BOG TURTLE
CONSERVATION PLAN for NORTH CAROLINA

July 13, 2023

NORTH CAROLINA WILDLIFE RESOURCES COMMISSION

THANK YOU TO ALL WHO CONTRIBUTED TO THE PLAN!

We want to thank the many organizations and people who contributed to the Bog Turtle Conservation Plan for North Carolina. It is a much stronger plan with the incredible involvement of these collaborators. We appreciate the time they took to provide valuable input and feedback. A big thank you to all who were involved!

Contributors to the NC Bog Turtle Conservation Plan

Project Bog Turtle (PBT), N.C. Wildlife Resources Commission staff and Commissioners, U.S. Fish & Wildlife Service (USFWS), U.S. Forest Service (USFS), National Park Service (NPS), Natural Resources Conservation Service (NRCS), The Nature Conservancy (TNC), NC State Parks, NC Natural Heritage Program, NC State College of Veterinary Medicine, NC Museum of Natural Sciences, Clemson University, North Carolina Wildlife Federation (NCWF), Tangled Bank Conservation LLC, Conserving Carolina, Blue Ridge Conservancy, Defenders of Wildlife, and Catawba Lands Conservancy.

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Cover page (from left to right, clockwise): Juvenile bog turtle (Gabrielle Graeter); probing for bog turtles (NCWRC); adult bog turtle (Jeff Hall); Juvenile bog turtle (Gabrielle Graeter)

EXECUTIVE SUMMARY

The bog turtle (*Glyptemys muhlenbergii*) occurs in the Blue Ridge Mountains and upper Piedmont eco-regions of North Carolina and is federally listed as Threatened by Similarity of Appearance with the northern population, which is federally listed as Threatened. Bog turtle habitat is typically dominated by sedges and sphagnum moss, has thick, soft muck, saturated soils, and numerous springs, with areas lacking canopy and others having shrubs and scattered small trees. Although there are 120 wetlands in NC with one or more records of a bog turtle, only 15 of those have had 10 or more individual bog turtles captured over the past 10 years. Sites with robust populations of 30 or more turtles likely number fewer than 10. Since the bog turtle was federally listed in 1997, it has become clear that the species faces the same threats in the southern United States as in the north. There is significant concern for this species in North Carolina as relatively few bog turtle populations remain, and most of those appear to be in decline. The North Carolina Wildlife Resources Commission (NCWRC) and partners are working to understand and address the numerous threats and implement persistent management, including restoration, of bog turtle habitat in the state. Many of the threats that this species faces originate from human land use, such as development and land use changes in the watershed. Wetland loss and degradation, vegetative succession, altered hydrology, increased predation, vehicles, barriers to movement, invasive species, disease, climate change, inappropriately managed grazing, and illegal collection and trade are threats to this species and its habitat. Ensuring the long-term viability across its current range in North Carolina for the next 100 years will require a continued multi-faceted approach to address the threats to bog turtles, which often vary in importance from site to site. Filling information gaps about distribution, monitoring populations, conducting research into limiting factors, habitat management and restoration, population management, land protection, outreach, and regulations and enforcement are all strategies the NCWRC will continue to support and use to achieve this goal.

BIOLOGICAL INFORMATION

Description and Taxonomic Classification

The bog turtle (*Glyptemys muhlenbergii*) is the smallest freshwater turtle in North America. Its most distinguishing feature is a large, bright yellow to orange blotch on each side of its brown head. The carapace and plastron are light brown to dark brown or black, and the scutes on the carapace sometimes have a light center or pattern of lines radiating out. It has a moderately domed carapace with a low keel, and the plastron is hinge-less. According to Ernst and Lovich (2009), the maximum straight-line carapace length (SCL) is 11.5 cm (4.5 in) for males and 9.6 cm (3.8 in) for females. In North Carolina, the maximum SCL recorded for males is similar at 11.1 cm SCL, but there is a record of a slightly larger female (11.0 cm SCL).

