Species Status Assessment Report

for the

Magnificent Ramshorn
(*Planorbella magnifica*)

Version 1.0

Photo credit: Andy Wood

August 2019

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

This document was prepared by Sarah McRae (USFWS-Raleigh Field Office) with assistance from Nicole Rankin (USFWS-Region 4) and the Magnificent Ramshorn SSA Technical Advisory Team (Arthur Bogan – NC Museum of Natural Sciences, Chris Eads – NC State University, Brena Jones – NC Wildlife Resources Commission, Ivanna Knox – NC Wildlife Resources Commission, Andy Wood – Coastal Plain Conservation Group, and Carson Wood – Coastal Plain Conservation Group). Sea level change maps were created by Doug Newcomb (USFWS–Raleigh Field Office).

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Species Status Assessment Report for the Magnificent Ramshorn (*Planorbella magnifica*) Prepared by the U.S. Fish and Wildlife Service

EXECUTIVE SUMMARY

This species status assessment is a comprehensive biological status review by the U.S. Fish and Wildlife Service (USFWS) for Magnificent Ramshorn (*Planorbella magnifica*), and provides an account of the species' overall viability and extinction risk. Magnificent Ramshorn is an air-breathing snail, approximately 1.5 inches in diameter, historically found in lentic systems in southeastern North Carolina. It was last documented in the wild in 2004.

Based on the results of repeated surveys from the 1980s to 2010s by qualified species experts, there appear to be no extant populations of Magnificent Ramshorn in the wild. Failure to detect the species in surveys to date in the species' historical habitat and suitable habitat in surrounding areas indicates that the species is extirpated in the wild. Captive populations are being held at three separate locations in North Carolina.

We used the best available information to describe the species' viability. We assessed the overall species status including the species' needs, current condition, and future condition with respect to the three factors of viability (see Table ES-1). The three factors of viability – resiliency, redundancy, and representation – are currently absent, which leads us to conclude that the Magnificent Ramshorn has no viability in the wild and is presumed extirpated in the wild.

Table ES-1. Species Status Assessment Summary for Magnificent Ramshorn

3Rs	Needs	Current Condition	Future Condition (Viability)
Resiliency (large populations able to withstand stochastic events)	• Lentic flow • Emergent vegetation • No salinity • Circumneutral pH	No known wild populations	No resiliency
Redundancy (number and distribution of populations to withstand catastrophic events)	Multiple populations throughout the range of the species	No known wild populations	No redundancy
Representation (genetic and ecologial diversity to maintain adaptive potential)	Genetic variation between populations	No known wild populations	No representation

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CHAPTER ONE – INTRODUCTION

1.1 Background

The Magnificent Ramshorn is a species of air-breathing snail endemic to southeastern North Carolina. Historically, it was documented from only four sites in the lower Cape Fear River Basin in North Carolina: 1) Greenfield Lake, a millpond located on a tributary to the Cape Fear River within the present city limits of Wilmington, New Hanover County, 2) Orton Pond (aka Sprunt's Pond), a millpond located on Orton Creek in Brunswick County, 3) Sand Hill Creek Pond (aka Pleasant Oaks Pond or Big Pond), a millpond on Sand Hill Creek in Brunswick County, and 4) McKinzie Pond, a millpond on McKinzie Creek, in Brunswick County (see Figure 3-1). Species-specific surveys of more than 100 potential sites (including most historical locations) over the last few decades have not documented any Magnificent Ramshorn snails, and the species is currently believed to be extirpated in the wild.

The Magnificent Ramshorn had previously been considered for listing under the Endangered Species Act of 1973, as amended (Act), and was assigned status as a category 2 candidate species in 1989. Category 2 was used to describe taxa for which there was some evidence of vulnerability, but for which there were not enough data to support listing. This system of categories was discontinued in 1996 (December 5, 1996; 61 FR 64481) in favor of maintaining a list that only represented those species for which we have on file sufficient information on biological vulnerability and threats to support a proposal to list as endangered or threatened, but for which preparation and publication of a proposal is precluded by higher priority listing actions. On April 20, 2010, Center for Biological Diversity (CBD) and others petitioned the USFWS to list the Magnificent Ramshorn as endangered or threatened under the Act as part of the megapetition to list 404 species in the southeastern United States (CBD 2010, p.852). On June 20, 2011, the USFWS published the annual Candidate Notice of Review and announced the Magnificent Ramshorn as a new candidate species with a Listing Priority Number of 2, indicating that the full species was imminently threatened by a high magnitude of threats. On September 27, 2011, the USFWS published a substantial 90-day finding for 374 species, including the Magnificent Ramshorn. On January 15, 2019, the USFWS received a notice of intent to sue from CBD because of lack of expeditious progress. The USFWS has agreed to submit the 12-month finding to the Federal Register in FY2020.

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

1.2 Analytical Framework

Because the Magnificent Ramshorn SSA has been prepared at the Candidate Assessment phase, it is intended to provide the biological support for the decision on whether to propose to list the species as threatened or endangered and, if so, to determine whether it is prudent to designate critical habitat in certain areas. Importantly, the SSA Report is not a decisional document by the U.S. Fish and Wildlife Service, rather it provides a review of available information strictly related to the biological status of the Magnificent Ramshorn. The listing decision will be made by the USFWS after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the *Federal Register,* with appropriate opportunities for public input.

For the purpose of this assessment, we define viability as the ability of the species to sustain resilient populations in natural pond ecosystems for at least three generations, or approximately 10 years. Using the SSA framework (Figure 1.1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its redundancy, representation, and resiliency (USFWS 2016a, entire; Wolf et al. 2015, entire).

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

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

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

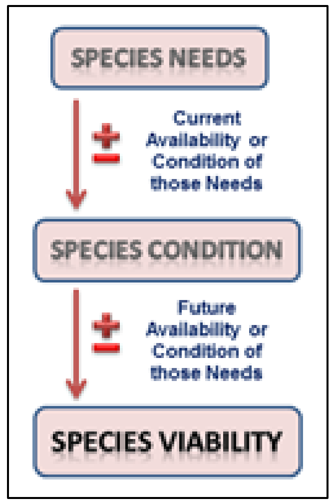


Figure 1-1 Species Status Assessment Framework

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

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

CHAPTER 2 – BIOLOGY AND LIFE HISTORY

In this section, we provide basic biological information about the Magnificent Ramshorn, including its physical environment, taxonomic history and relationships, morphological description, and reproductive and other life history traits. We then outline the resource needs of individuals and populations.

2.1 Taxonomy

The Magnificent Ramshorn was described by Pilsbry (1903) from the lower Cape Fear River region of North Carolina. The type locality was given as “Lower Cape Fear River in the vicinity of Wilmington, North Carolina” by H.A. Pilsbry in 1903 (Adams 1993, p.3). Pilsbry (1903) placed it in the genus *Planorbis* Muller 1774. Baker (1945) reassigned the species to the genus *Helisoma* Swainson 1840. He recognized two subgenera under *Helisoma* – *Pierosoma* Dall 1905 and *Planorbella* Haldeman 1842 – and placed the Magnificent Ramshorn under *Pierosoma*. Taylor (1966) subsequently elevated *Planorbella* to full genus rank and placed the subgenus *Pierosoma* within it. The species’ reproductive system (figured by Baker 1945: pl. 31, fig. 20), shell characters, and DNA sequence data all support *Planorbella magnifica* as a valid species (Baker 1945; Bogan et al. 2003, pp. 5 and 6). The USFWS has reviewed the available taxonomic literature, and is not aware of any challenges to the validity of this species.

Figure 2-1 Magnificent Ramshorn (credit: I.Knox, NC Wildlife Resources Commission)

The currently accepted classification is (Integrated Taxonomic Information System 2019):

Phylum: Mollusca
Class: Gastropoda
Order: Basommatophora
Family: Planorbidae
Genus: *Planorbella*
Species: *Planorbella magnifica*

2.2 Species Description

As adapted from Adams 1990a and 1993, and references therein: The Magnificent Ramshorn is a freshwater snail in the family Planorbidae (Pilsbry 1903), a family of air-breathing snails. It is the largest North American snail in this family. It has a discoidal (i.e., coiling in one plane), relatively thin shell that reaches a diameter commonly exceeding 35 millimeters (mm) (1.38 inches) and heights exceeding 20 mm (0.79 inch) (Figures 2-1, 2-2). The great width of its shell, in relation to the diameter, makes it easily identifiable at all ages. The shell is tan/brown colored and is thin and fragile. The body underneath the thin shell is a dark, maroon color and has leopard-like spots (I,Knox, pers. comm., email to S.McRae, 8/23/2019;

Figure 2-2 Magnificent Ramshorn shell is about the size of a quarter coin (credit: C.Eads)

Figure 2-1). The center of the shell is deeply sunken on each side, with coils having steep slopes which form acute to sub-acute angles on the outside edges of the coils. The aperture of the shell is somewhat bell-shaped and very wide, extending beyond the sides of the shell.

2.3 Life History

Like other species in the family Planorbidae, the Magnificent Ramshorn has the ability to breathe air. Rather than having gills, the mantle cavity walls are heavily vascularized and form a lung sac (adapted from Baker 1945, p. 17). This gives the snails the ability to draw oxygen out of the air, as well as breathe under water. However, the length of time the species can live out of water is unknown and likely depends on several factors such as air humidity levels and air temperature. While juvenile Magnificent Ramshorns have eyes, the eyes gradually disappear as the snails grow and adults of the species are blind (Dall 1907, p. 90; Bartsch 1908, p. 698; Adams 1993, P. 18). Dall (1907, p. 90) reported that the life span of the Magnificent Ramshorn is likely about 2 years; Adams (1993, p. 18) reported that a study of growth rest lines on the shells of available specimens support a 2-3 year lifespan (the species' metabolism and growth slow down during the winter months, leaving growth rings similar to growth rings on trees).

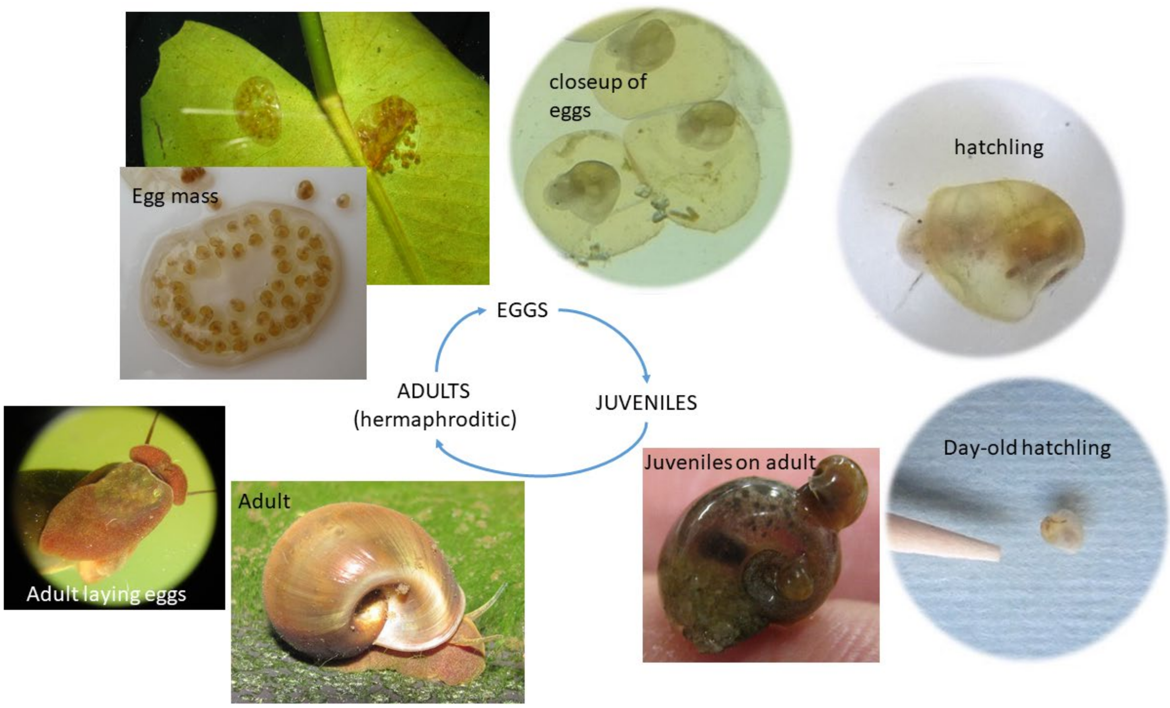


Figure 2-3 Magnificent Ramshorn Life Cycle (photos: A.Wood and C.Eads)

