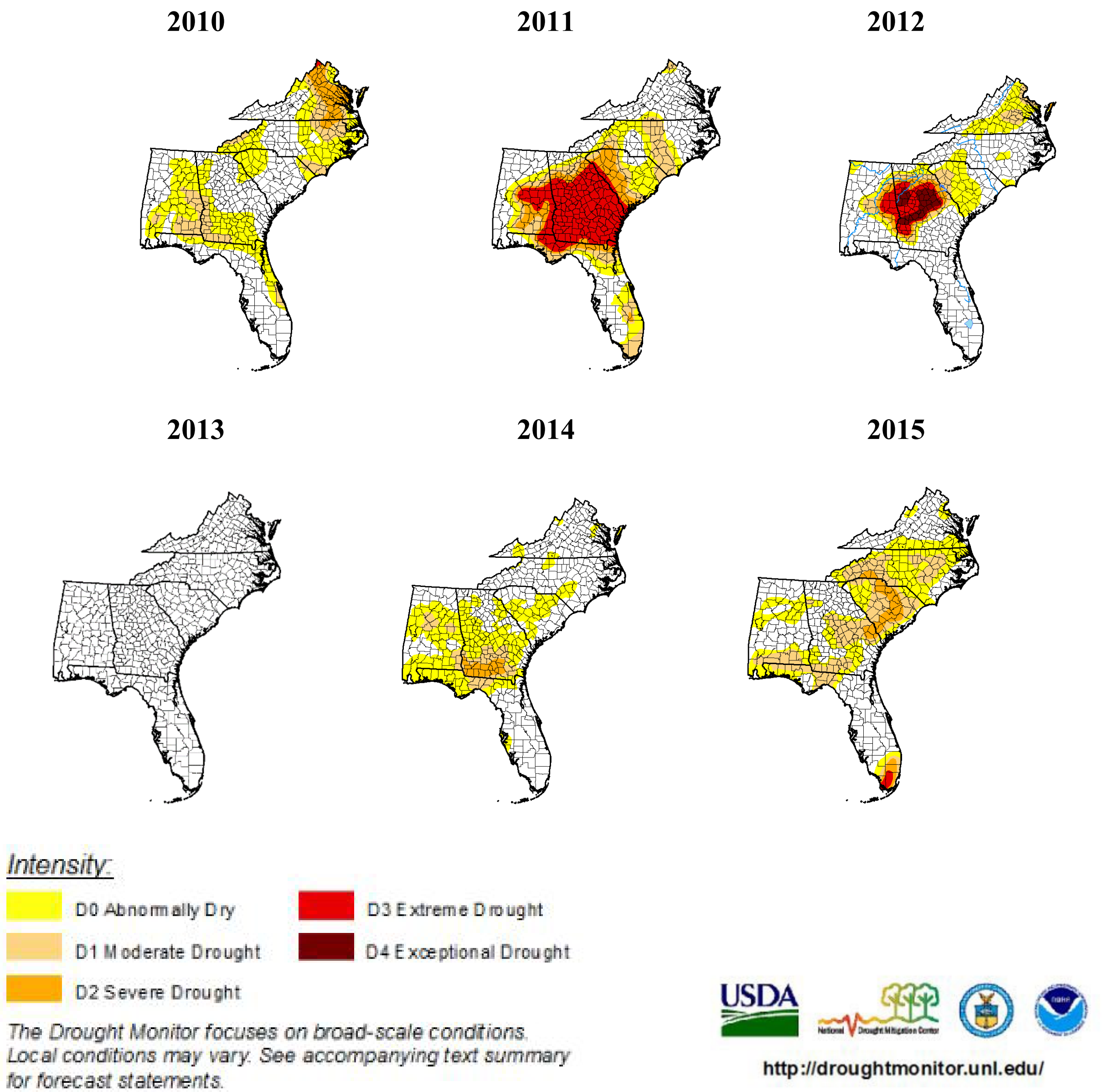

Figure B-2. U.S. Drought Monitor Southeast annual image for 1st week in September from 2010 to 2015 (U.S. Drought Monitor 2020, unpublished data).