The *Glyptemys* genus comprises only two species — the bog turtle and the wood turtle (*Glyptemys insculpta*). Before 2001, the bog turtle and wood turtle were considered part of the genus *Clemmys*, but morphological and genetic analyses indicated these two species were much more closely related to each other than to the spotted (*Clemmys guttata*) or western pond turtle (*Actinemys marmorata*; Holman and Fritz 2001). Thus, the bog turtle and wood turtle were moved to the newly created *Glyptemys* genus, leaving the spotted turtle as the sole member of the *Clemmys* genus.

Life History and Habitat

Female bog turtles are sexually mature at about 6-7 years, though maturation can vary geographically (Ernst and Lovich 2009). They typically mate in spring, from March-June, and 21-31 days after copulation, females lay their eggs, with most nests laid from May-July. They choose locations in sedge and rush tussocks or sphagnum moss and lay from 1-6 eggs, with averages of 3.1-eggs reported from a Maryland study and 3.28-eggs from a recent study in North Carolina (Wilson et al. 2003, Knoerr 2018).

The species is found in a variety of spring-fed bogs and fens that have soft saturated soils, including the Swamp-Forest Bog Complex, Southern Appalachian Bog, French Broad Valley Bog, Low Mountain Seepage Bog, and Southern Appalachian Fen (Schafale 2012). They are also found in "meadow bogs," which have a plant community degraded from their original condition due to anthropogenic influences (Herman 2000); therefore, meadow bogs are not included in Schafale's classification system (2012). Bog turtle habitat is typically dominated by sedges and sphagnum moss, has thick, soft muck, saturated soils, and numerous springs, with some areas lacking canopy and others having shrubs and scattered small trees (Buhlmann et al. 2008, Feaga et al. 2012). Plants often associated with these wetlands include sedges (*Carex* spp.), rushes (*Scirpus* sp., *Juncus* sp.), sphagnum moss (*Sphagnum* spp.), skunk cabbage (*Symplocarpus foetidus*), poison sumac (*Rhus vernix*), alder (*Alnus* spp.), willows (*Salix* spp.), and a variety of ferns (Herman and George 1986, Tryon 1990). Meadow bogs have many of the same components of the classified bog community types, including similar hydrology, soil types, and vegetation, but are sometimes lacking the same plant diversity. Bog turtles are often found in meadow bogs, including those that are currently grazed or have a history of grazing.

Gary Peeples/USFWS

Most publications describe the habitat features observed in sites inhabited by bog turtles rather than specifying the habitat needs of bog turtles. Herein we define “suitable habitat” and “high-quality bog turtle habitat” based on what we know of bog turtle ecology and habitat use in North Carolina (see Glossary). The terms are likely applicable to bog turtle habitat in other states and regions.

1. *Suitable bog turtle habitat will contain the following, at a minimum*:
   1) soft, saturated soils
   2) spring-fed hydrology, and
   3) an area with low vegetation (no canopy) that gets full sun.
2. *High-quality bog turtle habitat consists of the above plus the following characteristics*:
   1) areas with deep, loose, low-strength soils (Feaga et al. 2013),
   2) presence of sphagnum mosses, rushes, sedges, and some wetland shrub species,
   3) mosaic of low and shrubby vegetation with one or more relatively large areas with very low vegetation (ideally sphagnum, but also rushes and sedges) that receive full southern exposure sun,
   4) relatively unaltered hydrology with stable groundwater levels that are 8 cm ± 1 cm (3.1 in ± 0.4 in) average depth from surface over multiple years, without flooding and inundation (Feaga 2010),
   5) presence of subsurface root structures and/or tunnels,
   6) adequate vegetation to conceal turtles when basking on surface,
   7) minimal land-based threats within habitat and / or adjacent property (e.g., busy roads, exotic-invasive plant species, etc.).