2.4 Reproduction

Members of the Planorbidae family are hermaphroditic (individuals have both male and female reproductive organs) (Figure 2-3; Baker 1945, p. 4). However, it is currently unknown whether they self–fertilize their eggs, mate with other individuals of the species, or both. Wood (2004, p. 12) reported that, while he has not precisely documented mating, he has observed pairs bonded to one another for more than 15 minutes. It is believed that in the wild the species reaches sexual maturity at two years of age; however, Wood (2004, p. 2) reported that in captivity, possibly due to a supplemental diet, the species can reach sexual maturity during the first year of age. The

Magnificent Ramshorn lays fertilized eggs on the undersides of leaves of aquatic vegetation. In captivity the species has also been reported to lay eggs on any smooth, submerged material, including the sides of containers in which they are held (Wood 2004, p. 12; Eads and Levine 2014, p.5). Adams (1993, p.17), Wood (2004, p 12; 2010 p. 4), and Levine and Eads (2014, p.4), and I.Knox (pers. comm., email to S.McRae, 8/23/2019) reported egg laying is likely triggered by water temperature and lengthening daylight hours and typically begins in April, with maximum egg production occurring during June and July, and likely extends as late as October. It is currently unknown how many egg masses can be produced by an individual snail. Typically egg masses contain 20 to 30 eggs and, depending on water temperature, eggs hatch within 16 to 25 days (Wood 2010, p. 4; Eads and Levine 2014, p.4), although in 2011 some egg masses hatched within 14 days (Wood pers. comm 2012). Empty egg masses with no embryos were noted during the first week of April with viable egg masses appearing the second week in April (I.Knox, pers. comm., email to S.McRae, 8/23/2019).

Figure 2-4 Three juvenile Magnificent Ramshorns of different ages (credit: C.Eads)

2.5 Diet

Like other members of the Planorbidae family, the Magnificent Ramshorn is believed to be primarily herbivorous, feeding on submerged aquatic plants, algae, and detritus (decomposing plant material) (Baker 1945, p. 19; Wood 2004, p. 13). Wood (2004, p. 13) observed that the Magnificent Ramshorn showed a preference for spatterdock, especially the ripe seed head of the plant, and the biofilm on decaying spatterdock (A.Wood, personal communication to G. Ahearn, August 2, 2018). However, in captivity, the species has also been reported to feed on Carolina fanwort (*Cabomba caroliniana*) (D. DuMond pers. comm. to Adams 1993), algae, detritus, lettuce, and commercial foods containing algae meal and spirulina (Wood 2004, pp. 1, 7 and 13).

2.6 Age, Growth, Population Size Structure, and Fecundity

Most of the information known about the demographics of the Magnificent Ramshorn have been gathered through studies of captive populations. Life history information is summarized below (Table 2-1). Recent observations indicate that growth lines are distinct when there is a calcium deficiency, and less so when given enough calcium (I.Knox, pers.comm., email to S.McRae, 8/23/2019).

Table 2-1. Magnificent Ramshorn Life History Traits

Attribute	Description	Citation
Clutch Sizes	3-30 in captivity 20-30 in captivity 23.2 ± 9.3 (Range: 4-44 eggs) 15-43, average of 30 in captivity Average of 25	C. Eads, personal communication, 6/1/2018 (Wood, 2010) C.Eads, personal communication, email to S.McRae, 8/6/2019 (Wood, 2004) I.Knox, personal communication, email to S.McRae, 8/23/2019
Maximum rate of clutch laying	1 clutch every 3-4 days 5 clutches within two weeks, could be affected by egg density 1 clutch every two days in April then begins to slow as season progresses	A. Wood, personal communication, 8/2/2018 C. Eads, personal communication, 6/28/2018 A. Wood, personal communication, 8/2/2018 I.Knox, personal communication, email to S.McRae, 8/23/2019
Time to Hatching	Hotter temperature = shorter incubation time 100% by 14 days in captivity 16-25 days in captivity depending on water temperature 13-14 days at 82° F in captivity 12-16 days	A. Wood, personal communication, 8/2/2018 (Wood, 2004, Pg. 1) (Wood, 2004, Pg. 10) (Adams, 1993) I.Knox, personal communication, email to S.McRae, 8/23/2019
Size at Hatching	Averaged 1.0-1.5 mm diameter 1.0 mm across aperture Approximately 1.5 mm diameter	(Wood, 2010, Pg. 4) (Wood, 2004, Pg. 10) (Adams, 1993)

	<1.0mm	I.Knox, personal communication, email to S.McRae, 8/23/2019
Survival at Hatching	Nearly 100% hatching success in captivity All hatch but some will die within first week	A. Wood, personal communication, 8/2/2018 C. Eads, personal communication, 6/1/2018 (Wood, 2004) I.Knox, personal communication, email to S.McRae, 8/23/2019
Growth Rates	1 mm per day for first 5-7 days 0.55 mm per day 15 days after hatching, slows at 10mm, with 100 days having size of 15.2mm (likely from low temperatures) 3-5mm in first week; gradually slows to ~1mm every week until 10mm diameter, then slows to 1mm every 2-3 weeks until about 15mm diameter, then slows to 1mm a month at >15mm	(Wood, 2010) (Adams, 1993) I.Knox, personal communication, email to S.McRae, 8/23/2019
Survival of Juveniles	~10% survival before 1 cm diameter, most die within first week in captivity Low survival in captivity Low survival (<20%) before reaching 1 cm in captivity (absence of predators), unknown causes in captivity ~25% juvenile survival in captivity	A. Wood, personal communication, 8/2/2018 C. Eads, personal communication, June 1st, 2018. (Wood, 2010, Pg. 4) (Bartsch, 1908, Pg. 698) (Adams, 1993, Pg. 18) I.Knox, personal communication, email to S.McRae, 8/23/2019
Time of Sexual Maturity	Within a year and as early as 4 months indoors in captivity at 75-80 F, typically after 1 year outdoors in captivity	(Wood, 2004)
Size at Sexual Maturity	1-1.5 cm diameter at one year of age 18mm diameter	(Wood, 2004, Pg. 11) I.Knox, personal communication, email to S.McRae, 8/23/2019

Survival at Sexual Maturity	50-80% survival after reaching 1 cm diameter in captivity 50% based off estimates of numbers at each life stage made in captivity	A. Wood, personal communication, 8/2/2018 (Adams, 1993)
Adult Size	2 cm across aperture, largest observed was 2.23 cm aperture 35mm (1.38 inch)	(Wood, 2004, Pg. 11) (Adams, 1993)
Longevity	About 2-3 years	(Adams, 1993)
Breeding Season	Warmer months of April-September (above 60° F), although seen earlier (March)/later (October)	(Wood, 2010) (Wood, 2004)
Number of Breeding Seasons	Only experience 1 season egg laying during lifetime	A. Wood, personal communication, 8/2/2018
Most Active Hours	Nighttime Activity increases when lights turn on in the morning, then slows midday, and increases in mid-afternoon in captivity	(Wood, 2004, Pg. 10) I.Knox, personal communication, email to S.McRae, 8/23/2019
Population Density (historical)	Estimated 1 per 100 square feet or 400-500 adults per acre, so about 240,000-300,000 adults in Orton Pond (600 acres); 32,000-40,000 adults in Sand Hill Creek Pond (80 acres); 80,000-100,000 adults in Greenfield Lake (200 acres); double if including juveniles	(Adams, 1993)

2.7 Habitat

Although the Magnificent Ramshorn is considered a large snail, its shell is thin and fragile indicating that it is adapted to lentic (still or slow flowing) aquatic habitats (Bartsch 1908, p. 697; Adams 1993, pp. 2 and 3). Available information indicates that suitable habitat for the species is restricted to relatively shallow, sheltered portions of still or sluggish, freshwater bodies with an abundance and diversity of submerged aquatic vegetation and a circumneutral pH (pH within the range of 6.8 – 7.5) (Figure 2-5; Table 2-2; Adams 1993, p. 8).

The pre-settlement distribution and habitat use of the species is not well understood. The only known records for the species are post-1900 and are from manmade millponds constructed in the 1700s to provide a freshwater source for rice agriculture (Adams 1993, pp. 21 and 22). Species experts suggest that the Magnificent Ramshorn occupied beaver ponds prior to 1900. Around 1900, beavers were extirpated from the State of North Carolina and species experts hypothesize that millponds offered habitat conditions similar to beaver ponds and these remnant populations were the first and only observations of the species documented (Adams 1993 and references therein, p. 22). Experts also suggest that the snail may also have occupied sluggish portions of

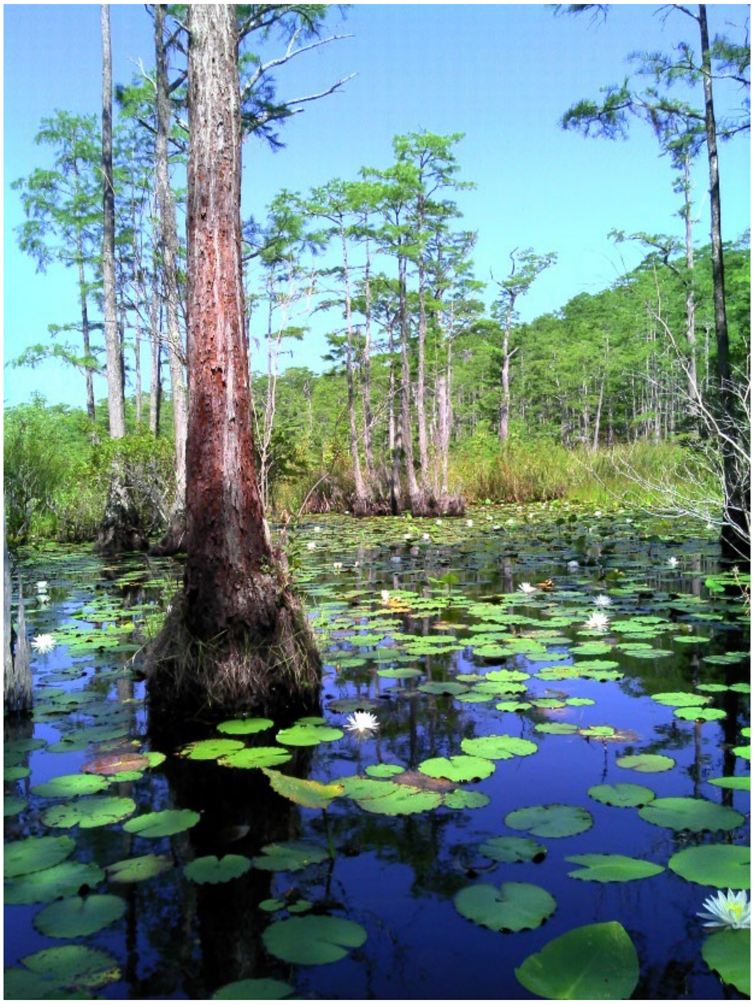


Figure 2-5 Typical habitat for Magnificent Ramshorn in Pleasant Oaks Pond (credit: USFWS)

tributaries to and the mainstem Cape Fear River until natural forces (e.g., sea level rise and changes in the inlet due to storm events) and/or navigational changes, which began as early as 1822, altered salinity regimes, flow and current patterns, and other hydrological conditions. These alterations would have made conditions unsuitable for the snail and limited it to portions of tributary streams providing suitable habitat protected from water quality and hydrological changes occurring elsewhere in the river basin (Adams 1993, pp. 21 and 22).

Bartsch (1908, p. 698) reported finding the Magnificent Ramshorn only in fragrant waterlily (*Nymphaea odorata*) and pondweed (*Potamogeton* sp.) beds in cove areas of Greenfield Lake. Adams and Gerberich (1988, p. 125), Adams (1993, p. 8), and Wood (2002, p. 1) also reported finding the species on aquatic vegetation including fragrant waterlily and spatterdock (*Nuphar lutem*), in similar sheltered habitat in Orton Pond, Sand Hill Creek Pond, and McKinzie Pond, respectively. However, Adams (1993, p. 8) reported that the species appeared to be more generally distributed in Sand Hill Creek Pond than what he observed in Orton Pond. Adams (1993, p. 8) reported that the maximum depth where he found the species in Orton Pond and Sand Hill Creek Pond was approximately one meter. The Planorbidae family of snails is on the whole a distinctly shallow-water group (Baker 1943, p. 17).