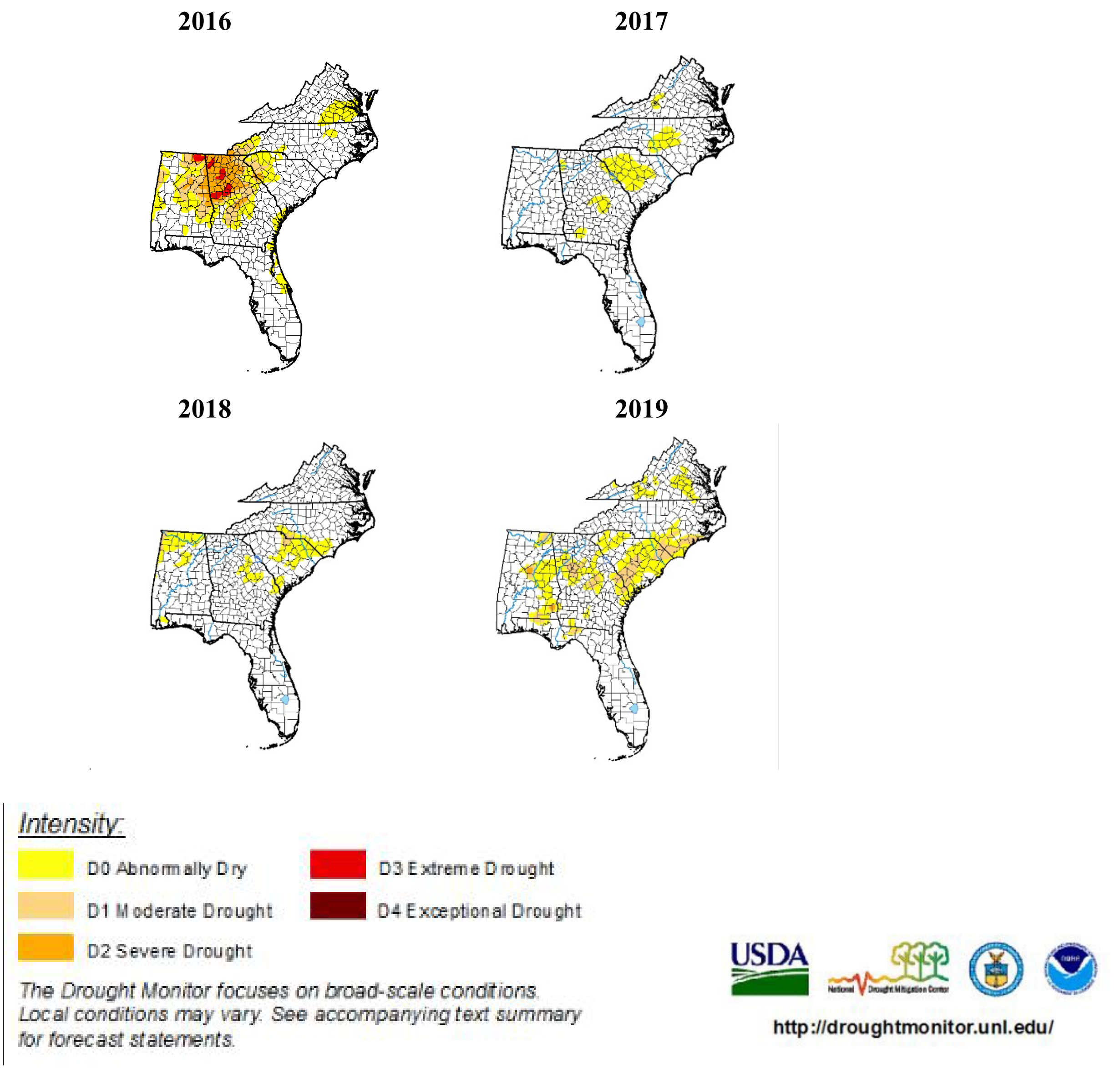

Figure B-3. U.S. Drought Monitor Southeast annual image for 1st week in September from 2016 to 2019 (U.S. Drought Monitor 2020, unpublished data).

Current Condition Weighting and Calculation

The current condition is a qualitative estimate based on the analysis of the three population factors (AU occupancy, approximate abundance, and non-native competition) and four habitat elements (instream habitat, water quality, salinity, water quantity/flow). Overall population condition rankings and habitat condition rankings were determined by combining the three population factors and four habitat factors, respectively. In order to do this, we assigned numbers to each category ranking (High = 3; Moderate = 2; Low = 1; Very Low = 0) and calculated an average condition score for each AU, weighted by the relative importance of the metric, as indicated in Table B-8. Population factors of AU occupancy and approximate abundance were weighted as equally important. For habitat factors, instream habitat/water quality was weighted the highest because this metric represented two of the primary influences on viability, and instream habitat is a critical need for the species that supports breeding, feeding, and sheltering. Water quality/flow was determined to be weighted second in importance because sufficient water flow in perennial streams maintains both habitat and water quality.

Table B-8. Weighting used for each condition metric to calculate overall population condition and habitat condition rankings.