Southern Appalachian Bog (Gary Peeples/USFWS)

Distribution and Population Status

In North Carolina, the bog turtle is found in the Blue Ridge Mountains and upper Piedmont eco-regions, and records exist within the Middle Tennessee-Hiwassee, Upper Tennessee, French Broad-Holston, Savannah, Santee, Upper Pee Dee, Kanawha, and Roanoke river basins (Beane et al. 2010; NCNHP 2021). The species has been documented in the following 25 counties: Alexander[1,2], Alleghany, Ashe, Avery, Buncombe, Burke, Caldwell[2], Catawba[2], Cherokee[1,2], Clay, Forsyth[1,2], Gaston, Graham[1,2], Henderson, Iredell[1], Macon, McDowell, Mitchell[2], Polk[2], Rutherford[2], Surry, Transylvania, Watauga, Wilkes, and Yancey (Fig. 1; NCNHP 2020).

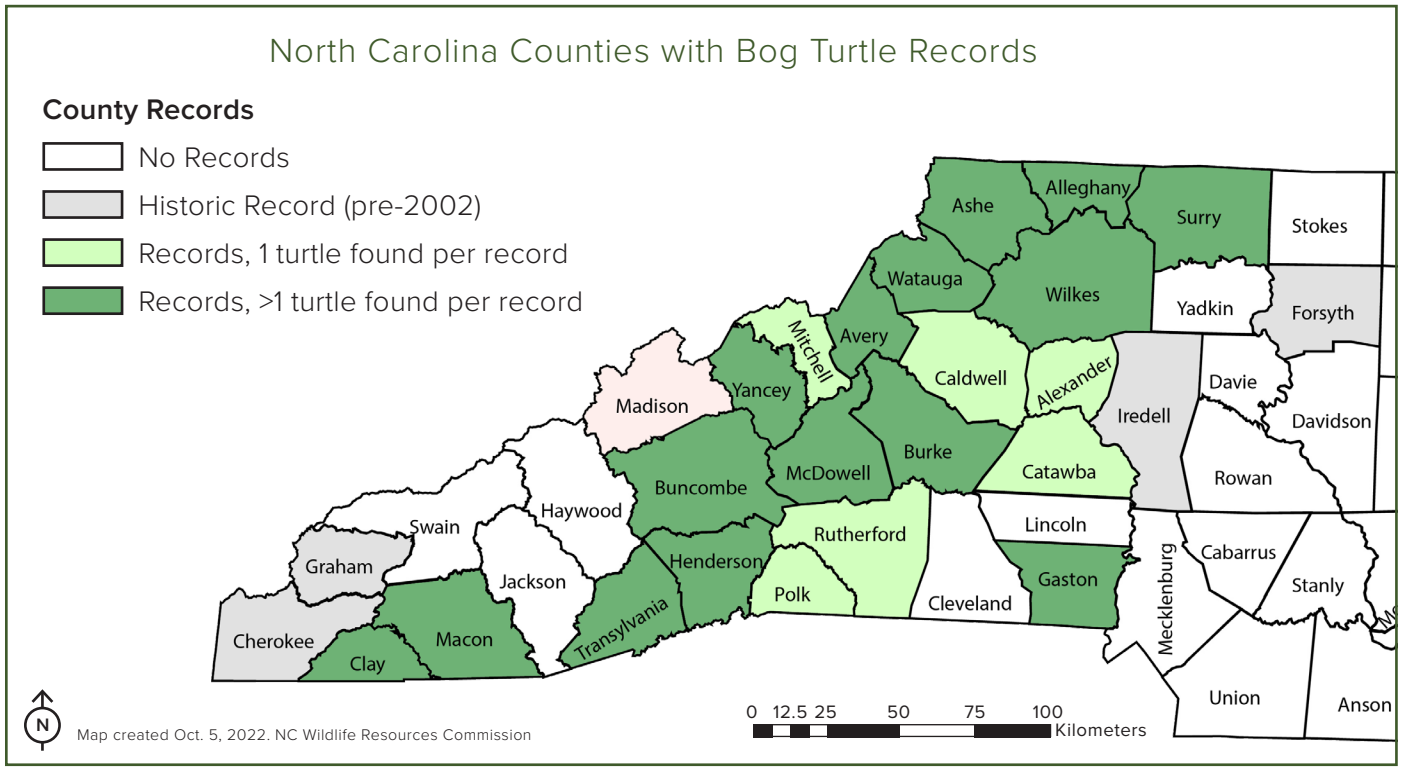


Figure 1. *North Carolina counties with bog turtle records, including counties that only have historical records (4 counties), counties with at least one extant record but with only one turtle ever observed per record (6 counties), and counties with at least one extant record with more than one turtle observed (15 counties). A record is historical if there is no documentation of the species from 2002-2021.*

[1] Counties where a live bog turtle has not been found in recent surveys (i.e., last 20 years, from 2002-2021).