Salinity and pH also are major factors limiting the distribution of the Magnificent Ramshorn. Wood (2002, p. 3) reported that captive held Magnificent Ramshorn snails ceased all activity, withdrew into their shell, and sank to the bottom of their tank within 24 hours of exposure to salinity levels of 1.0 part per thousand (ppt). Within 8 hours they withdrew into their shell and died within 36 hours if not removed from water with a salinity of 5 ppt. Also, Wood (2002, pp. 2 and 3) observed that Magnificent Ramshorn snails fed and moved around normally in water with a pH of 6.8 to 7.5, but that the snails' feeding and other activity would cease altogether at pH levels at or below 6.5 and at or above 8.0; however, snails at the Watha hatchery are kept at pH between 7.95 and 8.5 with no issues to health or activity (I.Knox, personal communication, email to S.McRae, 8/23/2019). Greenfield Lake (NC Department of Environment and Natural Resources [NCDENR] 2004, p. 331), Orton Pond, Sand Hill Creek Pond (Adams 1993, App. C Field Data Sheets) and McKinzie Pond (Wood pers. comm. 2010) were all reported to have a circumneutral pH, i.e., within the range 6.8 – 7.5. This is higher than typical for many of the water bodies in the region. This is believed to be due to significant input of groundwater from underlying limestone formations in the watersheds of the creeks feeding these impoundments (Adams and Gerberich 1988, p. 125).

Table 2-2 Important Habitat Elements for Magnificent Ramshorn

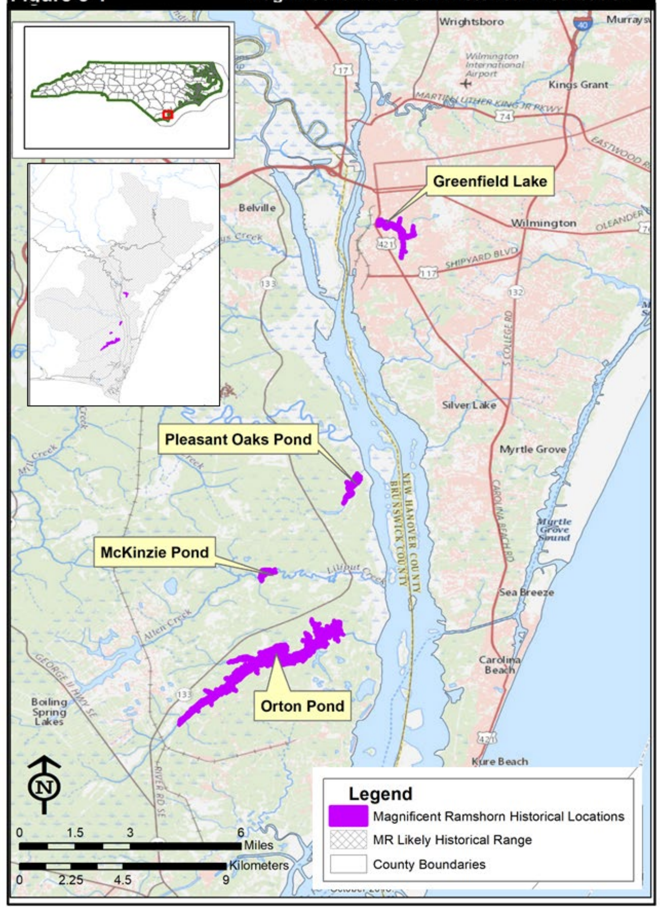
Attribute	Description	Citation
pH	Ideal is 6.8 to 7.5 - inactive below 6.5 and above 8	C. Eads, personal communication, 6/1/2018 (Wood, 2004) (Adams, 1993, Pg. 8)
Salinity	Ideal of 0 ppt; 1.0 ppt caused snails to withdraw	(Wood, 2004, Pg. 3) A. Wood, personal communication, 8/2/2018
Temperature	Still able to feed at 93° F 60° F and above - dormant below 60° F	(Wood, 2010, Pg. 5) (Adams, 1993, Pg. 20)
Hardness	Affects snail survival Uses 30 mg/l in the lab Kept between 60 ppm and 220 ppm at NCWRC Watha Hatchery Added coral material improved shell growth at NCSU Vet School “Hard” water - Snails had irregular shell shape which changed after calcium was added to their water	A. Wood, personal communication, 8/2/2018 C. Eads, personal communication, 6/28/2018 Jeff Evans, (2015). Ramshorn Propagation Updates Progress report (NCWRC). Chris Eads, (2015). Ramshorn Propagation Updates Progress report (NCWRC). (Wood, 2004, Pg. 11)

CHAPTER 3 – CURRENT CONDITION

The following describes the current condition of the Magnificent Ramshorn and its habitat, including references to potential habitat outside of the historically known range.

3.1 Historical Distribution

Figure 3-1 Magnificent Ramshorn Historical Distribution



The Magnificent Ramshorn is a southeastern North Carolina endemic species. The species is known from only four sites in the lower Cape Fear River Basin in North Carolina (Figure 3-1). Although the complete historical range of the species is unknown, given the size of the species and the fact that it was not reported until 1903 is an indication that the species may have always been rare and localized (Adams 1993, p. 2), but potentially in other beaver pond, millpond, or impounded habitats in southeastern North Carolina. Prior to 1992, the Magnificent Ramshorn had been recorded only from Greenfield Lake, a millpond located on a tributary to the Cape Fear River within the present city limits of Wilmington, New Hanover County, North Carolina (Bartsch 1908, pp. 697 and 698) and Orton Pond (also sometimes referred to as Sprunt's Pond), a millpond located on Orton Creek in Brunswick County, North Carolina (Adams and Gerberich 1988, p. 125; Adams 1990a, p. 27). During range-wide surveys in 1992 and 1993, Adams (1993, p. 4) recorded the species at one additional site, Pleasant Oaks Pond (also referred to as Sand Hill Creek Pond or Big Pond), a millpond on Sand Hill Creek in Brunswick County, North Carolina. In 2004, Andy Wood with the National Audubon Society discovered an additional small population of the species in McKinzie Pond, a millpond on McKinzie Creek, in Brunswick County, North Carolina (Andy Wood, Wilmington, NC, personal communication 2004). Species-specific surveys of over a hundred potential sites over the last few decades have not documented any additional localities (Appendix A).

Although the complete historical range of the Magnificent Ramshorn is unknown, available information indicates that the species was likely once an inhabitant of beaver ponds on tributaries in the lower Cape Fear River basin; the species may also have once inhabited backwater and other sluggish portions of tributaries and the main channel of lower Cape Fear River (Adams 1993, pp 21-22). Beaver pond habitat was eliminated throughout much of the lower Cape Fear

River as a result of the extirpation of the beaver due to trapping and hunting during the 19th and early 20th centuries. This, together with draining and destruction of beaver ponds for development, agriculture and other purposes, is believed to have led to a significant decline in the in the snails' habitat and significant reduction in its abundance (Wood 2010, pp. 6 and 7). Also, dredging and deepening of the Cape Fear River channel, which began as early as 1822, and opening of the Atlantic Intercoastal Waterway (through Snow's Cut) in 1930 for navigational purposes have caused saltwater intrusion, altered the diversity and abundance of aquatic vegetation, and changed flows and current patterns far up the river channel and its lower tributaries (Adams 1993, p 22; Wood 2010, p 7). Under these circumstances, the Magnificent Ramshorn could have survived only in areas of tributary streams not affected by salt water intrusion and other changes, such as the millponds protected from saltwater intrusion by their dams (Adams 1993, p. 22).

The Magnificent Ramshorn was last recorded in Greenfield Lake by Bartsch in 1908 (Adams and Gerberich 1988, p. 125; Adams 1990a, p. 27); it was last seen in Pleasant Oaks Pond in 1994 (Wood 2002, p. 9) and the last and only observation of the species in McKinzie Pond was in 2004 (Wood, pers. comm. 2008 and 2010). The species is now believed to be extirpated from these three localities (see Appendix A). Adams and Gerberich (1988, p. 125) last observed a living specimen in Orton Pond in 1986. During a subsequent survey in 1987, they were able to find only shell material and reported that much of the aquatic vegetation had died back. Access to the Orton Pond has since been restricted by the landowner (Adams and Gerberich 1988, p. 125; William Adams, Wilmington, NC, pers. comm. 1990 and 2003; Wood pers. comm. 2009, 2015) and it is unknown if the species still survives in the pond.

In 1992, Andy Wood established a captive, refuge population of the Magnificent Ramshorn at the North Carolina Aquarium at Fort Fisher, North Carolina, under a captive propagation permit issued by the North Carolina Wildlife Resources Commission (NCWRC). Salt contamination of the aquaria in which the snails were held, believed to have been caused by salt-laden air circulating within the facility, subsequently forced Wood to establish holding facilities for the snail at his personal residence (Wood 2004, p. 9). Currently, there are approximately 300 snails at the Wood residence. In early 2012, a small (35 individuals) captive population was established at NC State University's (NCSU) Veterinary School's Aquatic Epidemiology Conservation Laboratory in Raleigh, North Carolina. Since 2017, NCSU has expanded its Magnificent Ramshorn propagation capacity, and currently has a population of approximately 3,000 snails from the original 35 founding population of snails. Additional facilities for holding and propagating the Magnificent Ramshorn at the NCWRC's fish hatchery in Watha, North Carolina have been established. In 2011, efforts at the Watha hatchery were initially deemed unsuccessful, however a few adult snails survived and were allowed to overwinter (2012). The hatchery expanded its snail

Figure 3-2 Tanks holding Magnificent Ramshorn at CPCG's Snail Sanctuary (credit: USFWS)

holding capacity in summer 2013 and 2015. At this time, all tanks at Watha are operational and supporting *P. magnifica*, with a population of approximately 2,000 snails from a founding population of ~50 animals.

3.2 Current Distribution

Available information indicates that the Magnificent Ramshorn is likely extirpated from the wild. Presently, the only known surviving individuals of the species are being held as part of captive populations; one established and maintained by CPCG at a private residence in Pender County, North Carolina (Figure 3-2), one at NCSU's Veterinary School's Aquatic Epidemiology Conservation Laboratory in Raleigh, North Carolina, and another at the NCWRC's Watha State Fish Hatchery in Watha, North Carolina.

3.3 Current Condition of Historical Locations

The extirpation of the Magnificent Ramshorn from Greenfield Lake is likely attributable to alteration of the lake's water quality and chemistry resulting from past events. These include breaks in sewerlines on the bottom of the lake; sewage overflow from nearby manholes during storm events; runoff of fertilizers, sediment, toxic chemicals, and other pollutants from the heavy development within the watershed; and/or, efforts by the city to control aquatic plants and algae within the lake (Adams 1990b, p. 104). As a result of heavy nutrient input, Greenfield Lake has become eutrophic and the majority of the aquatic vegetation currently present within the lake is filamentous green algae (Hackney and Brady 1996, p. 19; Adams pers. comm. 2003). Also, the city routinely conducted winter water-level drawdown in the past, in an attempt to control aquatic plant and algae levels within the lake. These drawdowns also likely had an adverse effect on the snail, as well the aquatic vegetation on which it is generally found (Adams 1990b, p. 104).

The Pleasant Oaks Pond population of the Magnificent Ramshorn is believed to have been extirpated in 1996 when the dam on the pond was breached during flooding associated with Hurricane Fran. Drawdown of the pond due to failure of the dam and saltwater intrusion into the pond affected both the Magnificent Ramshorn as well as the aquatic vegetation providing habitat for the snail, and researchers were unable to locate the snail during a subsequent survey (Wood pers. comm. 1996). This population of the species was last surveyed in 2007 and no evidence of the snail was found (Wood 2010, p. 2).

The Magnificent Ramshorn was last observed in McKinzie Pond in 2004 (Wood pers. comm. 2008). This population of the species is believed to have been extirpated due to saltwater intrusion resulting from the compromised dam (see section 4.1 below) and prolonged drought conditions. The reduction of freshwater levels feeding the stream allowed the tidal flow of saltwater to extend further up McKinzie Creek into the area harboring the snail (Wood pers. comm. 2008). Wood (2010, p. 2) reported that much of the submerged freshwater aquatic vegetation that previously flourished at this site, including spatterdock and cabomba, was damaged by saltwater.