	Condition Metric	Weighting
Population Factors	Analysis Unit Occupancy Decline	3
	Approximate Abundance	3
Habitat Factors	Instream Habitat/Water Quality	3
	Water Quality	1
	Salinity	1
	Water Quantity/Flow	2

The **overall population condition score** was calculated using the following equation:

$$\frac{(3*\text{AU occupancy score}) + (3*\text{Approx. Abundance score})}{\text{Total of all weightings } (3+3)}$$

The **overall habitat condition score** was calculated using the following equation:

$$\frac{(3*\text{Instream Hab/WQ score}) + (1*\text{ WQ score}) + (1*\text{Salinity score}) + (2*\text{Water Quantity score})}{\text{Total of all weightings } (3+1+1+2)}$$

WQ: water quality

Because population factors are direct indicators of Chowanoke crayfish condition, we weighed population factors (direct measures) two times higher than habitat factors (indirect measures) when estimating the summary current condition. However, when the AU occupancy condition was estimated to be ø (i.e., when all HUC10s are not occupied), this presumed or likely extirpated condition superseded all other category rankings and was assigned as the overall population condition and overall condition (note: this occurred for future condition analysis).

The summary **current condition score** was calculated using the following equation:

$$\frac{(2*\text{overall population condition score}) + (1*\text{overall habitat condition score})}{\text{Total of all weightings } (2+1)}$$

The scores were converted to qualitative rankings, as summarized in Table B-3. Scores for populations (e.g., Chowan, Roanoke) were calculated similarly as the condition metrics (i.e., weighted by AU area). Table B-9 provides a summary of the scores and rankings for overall population and habitat condition and current condition.

Table B-9. Overall population condition, habitat condition, and current condition scores and rankings by AU and population.

Population	Analysis Units	Overall Population Condition Score	Overall Population Condition	Overall Habitat Condition Score	Overall Habitat Condition	Current Condition Score	Current Condition
Chowan		2.9	**High**	2.9	**High**	**2.9**	**High**
	Nottoway	3.0	**High**	3.0	**High**	3.0	**High**
	Meherrin	3.0	**High**	3.0	**High**	3.0	**High**
	Blackwater	2.0	**Moderate**	3.0	**High**	2.3	**Moderate**
	Chowan	3.0	**High**	2.4	**Moderate**	2.8	**High**
Roanoke		2.5	**High**	2.9	**High**	**2.6**	**High**
	Middle Roanoke	2.5	**High**	3.0	**High**	2.7	**High**
	Lower Roanoke	2.5	**High**	2.9	**High**	2.6	**High**

APPENDIX C: FUTURE CONDITIONS METHODOLOGY

The Chowanoke crayfish future conditions are based on an evaluation of effects of the three future scenarios (described in Chapter 5) on the six population and habitat factors described in Chapter 4 and Appendix B. Based on the information described below and the condition categories table (Table B-2), the Chowanoke crayfish SSA team assigned condition rankings (i.e., high, moderate, low, very low, ø) to each of the AUs for each of the population and habitat factors and years (2030, 2050, 2070). The same approach used to calculate current condition (e.g., scoring, condition rankings, weighting factors, and equations in Appendix B) was applied to calculate future condition scores.

Basis for Projecting Population Factors

Analysis Unit Occupancy Decline: Population factor remains the same, except a HUC10 watershed within the AU will become unoccupied when salinity conditions become low or very low due to SLR or crayfish condition becomes very low. If all HUC10 watersheds become unoccupied, then the AU overall condition is estimated to be ø or likely extirpated.

Approximate Abundance: Population factor remains the same, except decreases due to overall low habitat quality condition or crayfish condition becomes very low.

Basis for Projecting Habitat Factors

Instream Habitat/Water Quality

To forecast future urbanization in our future scenarios, we used the SLEUTH (Slope, Land use, Excluded area, Urban area, Transportation, Hillside area) model projections for the Southeast (Belyea and Terando 2012, unpublished data; Terando et al. 2014, entire). For each of the future urbanization projections in 2030, 2050, and 2070, Belyea and Terando et al. (2012, unpublished data) provided urbanization probabilities in GIS raster files, similar to Figure C-1. GIS analyses was used to determine moderate percentage increases in urbanization (greater than or equal to 50-percent probability) and maximum percentage increases in urbanization (2.5-percent to 100-percent probabilities) for each of the HUC10 watersheds and active river area (ARA). Because urban growth is an indicator of an increase of development and impervious surfaces, we assumed any percentage increase in urbanization in the HUC10 watersheds was an equivalent percentage increase in impervious surfaces in the HUC10 watershed and ARA. GIS analyses was also used to assess which 2016 NLCD land cover types were affected by the increase in urbanization in the ARA. For each of the year and urbanization scenarios (i.e., moderate, maximum), the increased urbanization affected on average 83 to 100 percent of forest and wetlands land cover. Therefore, we assumed any percentage increase in urbanization in the ARA was an equivalent percentage loss in forest/wetlands land cover in the ARA. Tables C-1 and C-2 provide the average watershed percentage of impervious surfaces and average percentage of forested/wetlands in the ARA by AU.