[2] Counties that only have single road records and/or sites with only one turtle ever captured.

The southern population of bog turtle is federally listed as Threatened due to Similarity of Appearance (T(S/A)) and state listed in North Carolina as Threatened. The species is ranked S2 (State Imperiled; typically, 6-20 occurrences or few remaining individuals) by the North Carolina Natural Heritage Program and has a global rank of G2 (Imperiled – at high risk of extinction; NCNHP 2020, NatureServe 2021). The IUCN Rank for the species is Critically Endangered.

Surveys for the species have occurred regularly since the mid-1970s in the state (Herman 2003). There are 167 confirmed occurrence records for the species in the state — 36 of which are solely road records with no habitat present nearby (likely individuals dispersing on landscape), seven are locations without any known wetland habitat, and four are locations where the habitat (and often the exact location) is unknown (Fig. 2). One hundred twenty (120) location records are from wetland habitat — 38 of which are not considered a population because only one turtle was found at each of these locations. Of the 120 records from wetland habitat, only 82 sites have a record of two or more individual turtles being captured and have the potential to be considered a population based on known numbers (Fig. 2).

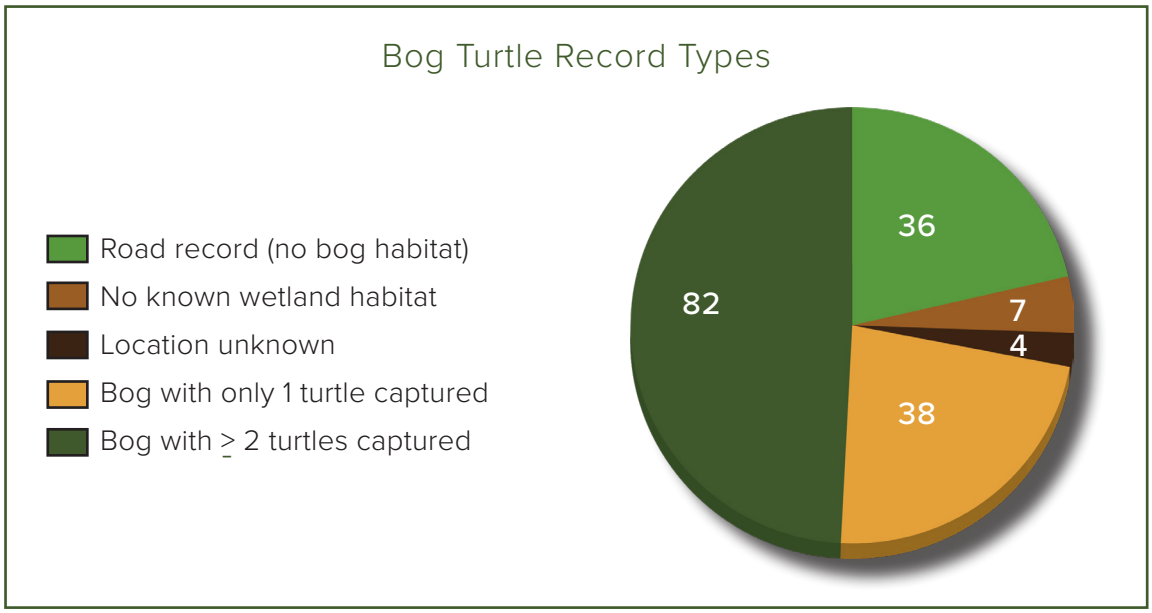


Figure 2. *Breakdown of the number of each record type for bog turtles in North Carolina as of February 10, 2021. Of 167 total locations with bog turtle records, only 82 have a record of 2 or more individual turtles being captured.*