Access to Orton Pond by researchers surveying for the Magnificent Ramshorn snail has been restricted since 1990 (Adams and Gerberich 1988, p. 125; Adams pers. comm. 1990 and 2003; Wood pers. comm. 2009). However, Adams (1993, p. 9) reported that nuisance aquatic vegetation growth was increasing significantly in the pond in the late 1980s, possibly due to increased nutrient supply in the headwater reaches of Orton Creek from golf course and other development activities in the Boiling Springs Lakes area. He also reported that the landowners unsuccessfully attempted to control the aquatic vegetation by a partial drawdown of the lake during the winter 1989/1990, a method extremely detrimental to species like the Magnificent Ramshorn. It is currently unknown whether the snail survived this drawdown or whether the owners made subsequent attempts to control aquatic vegetation in Orton Pond that may have eliminated the species.

Figure 3-3 Captive Magnificent Ramshorn Snails at NC State University (credit: C.Eads)

3.4 Current Condition of Populations

Species-specific surveys of over a hundred potential sites since the mid-1990s have not documented live Magnificent Ramshorn snails in the wild. Currently, the Magnificent Ramshorn is presumed extirpated from the wild, and is known only from three established captive populations, one population currently comprised of approximately 300+ adults, one with approximately 2,000+ adults, and one population of 3,000+ adults (Figure 3-3).

CHAPTER 4 – FACTORS INFLUENCING VIABILITY

In this chapter, we evaluate the past, current, and future factors that are affecting what the Magnificent Ramshorn needs for long term viability. Aquatic systems face a multitude of natural and anthropogenic threats and stressors. The Magnificent Ramshorn Technical Expert Team and the North Carolina State Wildlife Action Plan identified several factors that have impacts on habitats (see red circles in Figure 4.1 below). We examined pathways for each factor and how each factor affects (influences) the habitat, and therefore the species. Each "influence" is examined for its historical, current, and potential future effects, as described below. The current and expected distribution and abundance also determine viability and, therefore, vulnerability of the species to extinction.

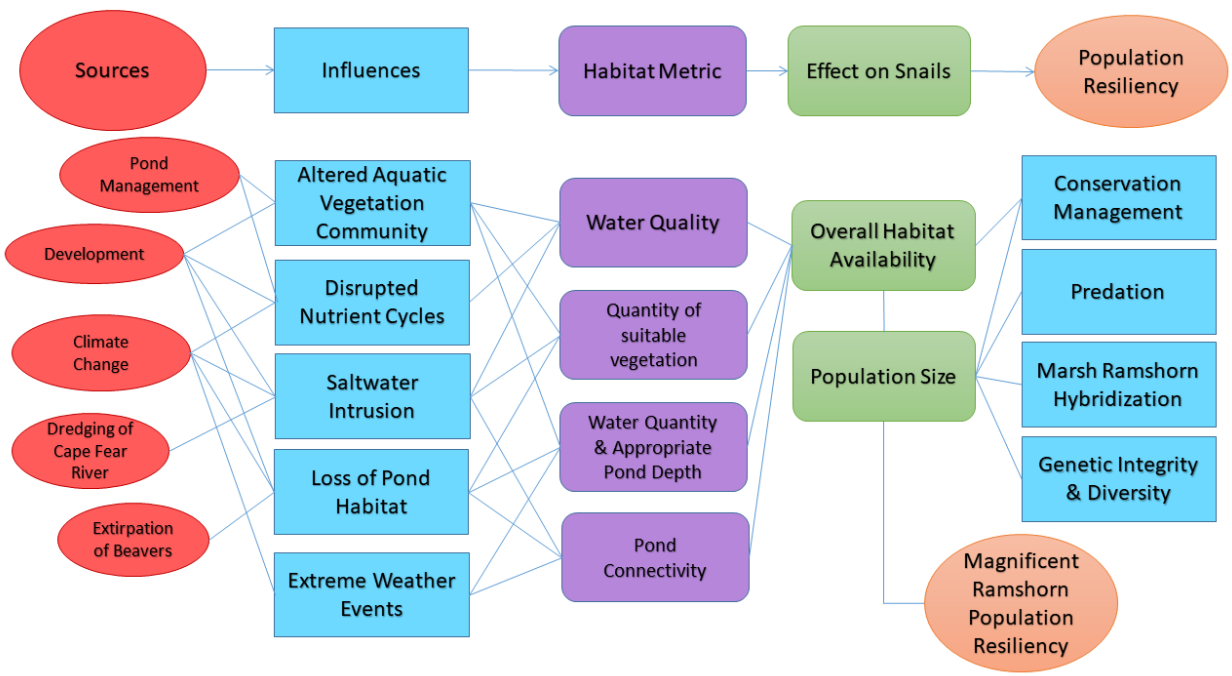


Figure 4-1 Influence Diagram for Magnificent Ramshorn, including factors influencing population resiliency

4.1 Loss of Lentic (Pond) Habitats

Although the complete historical range of the Magnificent Ramshorn is unknown, available information indicates that the species was likely once an inhabitant of beaver ponds on tributaries in the lower Cape Fear River basin; the species may also have once inhabited backwater and other sluggish portions of the main channel or tributaries of lower Cape Fear River (Adams 1993, pp 21-22). Beaver pond habitat was eliminated throughout much of the lower Cape Fear River as a result of the extirpation of the beaver due to trapping and hunting during the 19th and early 20th centuries. This, together with draining and destruction of beaver ponds for development, agriculture and other purposes, is believed to have led to a significant decline in the in the snails' habitat and significant reduction in its abundance (Wood 2010, pp. 6 and 7).

Adams (1993, p.26) noted the loss of ponds due to hurricanes. Several ponds that were created or maintained by old mill dams have structures that will or have failed during catastrophic events. The catastrophic rainfall can overtop old mill dam structures and cause portions of them to wash out, thus draining the ponds behind them. This is likely what happened at McKinzie Pond.

4.2 Saltwater Intrusion

Historical and current dredging and deepening of the Cape Fear River channel for navigational purposes have caused saltwater intrusion, altered the diversity and abundance of aquatic vegetation, and changed flows and current patterns far up the river channel and its lower tributaries (Figure 4-2; Adams 1993, p 22; Wood 2010, p 7). With these alterations in habitat, Magnificent Ramshorn can only survive in areas not affected by salt water intrusion and other changes, such as the millponds protected from saltwater intrusion by their dams (Adams 1993, p. 22).

Figure 4-2 "The sentinel of the freshwater wetland is the cypress tree - they are the first to die when a freshwater wetland becomes salinized." –L.Cahoon. Dead cypress along the Cape Fear River. (credit: V.Holman)

Climate change and sea level rise pose a significant long term threat to the survival of the Magnificent Ramshorn. As previously noted, the Magnificent Ramshorn is salt intolerant (Wood 2002, p.3) and saltwater intrusion into its habitat is one of the primary factors that has contributed to its extirpation in the wild. During the past century, sea level has risen by 8+ inches and available information indicates the rate of sea level rise is increasing (US Global Change Research Program [USGCRP] 2009, p. 18, Kopp et al. 2015, p.700). Sea levels are rising at a rate of about an inch per year (5 inches from 2011-15) in some areas along the East Coast of North Carolina (Valle-Levinson et al. 2017, p.7876). While future rates of sea level change are uncertain and dependent upon ice sheet response to climate change, continued sea level rise threatens the southeastern US coastal zone with retreat of shorelines, inundation of coastal wetlands and streams, and increased salinity of estuaries, coastal wetlands, and tidal rivers and creeks, pushing freshwater coastal ecosystems further inland. In addition, in the future the southeastern US is threatened with potential higher average temperatures (resulting increased evaporation rates), less frequent rainfall (resulting in potentially more frequent and longer dry periods), and an increase in intensity of storm events, including hurricanes; all of which are likely to increase the rate and upstream distance of salt water intrusion into coastal streams. Also, higher average temperatures and longer periods between rainfall events, together with increased development and human population levels in Brunswick and New Hanover Counties, will result in an increased demand on freshwater systems for drinking, irrigation, and other water needs, exacerbating the effects of sea level changes on streams in the lower Cape Fear River basin which encompass the entire known historic range of the Magnificent Ramshorn (adapted from USGCRP and references therein 2009, pp. 1111-116).

4.3 Disrupted Nutrient Cycles – Pollution and Nutrient Inputs

The human residential population of Brunswick and New Hanover Counties is rapidly increasing – both counties are popular vacationing and retirement areas (see Section 5-6). Results of the 2010 census indicate both counties are among the most rapidly developing counties in the state with population growth greater than 25% during the period of 2000-2010 (http://www.wral.com/news/national_world/national/flash/9204746/). Typically, as development increases, the input of nutrients (through both surface and groundwater), silt, and other pollutants into the aquatic system increases. Increased input of these pollutants into the stream from point and non-point sources may result in eutrophication, decreased dissolved oxygen concentration, increased acidity and conductivity, and other changes in water chemistry. Poorly planned development within the watersheds feeding areas that formerly harbored the Magnificent Ramshorn or that may provide potential habitat for the species also has the potential to reduce groundwater levels, which could have a serious adverse effect on pH, water hardness, and salinity levels.

4.4 Altered Aquatic Vegetation Communities

Aquatic vegetation is common in pond systems, but sometimes the vegetation can be invasive and overwhelm the aquatic system. Managing vegetation in ponds takes many forms – some practices are compatible with molluscan pond inhabitants (like the Magnificent Ramshorn), such as aeration, or mechanical cutting/removal, but some practices can significantly impact snails, such as using grass carp, copper-based herbicides, or drawing water out of the pond and subsequently drying out vegetation for complete removal. The latter practices result in snail mortality – either from complete elimination of aquatic vegetation on which the snails depend, exposure to toxic metals like copper, or from lethal temperatures, predation, or desiccation from no access to water (Adams 1993, p.12).

4.5 Extreme Weather Events

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

Impacts from climate change affect sea level changes, alterations in precipitation patterns and subsequent delivery of freshwater, nutrients, and sediment, and changes in the frequency and intensity of coastal storms (Michener et al. 1997, p.770; Scavia et al. 2002, p.149; Neumann et al. 2015, p.97). During the time (1990s-2000s) when Magnificent Ramshorn became extremely rare in the wild, three of the top five strongest/most intense storms experienced in Wilmington, NC were in 1996, 1998, and 1999 (Table 4-1; Figure 4-3), and caused massive flooding and saltwater intrusion into the ponds where Magnificent Ramshorn occurred.

Table 4-1. Strongest Storms in Wilmington, NC History. Data from National Weather Service (https://www.weather.gov/ilm/Top_20_Storms)

Rank	Event Name	Date
1	Hurricane Floyd	9/16/1999
2	Hurricane Fran	9/5/1996
3	Hurricane Donna	9/11/1960
4	Hurricane Florence	9/14/2018
5	Hurricane Bonnie	8/26/1998

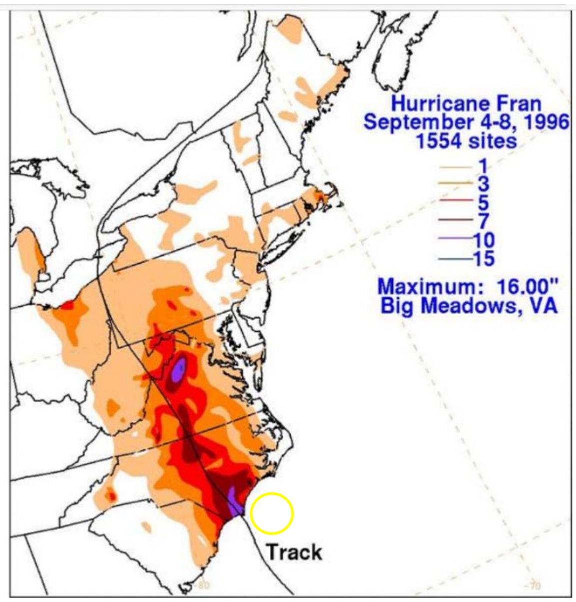


Figure 4-3 Map of rainfall from Hurricane Fran, 1996. Yellow circle indicates Magnificent Ramshorn range. (credit: National Weather Service)

In the "Threats" section of the North Carolina Wildlife Action Plan (NCWRC 2015, p.5-48), climate change is seen as a "very high" threat to the Magnificent Ramshorn. In addition, in an assessment of ecosystem response to climate change, factors associated with climate change ranked high with other factors that were deemed imminent risks to Magnificent Ramshorn historical population locations (e.g., development, pollution, flood regime alteration, etc.; NCNHP 2010, entire). Furthermore, it should be recognized that the greatest threat from climate change may come from synergistic effects. That is, factors associated with a changing climate may act as risk multipliers by increasing the risk and severity of more imminent threats (Arabshahi and Raines 2012, p.8). As a result, impacts from rapid urbanization in the region might be exacerbated under even a mild to moderate climate future (see Section 5.6).