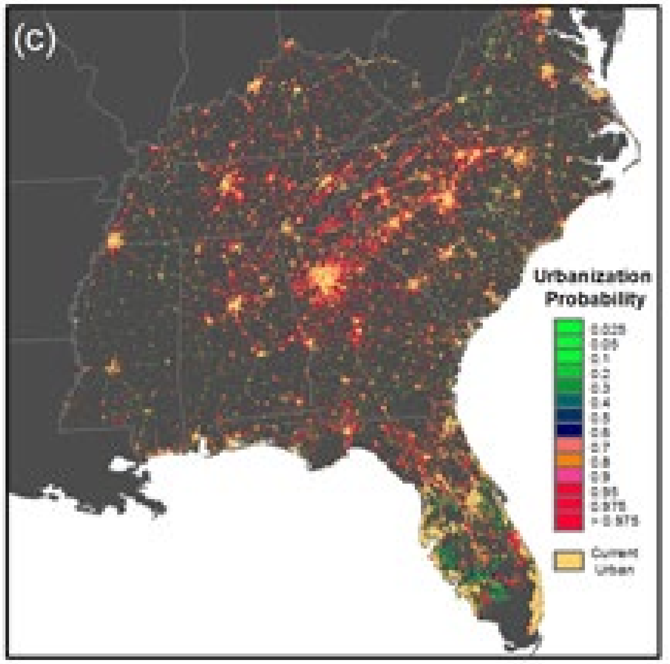

Figure C-1. “Business-as-usual” urbanization scenario for the southeastern United States from Terando et al. (2014, p.3). (c) is the projected urban land cover in 2060, with the probability of urbanization indicated by color based on Monte Carlo simulations.

Effect of Red Swamp Crayfish and Virile Crayfish on Instream Habitat/Water Quality

To project and incorporate the effects of two nonnative crayfish species, red swamp crayfish and virile crayfish, on the instream habitat/water quality metric for Scenario 2, we first developed categories to describe the condition of the species: presence or absence of each nonnative crayfish in the watershed and at the same location as Chowanoke crayfish (Table C-3). To determine current distribution and abundance of each nonnative crayfish, the species’ occurrence data was obtained from multiple sources and converted to multiple shapefiles in Arc GIS Pro (NCWRC 2019b, unpublished data; NCMNS 2011, unpublished data; Service 2020b, unpublished data; Williams and Foltz 2019, unpublished data; VDGIF 2019, unpublished data; Thoma 2019, unpublished data). We assigned category rankings to each of the AUs for the current red swamp or virile crayfish data based on displaying this data in GIS with the Chowanoke crayfish occurrence data, hydrology lines, and watershed boundaries and visually determining the number of sites and red swamp or virile crayfish in the same watershed (HUC10) or location as the Chowanoke crayfish (Tables C-4 and C-5). We then projected the dispersal rates of red swamp crayfish for Scenario 2 based on the effects of climate change (e.g., warming temperature, frequency of flooding and droughts, and sea level rise (SLR)) (Tables C-6 and C-7). We project expansion of virile crayfish for Scenario 2 to be moderate and limited to the Roanoke River basin where it is currently known to occur; we assume that flooding, droughts, and development will have greater influence on its expansion than warming temperatures and sea level rise based on the climate matching analysis conducted by the Service (2015a and 2015b; entire). As described in Section 3.2.2, streams that are most susceptible to virile crayfish are those that are affected by impoundments, degraded by other anthropogenic disturbances, or at lower elevations and have naturally high silt loads (Loughman 2013, pp. 63–66). We anticipate that Middle Roanoke AU will experience greater expansion of virile crayfish because its streams have lower stream order (fourth and fifth order) and the Chowanoke crayfish subpopulation is isolated.

When there is a low red swamp crayfish condition, instream habitat/water quality factor will decrease by one ranking (e.g., from high to moderate or moderate to low); if red swamp crayfish is high or moderate condition, instream habitat/water quality will remain the same. We do not anticipate red swamp crayfish reaching a very low condition because negative impacts from introductions have primarily been observed with other *Procambarus spp*. in the North and South Carolina (Kendrick et al. 2019, p. 1; Service 2019c, p. 1; Kendrick 2021, pers. comm.). For the virile crayfish, a similar approach will be applied. In addition, when there is a very low virile crayfish condition, instream habitat/water quality factor will be reduced by two rankings, one or more HUC10 watersheds within the AU will become unoccupied, and approximate abundance will decrease by one ranking. We assume that virile crayfish will affect Chowanoke crayfish's population factors when there is a very low virile crayfish condition and reduced habitat conditions, because of virile crayfish's effect on available habitat for refugia and food, as observed for other *Faxonius* spp., thereby competing for available resources with the Chowanoke crayfish (Loughman 2010, p. 52). If all the HUC10 watersheds within the AU become unoccupied, then the population and overall condition is likely extirpated.

Salinity

Sea level rise was projected for the Chowan and Roanoke River basins based on the Global Mean Sea Level rise scenarios (Low Intermediate, Intermediate, High Intermediate, High, and Extreme) that were modeled locally at Duck, North Carolina for 2030, 2050, and 2070 (Sweet et al. 2017, entire; NOAA 2020a, b, and c, unpublished data).