There are 120 wetlands in North Carolina that have bog turtle records, but only 23 of those have had ≥10 individual bog turtles captured over the past 20 years (Fig. 3). Only 15 sites have had ≥10 individual bog turtles captured in the most recent 10 years, indicating a decline from the original 23 sites. A population of 10 turtles is below the species' Minimum Viable Population threshold of 15 adult females (Shoemaker et al. 2013). This species generally has a 1:1 female-male ratio, meaning we are aiming for a minimum of 30 adults (15 females, 15 males). However, we only know of 10 sites that have had ≥30 turtles captured over the past 20 years, and this is slightly inflated because our numbers in this calculation include hatchlings and juveniles (Fig. 3). Using this definition, only 8% (10 populations) of the original 120 wetlands with bog turtle records are considered potentially viable populations today (Shoemaker et al. 2013). Survey effort was not recorded during the first portion of the 20-year period examined; therefore, that measure cannot be incorporated into our analyses. Further, there have been constraints on our ability to survey sites evenly due to property access and staff capacity issues, and limitations of available monitoring techniques. Hence, we focus survey and monitoring efforts on a subset of sites that include the most viable populations. We deduce that if the best, most viable and abundant populations are in decline, then populations at sites where we rarely locate a turtle, are also in decline. Recently we have developed additional monitoring techniques and received additional funding that is allowing us to evaluate understudied and historical populations. Soon we will have a more comprehensive summary of the status of the species. Until then, the best available data indicate that there are ≤10 robust bog turtle populations in North Carolina.