4.6 Predation

Prior to its extirpation from the wild, the Magnificent Ramshorn and its eggs were undoubtedly consumed by various predators, including other aquatic snails (species like the Marsh Ramshorn

[*Planorbella trivolvis*] are believed to feed on the eggs of other snails), predatory insects, snail-eating fish such as the redear sunfish (*Lepomis microlophus*), amphibians and aquatic reptiles (e.g., aquatic turtles and bullfrogs), small mammals, and waterfowl and wading birds (Baker 1945, p. 19 and Wood 2004, pp. 1, 11, and 12). Predation by naturally occurring predators is a normal aspect of the population dynamics and generally would not be considered to pose a significant threat to a healthy population. However, if a predator or predators were to obtain access to the refuge population, the only known surviving individuals of the species, this could potentially lead to the species' extinction. Also, predation pressure should be considered when planning recovery and reintroduction efforts for small populations.

4.7 Hybridization

Adams (1993, p.5) noted that *Planorbella magnifica* x *P. trivolvis* hybrids were found in the wild as well as hybrid young reared from egg masses laid in captive populations. During his initial attempt to propagate the Magnificent Ramshorn, Wood (2004 pp. 8 and 12) documented hybridization between the Magnificent Ramshorn and the more common Marsh Ramshorn (*P. trivolvis*) (Figure 4-4). Hybrid young bear characteristics of both species, assuming the shell shape of the Marsh Ramshorn but the coloration, shell surface sculpture, and soft-part markings of the Magnificent Ramshorn (Adams 1993, p.5). Although hybridization is not believed to have played a significant role in the extirpation of the Magnificent Ramshorn from the wild, it could adversely affect efforts to recover the species.

Figure 4-4 Top view of a marsh ramshorn, *Helisoma trivolvis* (Say), next to a strand of hydrilla. Specimen approximately 2 cm. Photograph by Lyle J. Buss, University of Florida.

4.8 Genetic Diversity

Currently, all known live Magnificent Ramshorns are descendants from snails from Pleasant Oaks and McKinzie ponds. The captive population from Pleasant Oaks underwent a bottleneck – all but 12 snails died during Hurricane Fran in 1996. Offspring of wild-caught Magnificent Ramshorns from McKinzie Pond (collected in 2004) were introduced in 2007 to captive offspring of the original 12 Magnificent Ramshorns from Pleasant Oaks Pond. All snails in captivity today are descendants from both of those populations. Given that the snails have a short life span of about 2-3 years, those animals that are in captivity but in different locations may have developed some unique genetic aspects. Future management of the species may require mixing of captive populations to maintain genetic diversity, but further analysis is needed to determine frequency and necessity.

4.9 Ongoing Conservation Management

In 2008, biologists with the USFWS, NCWRC, North Carolina Department of Transportation and Andy Wood met to evaluate some of the borrow pit ponds in Brunswick and New Hanover Counties to determine their suitability as habitat for the snail. One pond on a tract of land that remains for sale by the owner in New Hanover County has been identified as a likely location, however efforts to obtain funding to acquire the property have been unsuccessful.

In 2012, NCWRC staff assessed the availability of potential habitat on their property at Holly Shelter Gamelands in Pender County, North Carolina. At the time, no ponds existed that would be suitable for the Magnificent Ramshorn, and despite ideas to create pond habitat that could allow a population to be established in the wild, no appropriate sites were available.

In 2012-2013, several potentially suitable locations, including a portion of Orton Pond, McKinzie Pond, Pleasant Oaks Pond (Sand Hill Creek/Big Pond), and nearby Pretty Pond, were all brought under single ownership. In 2014, the landowner approached the USFWS to determine the possibility of restoring the snail to Big Pond at the Pleasant Oaks Plantation. Discussions between USFWS and the landowner began to assess snail restoration potential.

In 2015, NCWRC, the USFWS, and The Nature Conservancy (TNC) began to consider the potential to grow Magnificent Ramshorn snails in a borrow pit on the Green Swamp Preserve in Brunswick County. If water lilies and spatterdock could be introduced successfully in 2016-2017, the habitat may be suitable for an introduction. NCWRC and the USFWS translocated spatterdock to the pond in fall 2017, but they did not survive the 2018 summer. In addition, pH values of the borrow pit pond have been very low (between 4-5), therefore the Green Swamp location is no longer deemed suitable for introduction of Magnificent Ramshorn snails.

The NC Division of Water Resources and the USFWS are working with the city of Wilmington, North Carolina to improve the water quality of Greenfield Lake which formerly supported the species (Greenfield Lake is currently on the state's list of impaired water bodies). In 2017, the USFWS secured funding for a project aimed at restoring water quality in Greenfield Lake. The University of North Carolina at Wilmington assessed nutrient inputs into Greenfield Lake in order to inform lake restoration guidance, ultimately to improve the quality of lake habitat for reintroduction of the Magnificent Ramshorn. This builds off of a 9-element restoration plan for Greenfield Lake that has been approved for implementation by the NC Division of Environmental Quality (Mallin et al. 2018, p.28).

In 2018, NCWRC staff revisited 17 ponds on Holly Shelter Game Lands; only one pond/borrow pit had a circumneutral pH, but was being used for Gopher Frog Recovery (note: gopher frogs require ephemeral ponds and therefore could not coexist with snails needing permanent water availability year-round). The discovery of borrow pit water quality led NCWRC to begin looking for established borrow pits on other state lands which were found in a section of Green Swamp Game Land in Brunswick County. A borrow pit at that location appears promising as potential habitat, having neutral pH, consistent water availability even in years of high drought, and electrofishing results showed no shell-specific predators exist. Current plans to modify the Green Swamp pond are: to create a shallow area for the snails to have easier access to water surface, introduce emergent vegetation to aid in the snail diet, habitat, and a place to lay eggs, add lime to create consistently neutral pH, and add calcium carbonate to aid in buffering capacity.

Also in 2018, USFWS Staff performed a desktop analysis to determine the suitability of potential habitats within the former range to support introduction of Magnificent Ramshorn snails. The results of the analysis are being used by staff to field verify suitability of potential locations. In preparation for potential introduction, the USFWS has drafted experimental protocols to detail necessary steps for possible introduction of the species into the wild. Further, the USFWS is in the process of drafting a Candidate Conservation Agreement with Assurances for landowners interested in contributing to the conservation of the species.

4.10 Captive Population Management

Captive holding of the Magnificent Ramshorn began in the early 1990s, when Adams collected individuals to learn about their life history requirements (Adams 1993). In the mid-1990s, snails were held in captivity at the NC Aquarium at Fort Fisher, but were later moved to a private residence due to the influence of salt-laden air at the aquarium. Mr. Wood of the Coastal Plain Conservation Group has maintained a snail sanctuary at his residence since the mid-1990s. The founding colony continues to prosper under Mr. Wood's care.

In early 2012, a small (35 individuals) captive population was established at NC State University's (NCSU) Veterinary School's Aquatic Epidemiology Conservation Laboratory in Raleigh, North Carolina. These captive snails reproduced successfully, however problems with shell quality and high mortality were observed. Individual snails were lethargic, and their foot would protrude without it being associated with locomotion. Specimens were obtained and processed for histopathologic evaluation. Upon histopathologic review, the snails that were examined displayed evidence of a systemic bacterial infection. *Bacilli* were observed in multiple tissues. Aerobic cultures of tissue inoculums from moribund snails grew a multitude of organisms, however, no consistent isolate was made that could be associated with the tissues obtained from the affected snails.

It was hypothesized that the clinical problems and mortality were associated with the systemic infections noted during histopathologic examination. Snails were treated with an antimicrobial in an experimental design. Unfortunately, the experiments were unsuccessful in determining the causes of mortality because of potential cross-contamination that may have occurred between the treated and untreated tanks, or because of potential changes in nitrifying bacteria essential for mitigating the presence of toxic ammonia and nitrite in the aquaria. Additional research is needed to determine the nature and cause of the infection and mortality observed, as well as the short and long-term effects of changes in pH and other rearing parameters. Substantial additional work is needed to optimize the diets of the snails when held in captivity.

In 2014, an outdoor tank was set up at NCSU to compliment the indoor tank. Spatterdock was reared in an additional outdoor tank, with snail introduction to that tank in 2016. A "CVM Snail Team" of veterinary students formed to help with the care of the snails. In 2018, snails were moved to a new lab, consisting of four 200gal tanks, to be expanded to several more tanks, with a focus on producing large numbers of snails for possible introductions in the wild. Several potential introduction locations are being explored by USFWS and NCWRC staff.

Additional facilities for holding and propagating the Magnificent Ramshorn at the NCWRC's hatchery in Watha, North Carolina were established in 2011. Initial efforts at the Watha hatchery were deemed unsuccessful, however a few adult snails survived and were allowed to overwinter (2012) in an established tank with abundant vegetation. The hatchery expanded its snail holding capacity in summer 2013 with the addition of a second 600-gallon tank. Results of water quality tests in the second Watha tank allowed the addition of a dozen snails from the 2012/2013 cohorts in August 2014. In 2015, the hatchery added two tanks as well as a spatterdock nursery area. Initially those two tanks supported *P. magnifica*, but when the hatchery attempted to add two more tanks, they noticed there were no more living snails in any of their tanks. SAV introduced in 2012 grew well, and although attempts to introduce seedling spatterdock to both tanks were unsuccessful, the spatterdock nursery area has healthy growing plants. All Watha outdoor tanks are now enclosed in a predator exclosure with fully screened walls and covered by 60%+ shade cloth. Water is aerated, and calcium is added. In addition, an indoor recirculating system was constructed in 2018 with a series of tanks under full spectrum lighting, with filtration and calcium supplementation. There has been some snail mortality in the hatchery, due to the presence of planaria. However, use of commercial parasiticide and cleaning waste daily, not overfeeding tanks, and removing dead snails as soon as possible have shown success in reducing mortality. In 2018, NCWRC hired a 2-year snail technician position to focus on Magnificent Ramshorn husbandry at the Watha Hatchery.

4.11 Regulatory Mechanisms

The Magnificent Ramshorn is currently listed by the state of North Carolina as an endangered species. However, this designation does not protect the species from "incidental" harm, injury, death (impacts resulting from activities not specifically intended to harm the species) or provide any protection to the species' habitat except on state-owned lands.

In 2011, the USFWS reviewed prior Candidate Notice of Review information for the Magnificent Ramshorn and determined that the species was warranted for listing under the ESA, but precluded due to higher priority listing actions. The Listing Priority Number is a 2, indicating that the full species was imminently threatened by a high magnitude of threats:

> *Magnitude:* The Magnificent Ramshorn appears to be extirpated from the wild due to habitat loss and degradation resulting from a variety of human-induced and natural factors. The only known surviving individuals of the species are presently being captively held at a private residence, NCWRC's Watha Fish Hatchery, and a lab at NC State University's Veterinary School.
>
> *Imminence:* While efforts have been made to restore habitat for the Magnificent Ramshorn at one of the sites known to have previously supported the species, all of the sites continue to be affected and/or threatened by the same factors (i.e., salt water intrusion and other water quality degradation, nuisance aquatic plant control, storms, sea level change, etc.) believed to have resulted in extirpation of the species from the wild. Currently, only three captive populations exist, with approximately 5,300 snails in existence. Although robust captive populations have been maintained since 1993, a catastrophic event, such as a severe storm, disease, or predator infestation, affecting the captive populations could result in the near extinction of the species.