Using GIS, the following datasets were combined into a seamless digital elevation model (DEM) data set: the 2014 North Carolina Department of Public Safety LiDAR data Collection DEMs for 7 counties (Bertie, Chowan, Gates, Hertford, Martin, Northampton, and Washington) (North Carolina Department of Public Safety 2016, unpublished data); the 2016 USGS CoNED Topobathymetric Model (1859-2015) for Chesapeake Bay elevation data for the Virginia portion of the Chowan River basin (NOAA 2016, unpublished data). The DEM data is in NVD88 (National Vertical Datum 1988), while the modeled sea level rise heights at Duck, NC are in Mean High High Water (MHHW). To put them in the same datum of MHHW, a NOAA MHHW adjustment raster layer was subtracted from the DEM data (NOAA 2019, unpublished data). The Low Intermediate, Intermediate, High Intermediate, High, and Extreme sea level for 2030, 2050, and 2070 for the Duck, NC local sea level rise were obtained (NOAA 2020a, b, and c, unpublished data). Due to a difference in isostatic subsidence between the Roanoke River and Chowan River valleys and the tidal gage at Duck, NC, 1 millimeter/year was subtracted from the sea level rise estimates (North Carolina Coastal Resources Commission Science Panel 2015, pp. 15-18). Using GIS analyses of the adjusted DEM and MHHW raster data projections from Duck, NC, GIS raster files and maps were generated of areas in the Chowan and Roanoke River basins that would be progressively inundated by the Low Intermediate, Intermediate, High Intermediate, High, and Extreme sea level for 2030, 2050, and 2070 (see Figures 5-1 and 5-2 in Chapter 5). These maps and information about current salinity conditions in the Chowan and Roanoke Rivers were then used to project potential future salinity conditions.

Water Quantity/Flow

Water quantity/flow decreases due to effects of climate change (e.g., warming temperature, frequency of flooding and droughts, and SLR). To assist in projecting the changes in water quantity and flow, monthly mean model results for air temperature, precipitation, runoff, soil water storage, and evaporative deficit were obtained for RCP4.5 and 8.5 scenarios from the six AUs or HUC8 subbasins (USGS 2016, unpublished data). To capture the season when temperature would likely be the highest and during the low flow time of year (i.e., generally early September), summer mean values for 2020, 2030, 2050, and 2070 were calculated based on July, August, and September values (Table C-8). Because we did have information to support when drought or low flow conditions may occur based on these parameters, these data were qualitatively assessed with the regional information about the effects of climate change.

Table C-1. Current and future watershed average % impervious by AU in 2030, 2050, and 2070 for moderate and maximum urbanization growth.

				Average % Impervious Surfaces under Moderate Urbanization Growth			Average % Impervious Surfaces under Maximum Urbanization Growth		
Population	Analysis Unit (AU)	AU area (km^2)	Current Watershed Average % Impervious Surfaces	2030	2050	2070	2030	2050	2070
Chowan		8,625							
	Nottoway	3,567	0.6	2.2	4.2	6.4	3.5	6.1	8.7
	Meherrin	2,558	0.6	1.4	2.4	3.6	2.5	4.1	5.9
	Blackwater	485	0.4	0.8	1.3	1.9	1.1	1.8	2.7
	Chowan	2,015	0.5	1.1	1.6	2.3	1.7	2.7	3.8
Roanoke		2,980							
	Middle Roanoke	413	0.3	1.0	2.0	3.3	1.6	3.1	5.0
	Lower Roanoke	2,567	1.1	1.6	2.5	3.2	3.0	4.1	5.2

Table C-2. Current and future average % forested/wetlands in ARA by AU in 2030, 2050, and 2070 for moderate and maximum urbanization growth.

				Average % Forested/Wetlands in ARA under Moderate Urbanization Growth			Average % Forested/Wetlands in ARA under Maximum Urbanization Growth		
Population	Analysis Unit (AU)	Area of ARA Within AU (km^2)	Current Average % Forested/ Wetlands in ARA	2030	2050	2070	2030	2050	2070
Chowan		2,699							
	Nottoway	1,028	84	83	82	80	82	80	78
	Meherrin	770	82	82	81	81	81	80	79
	Blackwater	122	82	82	82	81	82	81	80
	Chowan	779	69	68	68	68	68	67	67
Roanoke		1,350							
	Middle Roanoke	120	74	74	73	72	73	72	71
	Lower Roanoke	1,229	78	77	77	76	76	76	75

Table C-3. Nonnative crayfish (red swamp or virile crayfish) condition categories

Condition Category	Nonnative Crayfish Condition
High	Nonnative crayfish not reported; or low levels of nonnative crayfish observed in watershed
Moderate	Low to moderate level of nonnative crayfish observed in the same location of Chowanoke crayfish; or moderate/high level of nonnative crayfish observed in the watershed
Low	High level of nonnative crayfish observed in the same location of Chowanoke crayfish
Very Low	Nonnative crayfish present at 1 or more site(s) within a population where the Chowanoke crayfish are now absent

Table C-4. Red swamp crayfish data and current condition by AU and population.

Population	Analysis Unit	Number of Sites Red Swamp Crayfish (RSC) Observed in Watershed	Number of Sites RSC Observed at Same Location	Total Number of RSC Observed in Watershed	Total Number of RSC Observed in Same Location	Red Swamp Crayfish Condition
Chowan						**High**
	Nottoway	0	0	0	0	High
	Meherrin	3	2	39	31	Moderate
	Blackwater	0	0	0	0	High
	Chowan	2	0	9	0	High
Roanoke						**Moderate**
	Middle Roanoke	0	0	0	0	High
	Lower Roanoke	10	0	105 (67)[1]	0	Moderate

[1]At three sites where RSC were observed in the watershed, RRNWR conducted repeated surveys from April and October 2013; for the other five sites, NCWRC surveyed them once. Sixty-seven is the total if we used the maximum collected in a single month by RRNWR in 2013. One hundred and five is the total if we added all the months during the repeated RRNWR surveys in 2013.

Table C-5. Virile crayfish data and current condition by AU and population.

Population	Analysis Unit	Number of Sites Virile Crayfish (VC) Observed in Watershed	Number of Sites VC Observed at Same Location	Total Number of VC Observed in Watershed	Total Number of VC Observed in Same Location	Virile Crayfish Condition
Chowan						**High**
	Nottoway	0	0	0	0	High
	Meherrin	0	0	0	0	High
	Blackwater	0	0	0	0	High
	Chowan	0	0	0	0	High
Roanoke						High
	Middle Roanoke	2	1	6	5	**Moderate**
	Lower Roanoke	1	0	1	0	High

Table C-6. Red swamp crayfish condition for Scenario 2.

Population	Analysis Units	Current	2030	2050	2070
Chowan		High	High	Moderate	Low
	Nottoway	High	High	Moderate	Low
	Meherrin	Moderate	Moderate	Low	Low
	Blackwater	High	High	Moderate	Low
	Chowan	High	High	Moderate	Low
Roanoke		Moderate	Moderate	Low	Low
	Middle Roanoke	High	High	Moderate	Low
	Lower Roanoke	Moderate	Moderate	Low	Low

Table C-7. Virile crayfish condition for Scenario 2.

Population	Analysis Units	Current	2030	2050	2070
Chowan		High	High	High	High
	Nottoway	High	High	High	High
	Meherrin	High	High	High	High
	Blackwater	High	High	High	High
	Chowan	High	High	High	High
Roanoke		High	High	Moderate	Moderate
	Middle Roanoke	Moderate	Moderate	Low	**Very Low**
	Lower Roanoke	High	High	Moderate	Moderate

Table C-8. Summer mean values for maximum and minimum air temperature from 2 meters above the surface, precipitation, runoff, soil water storage, and evaporative deficit (USGS 2016, unpublished data).