4.12 Summary

Figure 4-1 represents our understanding of the factors that influence Magnificent Ramshorn population resiliency. The most significant stressor that likely led to the extirpation of the Magnificent Ramshorn in the wild is the loss of suitable lentic (pond) habitat that individuals and populations need to complete their life history. The primary causes of historical habitat loss within the range of the Magnificent Ramshorn are related to anthropogenic activities coupled with extreme weather events that have altered water quality such that the breeding, feeding, sheltering, and dispersal needs of the snails cannot be met. The implementation of conservation measures from the Candidate Conservation Agreement with Assurances, along with the reintroduction of captive snails, could result in securing sustainable Magnificent Ramshorn populations in the wild.

CHAPTER 5 – SPECIES VIABILITY

We have considered what the Magnificent Ramshorn needs for viability and the current condition of the species and its habitats (Chapters 2 and 3), and we reviewed the factors that are driving the historical, current, and future conditions of the species (Chapter 4). We now consider what the species' future conditions are likely to be.

5.1 Introduction

Based on the factors previously mentioned in this report, the survival of the Magnificent Ramshorn would depend on persistence and protection of appropriate habitat within the historical range (i.e., optimal water quality and sufficient vegetation). Under these requirements, we evaluate the viability of Magnificent Ramshorn by considering the resiliency, redundancy, and representation of is populations.

5.2 Resiliency

Resiliency describes the characteristics of a species that allow it to recover from periodic disturbance, such as annual environmental variation and stochastic events. Magnificent Ramshorn populations were not able to survive habitat degradation resulting from impacts including saltwater intrusion, pollutant influx, and human alteration of aquatic vegetation communities, thus eliminating the species' resiliency.

5.3 Redundancy

Redundancy is defined for this analysis as having sufficient numbers of populations for the species to withstand catastrophic events. Both drought and hurricanes have affected that habitats that Magnificent Ramshorn populations rely on. Based on knowledge of the snails and the systems they depend on, the loss of habitat, and the lack of finding any Magnificent Ramshorns despite surveying dozens of possible locations, the Magnificent Ramshorn has no redundancy in the wild.

5.4 Representation

Representation is having the ecological diversity and/or genetic diversity within the species to be able to adapt to changing environmental conditions. The historical range of the species is narrow and limited to lentic habitats within the Coastal Plain of southeastern North Carolina. We do not know the level of genetic diversity of the captive animals, however we do know that the Magnificent Ramshorns in captivity are all descendants of adult snails from two distinct populations: Pleasant Oaks Pond and McKinzie Pond. The captive ramshorns have extremely limited representation, and since no Magnificent Ramshorns are known to exist in the wild, the species has no wild representation.

5.5 Current Viability Summary

The current assessment is that the Magnificent Ramshorn lacks the three factors for viability. Based on the findings of decades of surveys to find the species, the Magnificent Ramshorn is presumed to be extirpated in the wild.

5.6 Future Conditions for Potential Habitat within Historical Range
While the Magnificent Ramshorn is presumed extirpated from the wild, recovering the species means re-establishing self-sustaining populations in the wild. It is helpful to look at some projected threats/stressors (e.g., climate change, sea level change, human population growth/development pressure) and potential impacts to habitat that may be able to support resilient populations of Magnificent Ramshorn.

Climate Change
When taking into account future climate predictions, we considered the climate futures under RCP 8.5 and RCP 4.5 out to mid-century (2050-2060). RCP 8.5 ("Higher Emissions" in Figure 5-2 below) projects a possible future in which global emissions of heat-trapping gases continue to increase through the 21st century, whereas RCP 4.5 ("Lower Emissions" in Figure 5-2 below) projects a possible future in which the global emissions of heat-trapping gasses peak around 2040 and then decline (U.S. Climate Resilience Toolkit 2019, entire).

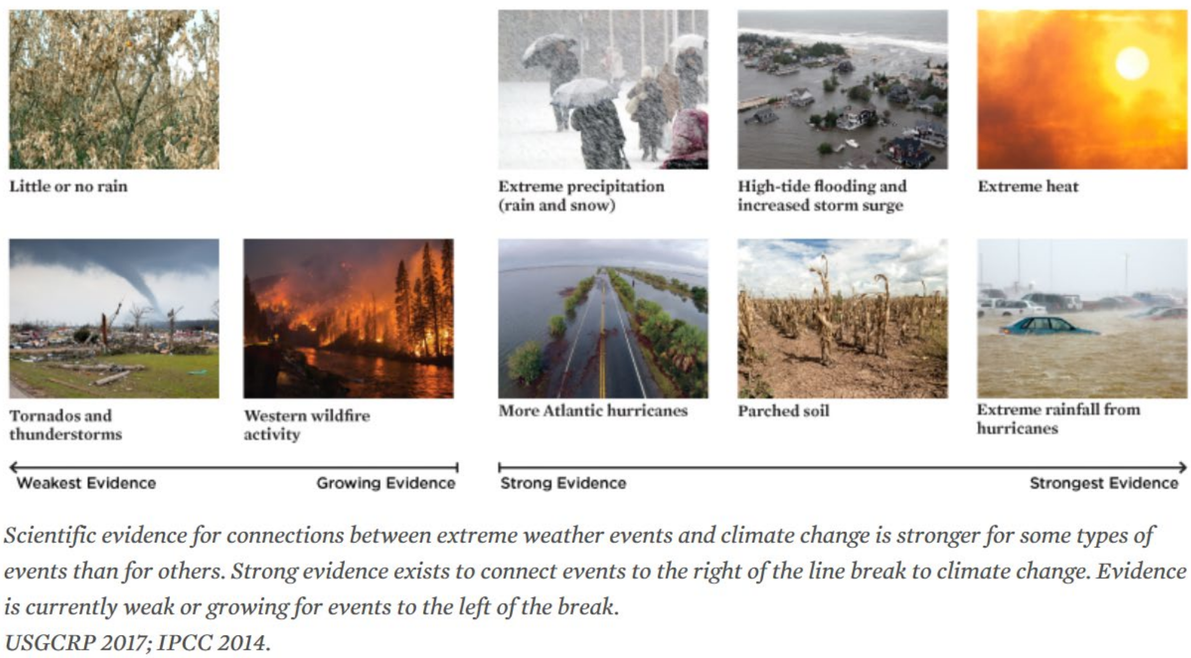


Figure 5-1 Connection between extreme weather events and climate change (credit: Union of Concerned Scientists, https://www.ucsusa.org/our-work/global-warming/science-and-impacts/climate-attribution-science)

Regardless of climate future, the following systematic changes are expected to be realized to varying degrees in the southeastern U.S., including southeastern North Carolina (Figure 5-1) (NCILT 2012, p.27; IPCC 2013, p.7; UNC Communications 2019, entire):

- More frequent drought
- More extreme heat (resulting in increases in air and water temperatures, see Fig 5-2 below)
- Increased heavy precipitation events (e.g., flooding)
- More intense storms (e.g., frequency of major hurricanes increases)
- Rising sea level and accompanying storm surge

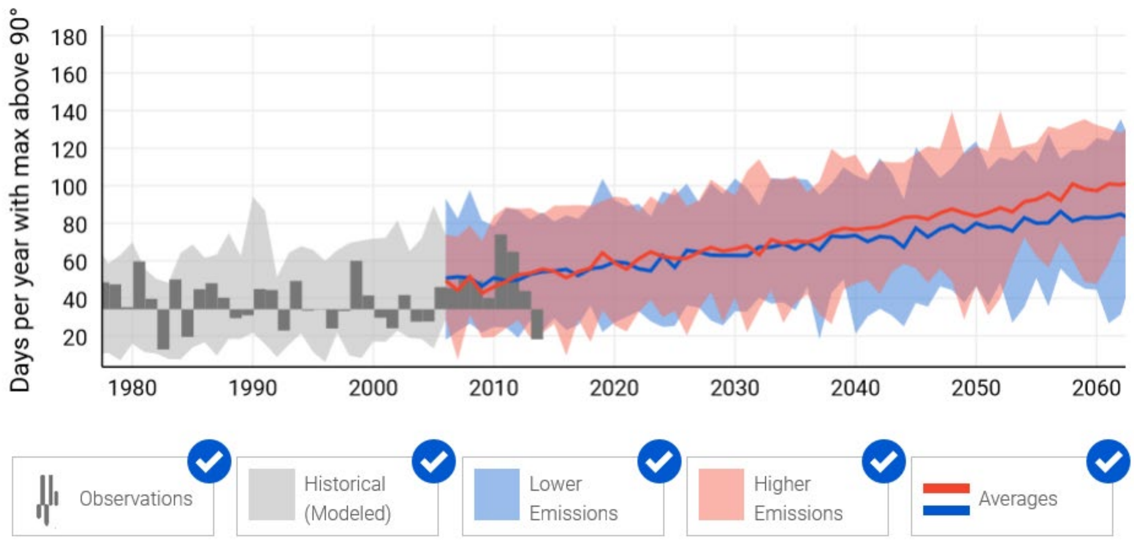


Figure 5-2 Future predictions of extreme heat, or days per year with max temperature above 90 degrees, in New Hanover County, NC (credit: U.S. Climate Resilience Toolkit, https://toolkit.climate.gov/)

Sea level change

The rate of Global Mean Sea Level (GMSL) rise is measured by altimeter and by a global network of tide gauges (Sweet et al. 2017, p.1). The main drivers for GMSL rise are atmospheric and ocean warming, which act to increase both the mass of the ocean, primarily through the melting of land ice (anthropogenic changes in the storage of water on land has been an additional effect), and the volume of the ocean, primarily through thermal expansion (Kopp et al. 2015, p.694; Sweet et al. 2017, p.1). Sea level change is not uniform across the globe and water levels vary in response to multiple processes operating over multiple temporal and spatial scales. Kopp et al. (2015, p.697) indicate that locally in North Carolina, sea level is also affected by response to sediment compaction, groundwater withdrawal, and tidal-range shifts.

USGS offers an interactive Sea Level Change Tool called TerriaJS Sea Level Change Map (https://maps.usgs.gov/sealevelchange/) that projects six sea level rise scenarios into the future (Figure 5-3). The USGS tool has similar projections as described in localized projections from Kopp et al. (2015, p.701). The tool scenarios are: Low (0.3m), Intermediate-Low (0.5m), Intermediate (1.0m), Intermediate-High (1.5m), High (2.0m), and Extreme (2.5m). Intermediate projections are in line with RCP 4.5, whereas High and Extreme projections are in line with RCP 8.5. Below is a graph that shows the range of scenarios for Wilmington, NC, with detailed measures below for 2020, 2030, 2040, and 2050:

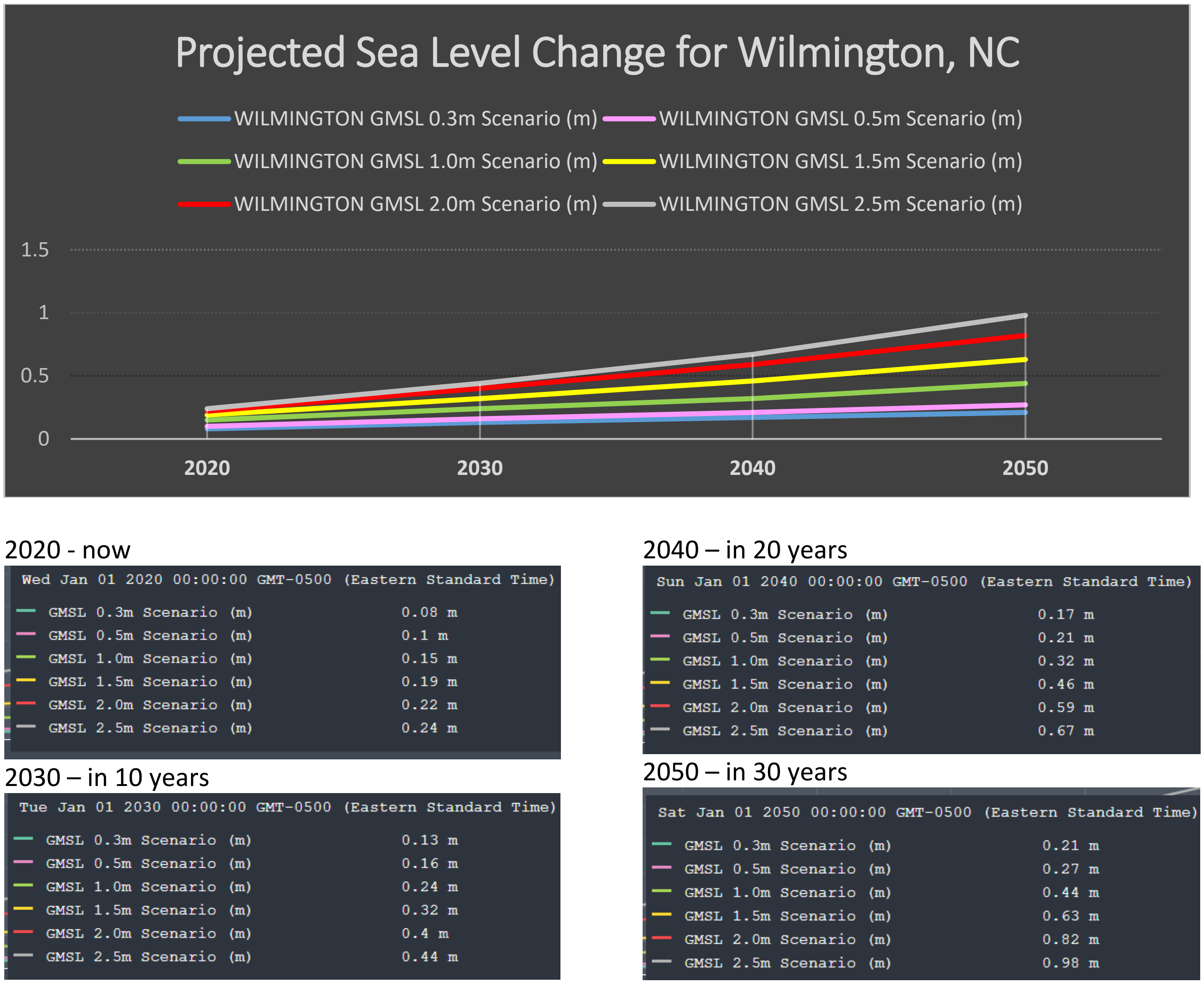


Figure 5-3. Projected sea level changes for Wilmington, NC, 2020 to 2050, under six different Global Mean Sea Level rise scenarios (credit: USGS Sea Level Change Tool)

We mapped these predicted changes using GIS files from the NOAA Sea Level Rise (SLR) Viewer (https://coast.noaa.gov/digitalcoast/tools/slr.html). To compare the USGS and NOAA tools, the NOAA "low" corresponds to the USGS GMSL 0.3m scenario, "intermediate low" corresponds to GMSL 0.5m, "intermediate" corresponds to GMSL 1.0m, "intermediate high" corresponds to GMSL 1.5m, "high" corresponds to GMSL 2.0m, and "extreme" corresponds to GMSL 2.5m. Ass seen in Figure 5-4, when sea level change is mapped with historical locations for the Magnificent Ramshorn, at least one of the historical locations (McKinzie Pond) will be inundated by 2040 under the intermediate scenario (comparable to GMSL1.0m in Figure 5-3), and therefore not remain suitable habitat for the snail. While the remaining three ponds appear to be "safe" from sea level rise, it is very possible that the dams could breach during storm events (as they have already been breached during previous storms).

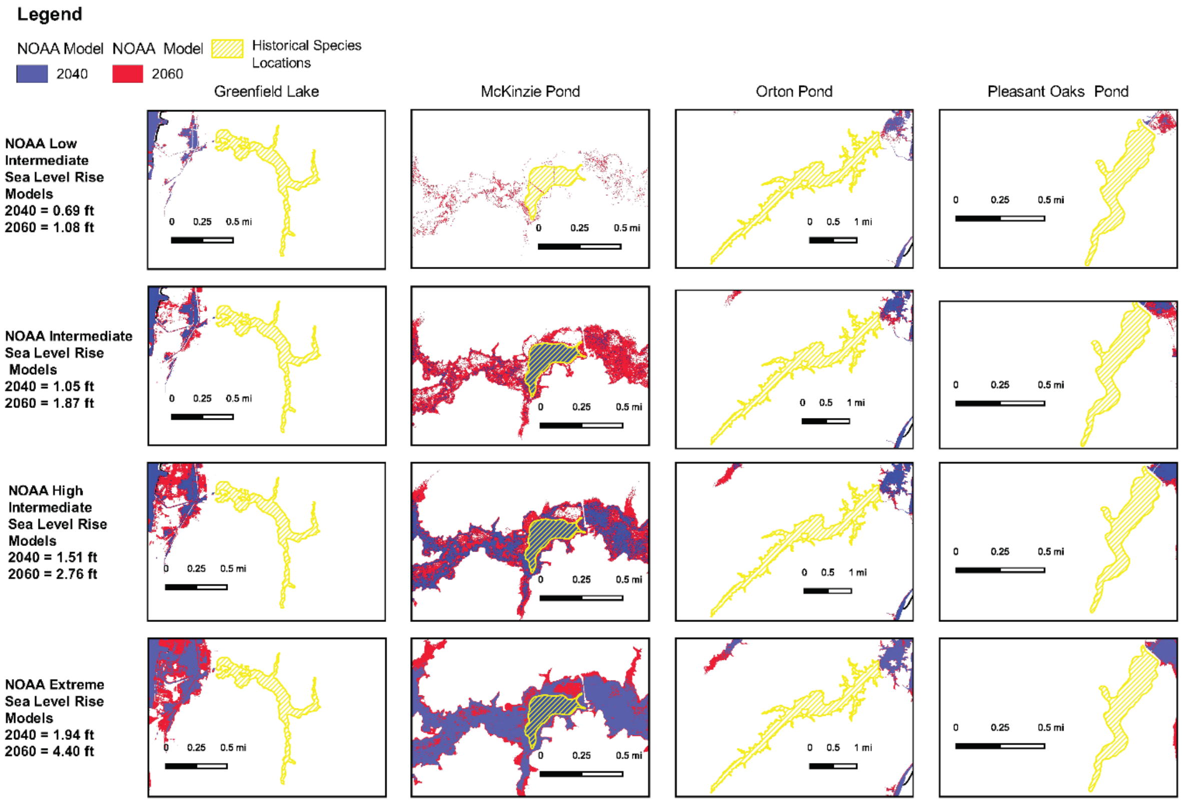


Figure 5-4 Sea level change maps of Magnificent Ramshorn's historical pond habitats using NOAA's SLR model scenarios, showing predictions out to 2040 and 2060. Note: low and high scenarios not shown (credit: D.Newcomb)

Human Population Growth

According to the U.S. Census Bureau (Table 5-1), the two counties (Brunswick and Pender Counties) within the historical range of the Magnificent Ramshorn have experienced the largest growth rates in North Carolina – averaging a 3.55% increase annually.

Table 5-1. Top NC Counties with Largest Growth Rates
(source: https://demography.cpc.unc.edu/2018/03/22/are-nc-county-growth-patterns-shifting/)

10 NC Counties with Largest Growth Rates, 2016-2017

Rank	County Name	Total Population		Growth, 2016-17		Components of Change	
		July 1, 2016 Estimate	July 1, 2017 Estimate	Numeric	Growth Rate	Natural Increase	Net Migration
1	Brunswick County	126,353	130,897	4,544	3.6%	-471	5,015
2	Pender County	58,897	60,958	2,061	3.5%	69	1,992
3	Johnston County	191,094	196,708	5,614	2.9%	863	4,751
4	Cabarrus County	201,573	206,872	5,299	2.6%	975	4,324
5	Currituck County	25,664	26,331	667	2.6%	42	625
6	Chatham County	69,824	71,472	1,648	2.4%	-80	1,728
7	Clay County	10,819	11,074	255	2.4%	-63	318
8	Franklin County	64,659	66,168	1,509	2.3%	121	1,388
9	Wake County	1,049,143	1,072,203	23,060	2.2%	7,386	15,674
10	Union County	226,540	231,366	4,826	2.1%	998	3,828

Source: U.S. Census Bureau

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In the United States, the Brunswick County metro area (which includes Myrtle Beach and Conway, SC) is the second fastest growing area in the country (Port City Daily 2018). These faster growing populations add pressure to local environments, particularly via land use change for development to support the human population growth.

5.7 Possible Future Conservation Scenarios/Strategies

Future viability for the Magnificent Ramshorn depends on maintaining multiple resilient populations over time. While the species is currently presumed extirpated from the wild, species experts have identified several strategies that will be important to build the future viability of the species. These could include:

1. Maintain at least two secure captive populations of Magnificent Ramshorn until such time as there are enough populations in the wild to no longer necessitate such an effort.
2. Re-introduce Magnificent Ramshorn snails to at least two known historical locations and establish monitoring protocol to ensure re-introductions are successful; augment until populations are established and success criteria are met.
3. Introduce Magnificent Ramshorn snails to at least two other locations with suitable habitat within the historical range of the species. Use monitoring protocol to ensure re-introductions are successful; augment until populations are established.

5.8 Species Status Assessment Summary

The goal of this SSA is to describe the viability of the species by addressing the needs of the species in terms of the 3Rs – resiliency, redundancy, and representation. We considered the historical range and current condition of the species, and we detailed important influences on the current and future habitat for the species. Based on the findings of surveys, the current assessment is that the Magnificent Ramshorn lacks the three factors for viability. We cannot project future conditions because there are no known extant populations on which we can project those conditions. The Magnificent Ramshorn is presumed to be extirpated in the wild.

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Appendix A. Magnificent Ramshorn Survey Records

Location	Year Surveyed	Number of Specimens	Surveyor	Citation
Unknown	1903	unknown	William P. Seal	Adams 1993, p.2
Greenfield Lake	1908	unknown	Bartsch	Adams 1993, p.2
Greenfield Lake	unknown	8 whole snails; ASNP A1726A	Pilsbry	Adams 1993, p.7
Pleasant Oaks Pond	unknown	One specimen; NCSM 23435	A.R. Wood	NC Museum of Natural Sciences Collection Database
Pleasant Oaks Pond	unknown	42 shells, dry; NCSM 23436	A.R. Wood	NC Museum of Natural Sciences Collection Database
Captive Population	unknown	5 specimens; NCSM 23438	A.R. Wood	NC Museum of Natural Sciences Collection Database
Orton Pond	unknown	1 snail, dry; NCSM 31773	W.F. Adams	NC Museum of Natural Sciences Collection Database
Greenfield Lake	unknown	19 shells; USNM 536817	Bartsch	Adams 1993, p.7
Orton Pond	unknown	4 shells; USNM 529486	Bartsch	Adams 1993, p.7
Aquarium specimens	unknown	1 shell; USNM 205958	Bartsch	Adams 1993, p.7
Greenfield Lake	unknown	34 shells; USNM 193321	Bartsch	Adams 1993, p.7
Orton Pond	unknown	5 shells; NCSM P468-P471	Adams and Gerberich	Adams 1993, p.7
Orton Pond	unknown	3 snails; USNM 857935	Adams and Gerberich	Adams 1993, p.7
Pleasant Oaks Pond	unknown	shells; UMMZ uncatalogued	Adams and Wood	Adams 1993, p.7
Greenfield Lake	1985	1 shell; ANSP 85941A	Pilsbry	Adams 1993, p.7
Greenfield Lake	1985	5 shells; ANSP 85941	Pilsbry	Adams 1993, p.7
Orton Pond	6/9/1985	1 shell; NCSM 31774	W.F. Adams	NC Museum of Natural Sciences Collection Database
Orton Pond	6/13/1985	1 shell; NCSM 31772	W.F. Adams	NC Museum of Natural Sciences Collection Database

Location	Year Surveyed	Number of Specimens	Surveyor	Citation
Greenfield Lake	1986	1 shell; paratype; MCZ 86814	Pilsbry	Adams 1993, p.7
Orton Pond	1986	1 snail, dry; NCSM 31776	W.F. Adams	NC Museum of Natural Sciences Collection Database
Greenfield Lake	1987	3 shells; ANSP 87342	Pilsbry	Adams 1993, p.7
Orton Pond	1987	1 shell; NCSM 31775	W.F. Adams	NC Museum of Natural Sciences Collection Database
Aquarium specimens	1988	aquarium specimens, shells; ASNP 88945	Pilsbry	Adams 1993, p.7
Orton Pond	1988	unknown	Adams and Gerberich	Adams 1993, p.2
Island Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Spring Branch	1985-1990	none found	Adams	Adams 1993, appendix D
Bradley Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Craig Creek ditch	1985-1990	none found	Adams	Adams 1993, appendix D
Northeast Cape Fear	1985-1990	none found	Adams	Adams 1993, appendix D
Goshen Swamp	1985-1990	none found	Adams	Adams 1993, appendix D
Grove Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Muddy Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Maxwell Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Rock Fish Creek	1985-1990	none found	Adams	Adams 1993, appendix D