		RCP4.5				RCP8.5			
HUC8 subbasin	**Metric (Summer Mean)**	**2020**	**2030**	**2050**	**2070**	**2020**	**2030**	**2050**	**2070**
Nottoway	Max 2-m Air Temp (F)	88.6	89.2	90.7	91.6	88.8	89.3	91.6	94.4
	Min 2-m Air Temp (F)	65.3	66.0	67.4	68.6	65.5	66.3	68.5	70.9
	Precip (in/mo)	5.0	5.0	4.6	5.0	4.4	4.7	4.5	4.7
	Runoff (in/mo)	0.5	0.5	0.4	0.4	0.5	0.4	0.4	0.4
	Soil Water Storage (in)	1.5	1.6	1.2	1.4	1.4	1.7	1.3	1.2
	Evap Deficit (in/mo)	1.0	1.0	1.2	1.3	1.2	1.0	1.5	1.6
Meherrin	Max 2-m Air Temp (F)	88.6	89.2	90.8	91.7	88.8	89.3	91.5	94.4
	Min 2-m Air Temp (F)	65.6	66.3	67.7	68.9	65.7	66.5	68.7	71.2
	Precip (in/mo)	5.0	5.0	4.6	5.0	4.4	4.8	4.5	4.7
	Runoff (in/mo)	0.5	0.5	0.4	0.4	0.5	0.4	0.4	0.4
	Soil Water Storage (in)	1.5	1.6	1.1	1.3	1.3	1.6	1.3	1.2
	Evap Deficit (in/mo)	1.0	1.0	1.2	1.3	1.3	1.0	1.5	1.5
Blackwater	Max 2-m Air Temp (F)	88.4	88.9	90.5	91.3	88.6	89.2	91.3	94.1
	Min 2-m Air Temp (F)	66.7	67.3	68.7	69.9	66.8	67.6	69.7	72.1
	Precip (in/mo)	5.4	5.3	4.9	5.3	4.7	5.2	4.8	4.9
	Runoff (in/mo)	0.5	0.5	0.4	0.5	0.5	0.5	0.4	0.4
	Soil Water Storage (in)	1.5	1.6	1.2	1.3	1.4	1.7	1.2	1.2
	Evap Deficit (in/mo)	0.9	0.9	1.1	1.2	1.1	0.9	1.4	1.5
Chowan	Max 2-m Air Temp (F)	88.3	88.7	90.2	91.1	88.3	89.0	91.0	93.5
	Min 2-m Air Temp (F)	67.4	68.0	69.3	70.5	67.5	68.3	70.3	72.6
	Precip (in/mo)	5.7	5.5	5.2	5.5	4.9	5.5	5.1	5.1
	Runoff (in/mo)	0.6	0.6	0.5	0.5	0.5	0.6	0.5	0.5
	Soil Water Storage (in)	1.9	2.0	1.5	1.6	1.7	2.2	1.6	1.5
	Evap Deficit (in/mo)	0.7	0.7	0.9	1.0	1.0	0.7	1.2	1.3
Middle Roanoke	Max 2-m Air Temp (F)	87.8	88.5	90.1	90.9	88.1	88.6	90.9	94.0
	Min 2-m Air Temp (F)	64.7	65.5	67.0	68.2	64.9	65.7	68.0	70.6
	Precip (in/mo)	4.4	4.5	4.2	4.4	4.0	4.1	4.0	4.2
	Runoff (in/mo)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	Soil Water Storage (in)	1.5	1.7	1.3	1.3	1.4	1.4	1.3	1.2
	Evap Deficit (in/mo)	1.1	1.2	1.4	1.4	1.4	1.2	1.7	1.7
Lower Roanoke	Max 2-m Air Temp (F)	89.1	89.5	91.1	91.9	89.2	89.7	91.8	94.3
	Min 2-m Air Temp (F)	67.4	67.9	69.3	70.5	67.4	68.2	70.2	72.5
	Precip (in/mo)	5.8	5.6	5.3	5.6	5.0	5.6	5.2	5.3
	Runoff (in/mo)	0.7	0.6	0.5	0.5	0.5	0.5	0.5	0.5
	Soil Water Storage (in)	2.3	2.3	1.8	1.9	2.0	2.5	1.9	1.9
	Evap Deficit (in/mo)	0.7	0.7	0.9	1.0	1.0	0.7	1.1	1.2

APPENDIX D: FUTURE CONDITION TABLES FOR CHOWANOKE CRAYFISH POPULATIONS

Scenario 1: 2030		Population Factors			Habitat Factors					
Population	**Analysis Unit**	**Analysis Unit Occupancy Decline**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**
	Nottoway	High	High	High	High	High	High	High	High	High
	Meherrin	High	High	High	High	High	High	High	High	High
	Blackwater	High	Low	Moderate	High	High	High	High	High	Moderate
	Chowan	High	High	High	Moderate	High	Moderate	High	Moderate	High
Roanoke		**High**	**Moderate**	**High**	**High**	**High**	**Moderate**	**High**	**High**	**High**
	Middle Roanoke	High	Moderate	High	High	High	High	High	High	High
	Lower Roanoke	High	Moderate	High	High	High	Moderate	High	High	High

Scenario 1: 2050		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy Decline**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**Moderate**	**High**	**High**	**High**
	Nottoway	High	High	High	High	High	Moderate	High	High	High
	Meherrin	High	High	High	High	High	Moderate	High	High	High
	Blackwater	High	Low	Moderate	High	High	High	High	High	Moderate
	Chowan	High	High	High	Moderate	High	Moderate	High	Moderate	High
Roanoke		**High**	**Moderate**	**High**	**High**	**High**	**Moderate**	**High**	**High**	**High**
	Middle Roanoke	High	Moderate	High	High	High	High	High	High	High
	Lower Roanoke	High	Moderate	High	High	High	Moderate	High	High	High

Scenario 1: 2070		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**Moderate**	**Moderate**	**Moderate**	**High**
	Nottoway	High	High	High	High	Moderate	Moderate	Moderate	Moderate	High
	Meherrin	High	High	High	High	High	Moderate	Moderate	High	High
	Blackwater	High	Low	Moderate	High	High	High	Moderate	High	Moderate
	Chowan	Moderate	High	High	Moderate	High	Low	Moderate	Moderate	Moderate
Roanoke		**Moderate**	**Moderate**	**Moderate**	**High**	**High**	**Low**	**Moderate**	**High**	**Moderate**
	Middle Roanoke	High	Moderate	High	High	High	High	Moderate	High	High
	Lower Roanoke	Moderate	Moderate	Moderate	High	High	Low	Moderate	Moderate	Moderate

Scenario 2: 2030		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**
	Nottoway	High	High	High	High	High	High	High	High	High
	Meherrin	High	High	High	High	High	High	High	High	High
	Blackwater	High	Low	Moderate	High	High	High	High	High	Moderate
	Chowan	High	High	High	Moderate	High	Moderate	High	Moderate	High
Roanoke		**High**	**Moderate**	**High**	**High**	**High**	**Moderate**	**High**	**High**	**High**
	Middle Roanoke	High	Moderate	High	High	High	High	High	High	High
	Lower Roanoke	High	Moderate	High	High	High	Moderate	High	High	High

Scenario 2: 2050		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**Moderate**	**Moderate**	**Moderate**	**High**
	Nottoway	High	High	High	High	Moderate	Moderate	Moderate	Moderate	High
	Meherrin	High	High	High	Moderate	High	Moderate	Moderate	Moderate	High
	Blackwater	High	Low	Moderate	High	High	High	Moderate	High	Moderate
	Chowan	High	High	High	Moderate	High	Moderate	Moderate	Moderate	High
Roanoke		**High**	**Moderate**	**High**	**Moderate**	**High**	**Moderate**	**Moderate**	**Moderate**	**Moderate**
	Middle Roanoke	High	Moderate	High	Moderate	High	High	Moderate	Moderate	Moderate
	Lower Roanoke	High	Moderate	High	Moderate	High	Moderate	Moderate	Moderate	Moderate

Scenario 2: 2070		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**Moderate**	**High**	**Moderate**	**Low**	**Moderate**	**Moderate**
	Nottoway	High	High	High	Moderate	Moderate	Moderate	Low	Moderate	High
	Meherrin	High	High	High	Moderate	High	Moderate	Low	Moderate	High
	Blackwater	High	Low	Moderate	Moderate	High	High	Low	Moderate	Moderate
	Chowan	Moderate	Moderate	Moderate	Low	High	Low	Low	Low	Moderate
Roanoke		**Moderate**	**Moderate**	**Moderate**	**Moderate**	**High**	**Low**	**Low**	**Moderate**	**Moderate**
	Middle Roanoke	ø	ø	ø	Very Low	High	High	Low	Low	ø
	Lower Roanoke	Moderate	Moderate	Moderate	Moderate	High	Low	Low	Moderate	Moderate

Scenario 3: 2030		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**
	Nottoway	High	High	High	High	High	High	High	High	High
	Meherrin	High	High	High	High	High	High	High	High	High
	Blackwater	High	Low	Moderate	High	High	High	High	High	Moderate
	Chowan	High	High	High	Moderate	High	Moderate	High	Moderate	High
Roanoke		**High**	**Moderate**	**High**	**High**	**High**	**Moderate**	**High**	**High**	**High**
	Middle Roanoke	High	Moderate	High	High	High	High	High	High	High
	Lower Roanoke	High	Moderate	High	High	High	Moderate	High	High	High

Scenario 3: 2050		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**
	Nottoway	High	High	High	High	High	High	High	High	High
	Meherrin	High	High	High	High	High	High	High	High	High
	Blackwater	High	Low	Moderate	High	High	High	High	High	Moderate
	Chowan	High	High	High	Moderate	High	Moderate	High	Moderate	High
Roanoke		**High**	**Moderate**	**High**	**High**	**High**	**Moderate**	**High**	**High**	**High**
	Middle Roanoke	High	Moderate	High	High	High	High	High	High	High
	Lower Roanoke	High	Moderate	High	High	High	Moderate	High	High	High

Scenario 3: 2070		Population Factors			Habitat Factors					
Population	**Analysis Units**	**Analysis Unit Occupancy**	**Approximate Abundance**	**Overall Population Condition**	**Instream Habitat/ Water Quality**	**Water Quality**	**Salinity**	**Water Quantity**	**Overall Habitat Condition**	**Overall Condition**
Chowan		**High**	**High**	**High**	**High**	**High**	**Moderate**	**Moderate**	**Moderate**	**High**
	Nottoway	High	High	High	High	Moderate	Moderate	Moderate	Moderate	High
	Meherrin	High	High	High	High	High	Moderate	Moderate	High	High
	Blackwater	High	Low	Moderate	High	High	High	Moderate	High	Moderate
	Chowan	High	High	High	Moderate	High	Moderate	Moderate	Moderate	High
Roanoke		**High**	**Moderate**	**High**	**High**	**High**	**Moderate**	**Moderate**	**High**	**High**
	Middle Roanoke	High	Moderate	High	High	High	High	Moderate	High	High
	Lower Roanoke	High	Moderate	High	High	High	Moderate	Moderate	High	High