Location	Year Surveyed	Number of Specimens	Surveyor	Citation
Millers Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Livingston Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Waymans Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Friar Swamp	1985-1990	none found	Adams	Adams 1993, appendix D
Big Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Cow Pen Branch	1985-1990	none found	Adams	Adams 1993, appendix D
Bogue Swamp	1985-1990	none found	Adams	Adams 1993, appendix D
White Marsh	1985-1990	none found	Adams	Adams 1993, appendix D
Juniper Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Clear Branch	1985-1990	none found	Adams	Adams 1993, appendix D
Waccamaw River	1985-1990	none found	Adams	Adams 1993, appendix D
Grissett Swamp	1985-1990	none found	Adams	Adams 1993, appendix D
Seven Creeks	1985-1990	none found	Adams	Adams 1993, appendix D
Lumber River	1985-1990	none found	Adams	Adams 1993, appendix D
Hood Creek	1985-1990	none found	Adams	Adams 1993, appendix D

Location	Year Surveyed	Number of Specimens	Surveyor	Citation
Jackey's Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Mallory Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Town Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Dews Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Pretty Pond	1985-1990	none found	Adams	Adams 1993, appendix D
MOTSU pond complex	1985-1990	none found	Adams	Adams 1993, appendix D
Royal Oak Swamp	1985-1990	none found	Adams	Adams 1993, appendix D
Lockwood's Folly River	1985-1990	none found	Adams	Adams 1993, appendix D
Shallotte River	1985-1990	none found	Adams	Adams 1993, appendix D
Singletree Swamp	1985-1990	none found	Adams	Adams 1993, appendix D
South River	1985-1990	none found	Adams	Adams 1993, appendix D
Black River	1985-1990	none found	Adams	Adams 1993, appendix D
Coharie Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Williams Old Mill Branch	1985-1990	none found	Adams	Adams 1993, appendix D
Six Runs Creek	1985-1990	none found	Adams	Adams 1993, appendix D

Location	Year Surveyed	Number of Specimens	Surveyor	Citation
Burgaw Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Moores Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Lake Singletary	1985-1990	none found	Adams	Adams 1993, appendix D
Cape Fear River	1985-1990	none found	Adams	Adams 1993, appendix D
Hammonds Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Carvers Creek	1985-1990	none found	Adams	Adams 1993, appendix D
Lyons Swamp	1985-1990	none found	Adams	Adams 1993, appendix D
Clear Pond	1991	none found	Adams	Adams 1993, appendix C
Boiling Spring Lake	1991	none found	Adams and Adams	Adams 1993, appendix C
Orton Rice Field Canal	1991	none found	Adams and Adams	Adams 1993, appendix C
Garden Lake	1991	none found	Adams and Adams	Adams 1993, appendix C
Small Orton Pond discharge canal	1991	none found	Adams and Adams	Adams 1993, appendix C
Orton Pond	1991	1 found	Adams and Owens	Adams 1993, appendix C
LakeTabor	1991	none found	Adams and Adams	Adams 1993, appendix C
Silver Lake	1991	none found	Adams and Adams	Adams 1993, appendix C
Bryants Mill Creek	1992	none found	Adams and DuMond	Adams 1993, appendix C
Magnolia Spring	1992	none found	Adams and DuMond	Adams 1993, appendix C
Burnt Mill Creek	1992	none found	Adams	Adams 1993, appendix C
Archers Creek	1992	none found	Adams and Porter	Adams 1993, appendix C

Location	Year Surveyed	Number of Specimens	Surveyor	Citation
Lake Waccamaw	1992	none found	Adams and Adams	Adams 1993, appendix C
Ollander Memorial Gardens Pond	1992	none found	Adams	Adams 1993, appendix C
Pond in Hugh MacRae Park	1992	none found	Adams	Adams 1993, appendix C
Temporary pond on Lullwater Drive	1992	none found	Adams and Lewis	Adams 1993, appendix C
Oldetowne Millpond	1992	none found	Adams	Adams 1993, appendix C
Municipal Golf Course retention pond	1992	none found	Adams	Adams 1993, appendix C
Burnt Mill Creek	1992	none found	Adams	Adams 1993, appendix C
County Line Borrow Pit	1992	none found	Adams	Adams 1993, appendix C
Downey Branch	1992	none found	Adams	Adams 1993, appendix C
Pleasant Oaks Pond	1992	5 plus 2 egg masses	Adams and Humphries	Adams 1993, appendix C
Beaverdam Pond	1992	none found	Adams and Humphries	Adams 1993, appendix C
First Pond (SC)	1992	none found	Adams and Dillon	Adams 1993, appendix C
Second Pond (SC)	1992	none found	Adams and Dillon	Adams 1993, appendix C
Liberty Pond	1992	none found	Adams	Adams 1993, appendix C
Boiling Springs Lake	1992	none found	Adams	Adams 1993, appendix C
Orton Creek	1992	none found	Adams	Adams 1993, appendix C
Pear Orchard Pond	1992	none found	Adams and Cooke	Adams 1993, appendix C
Pleasant Oaks Pond	1992	30-40 found	Adams and Wood	Adams 1993, appendix C
Town Creek Beaver Ponds	1992	none found	Adams	Adams 1993, appendix C

Location	Year Surveyed	Number of Specimens	Surveyor	Citation
McKinzie Pond	1992	none found	Adams, Alderman, McGrath	Adams 1993, appendix C
Rice Creek	1992	none found	Adams and Parker	Adams 1993, appendix C
Ashes Creek Ponds	1992	none found	Adams	Adams 1993, appendix C
Holly Shelter Creek	1992	none found	Adams	Adams 1993, appendix C
Motts Creek	1992	none found	Adams	Adams 1993, appendix C
Barnards Creek	1992	none found	Adams	Adams 1993, appendix C
Ness Creek	1992	none found	Adams	Adams 1993, appendix C
Prince George Creek	1992	none found	Adams	Adams 1993, appendix C
Smith Creek	1992	none found	Adams	Adams 1993, appendix C
Pleasant Oaks Pond	1993	4 snails; NCSM 32509	W.F. Adams	NC Museum of Natural Sciences Collection Database
Randall Parkway Lake	1993	none found	Adams	Adams 1993, appendix C
Greenfield Lake	1993	none found	Adams	Adams 1993, appendix C
Aquarium specimens, orginal stock from Pleasant Oaks Pond	1994	110 snails; NCSM 31777	W.F. Adams	NC Museum of Natural Sciences Collection Database
natal pond	1997	none found	A.R. Wood	Wood NCWRC Permit Report 2004
natal pond	1998	none found	A.R. Wood	Wood NCWRC Permit Report 2004
natal pond	1999	none found	A.R. Wood	Wood NCWRC Permit Report 1999
natal pond	2000	none found	A.R. Wood	Wood NCWRC Permit Report 2000

Location	Year Surveyed	Number of Specimens	Surveyor	Citation
natal pond	2001	none found	A.R. Wood	Wood ES Permit Report 2010
natal pond	2002	none found	A.R. Wood	Wood ES Permit Report 2010
natal pond	2003	none found	A.R. Wood	Wood ES Permit Report 2010
natal pond	2004	none found	A.R. Wood	Wood ES Permit Report 2010
blackwater creek	2004	none found	A.R. Wood	Wood ES Permit Report 2010
blackwater creek	2005	none found	A.R. Wood	Wood ES Permit Report 2010
natal pond	2005	none found	A.R. Wood	Wood ES Permit Report 2010
natal pond	2006	none found	A.R. Wood	Wood ES Permit Report 2010
Bonnetts Creek	2006	none found	A.Rodgers, N.Banish	NCWRC PAWS Database
Bonnetts Creek	2006	none found	A.Rodgers, N.Banish	NCWRC PAWS Database
natal pond	2007	none found	A.R. Wood	Wood ES Permit Report 2010
Harris Swamp	2007	none found	K.N. Medlin, A.M. Burroughs, C.L. Gregory, J.S. Gray, C.S. Underwood, C.D. Manley	NCWRC PAWS Database
blackwater creek	2008	none found	A.R. Wood	Wood ES Permit Report 2010
Town Creek	2008	none found	B.K. Jones, K.K. Irvine, J.L. Williams, J.A. Fridell, A.R. Wood	NCWRC PAWS Database
Pleasant Oaks Pond	2012	none found	A.R.Wood, C.Wood, S.McRae	McRae, pers. comm. 2019
Pleasant Oaks Pond	2013	none found	A.R.Wood	Wood ES Permit Report 2014
Rice Creek	2013	none found	A.R.Wood	Wood ES Permit Report 2014
Town Creek	2013	none found	A.R.Wood	Wood ES Permit Report 2014
Pleasant Oaks Pond	2014	none found	A.R.Wood	Wood ES Permit Report 2015

Location	Year Surveyed	Number of Specimens	Surveyor	Citation
Rice Creek	2014	none found	A.R.Wood	Wood ES Permit Report 2015
Town Creek	2014	none found	A.R.Wood	Wood ES Permit Report 2015
Rice Creek	2015	none found	A.R.Wood	Wood ES Permit Report 2016
Town Creek	2015	none found	A.R.Wood	Wood ES Permit Report 2017
Green Swamp Pond	2015	none found	B.K. Jones, S.E. McRae, Z.West, L.Kalies	NCWRC PAWS Database
Rice Creek	2016	none found	A.R.Wood	Wood ES Permit Report 2017
Town Creek	2016	none found	A.R.Wood	Wood ES Permit Report 2017
Tributary to Greenfield Lake	2016	none found	A.R.Wood	Wood ES Permit Report 2017
Indian Creek	2016	none found	A.R.Wood	Wood ES Permit Report 2017
Long Creek	2016	none found	J.M. Alderman, J.D. Alderman, L.Williams	NCWRC PAWS Database
Sills Creek	2016	none found	J.M. Alderman, J.D. Alderman, L.Williams	NCWRC PAWS Database
Black River	2016	none found	R.J.Heise, T.R.Black, T.R.Fox, W.T.Wood, M.Walter	NCWRC PAWS Database
Orton preserve pond	2016	none found	B.K.Jones, W.T.Wood, Z.West	NCWRC PAWS Database
Orton Creek	2016	none found	B.K.Jones, W.T.Wood, Z.West	NCWRC PAWS Database
Town Creek	2017	none found	A.R.Wood	Wood ES Permit Report 2018
Tributary to Greenfield Lake	2017	none found	A.R.Wood	Wood ES Permit Report 2018
Tributary to Pleasant Oaks Pond	2017	none found	A.R.Wood	Wood ES Permit Report 2018

Location	Year Surveyed	Number of Specimens	Surveyor	Citation
Indian Creek	2017	none found	A.R.Wood	Wood ES Permit Report 2018
Dews Creek	2017	none found	B.K.Jones, M.D. Fowlkes, A.Popp, J.McAlister	NCWRC PAWS Database
Town Creek	2017	none found	B.K.Jones, M.D. Fowlkes, A.Popp, J.McAlister	NCWRC PAWS Database
Town Creek	2018	none found	A.R.Wood	Wood ES Permit Report 2019
Tributary to Greenfield Lake	2018	none found	A.R.Wood	Wood ES Permit Report 2019
Indian Creek	2018	none found	A.R.Wood	Wood ES Permit Report 2019
Island Creek	2018	none found	A.R.Wood	Wood ES Permit Report 2019
Holly Shelter Gamelands	Sept 2018	17 locations; none found	B.K.Jones, I.Knox	B.K.Jones, pers. comm.
Green Swamp Gamelands & MOTSU	Nov 2018	none found	I.Knox	B.K.Jones, pers. comm.

ASNP = Academy of Natural Sciences of Philadelphia
MCZ = Museum of Comparative Zoology, Harvard University
USNM = United States National Museum (Smithsonian Institution)
NCSM = North Carolina State Museum of Natural Sciences
UMMZ = University of Michigan, Museum of Zoology