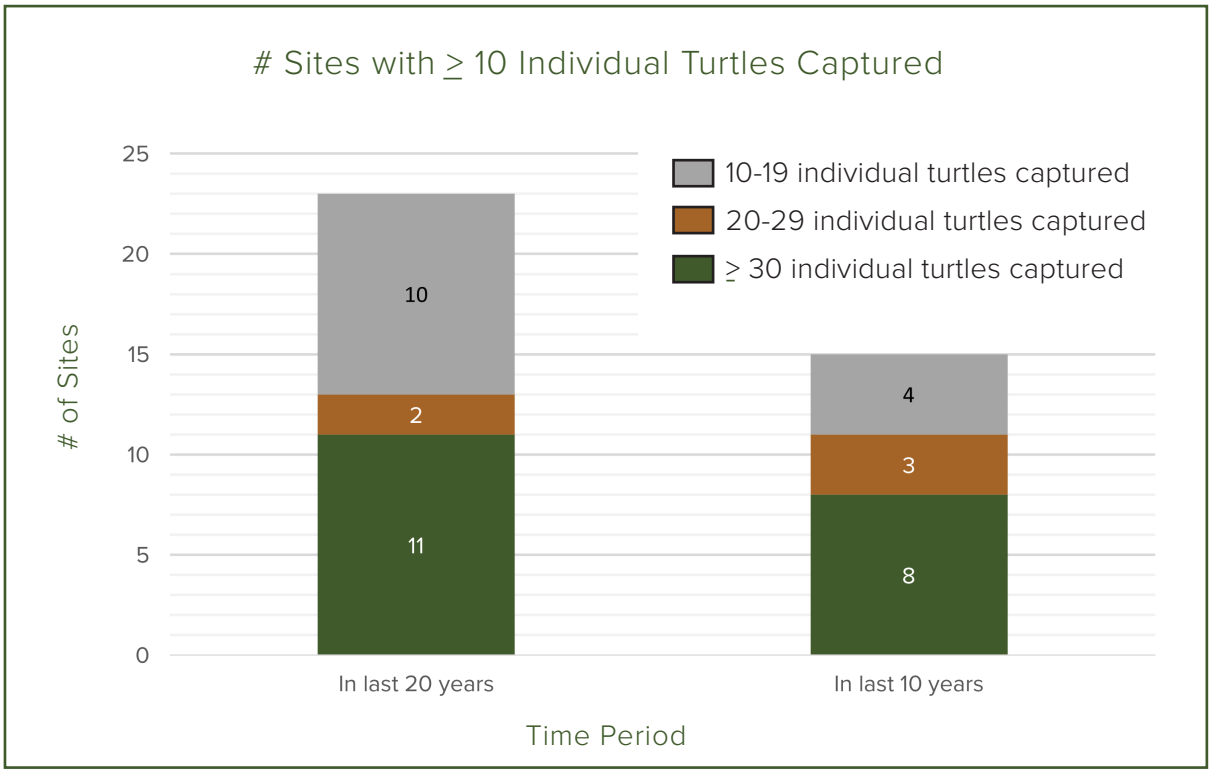


Figure 3. *Twenty-three sites have had ≥10 individual bog turtles captured over the past 20 years in western North Carolina. The number of sites with 10-19, 20-29, and ≥ 30 individual turtles observed over the past 20 years (2001-2020) and past 10 years (2011-2020) differ, but overall, the number of sites with bog turtles present has declined.*

Tutterow et al. (2017) found adult survivorship of bog turtles in North Carolina varied from 0.855 to 0.942 among eight intensively sampled populations — all below a 0.96 adult survival estimate documented for northern bog turtle populations (Shoemaker et al. 2013). Because these eight sites include the most robust known bog turtle populations in the state, other, less robust populations in North Carolina likely exhibit relatively low survival. Juvenile survivorship was evaluated at three sites that had adequate data and varied from 0.510 to 0.68, with the lower survivorship of 0.510 from a population in decline (Tutterow et al. 2017). We also observed a skew in age classes across all but two sites, with populations dominated by older individuals and few juveniles (Tutterow et al. 2017). Population models for a subset of these sites indicated that only the two most robust populations known to NC are considered stable, with all other known populations considered to be in decline (Tutterow et al. 2017, Knoerr 2018, NCWRC unpublished data). These estimates suggest without additional efforts, local and regional extirpations may occur (Pittman et al. 2011; Tutterow et al. 2017, Knoerr 2018).

Historical and Ongoing Conservation Efforts

There is a long history of bog conservation efforts by a diverse partnership in western North Carolina. Partners include, but are not limited to the following, Project Bog Turtle (PBT), NCWRC, U.S. Fish and Wildlife Service (USFWS), National Park Service, U.S. Forest Service, NC State Parks, NC Museum of Natural Sciences, NC Natural Heritage Program, The Nature Conservancy (TNC), Conserving Carolina, Blue Ridge Conservancy, Catawba Lands Conservancy, Tangled Bank Conservation, private landowners, and universities including UNC-Asheville, Appalachian State University, Clemson University, and Western Carolina University. In the 1970s, Dennis Herman and Robert Zappalorti began surveying for bog turtles in North Carolina and discovered many populations. In the late 1980s, several other NC Herpetological Society members, including Jeff Beane and Thomas Thorp, began to assist with bog turtle surveys. In 1995, Project Bog Turtle (PBT) was established and has been dedicated to locating and surveying populations and conserving bog turtles and their habitat in North Carolina. Since it was founded, PBT has hosted an annual meeting to coordinate and share information with collaborators.

Bog turtle nest (Gabrielle Graeter)

In the early 2000s, NCWRC biologists became more involved and began leading bog turtle survey and habitat management and restoration efforts in close collaboration with partners, including PBT. Increasingly, NCWRC biologists have been involved in monitoring bog turtles, primarily through collection of mark-recapture population data, but also through telemetry and monitoring of nests and habitat condition. The population dataset has yielded valuable information about population demographics, survivorship, population size, and trends.

NCWRC biologists have also played a key role in protection of mountain bogs via collaboration with private landowners, land trusts, and other partners to bring about fee-simple purchases, donations, and conservation easements. NCWRC has led and coordinated multiple research studies to increase our ability to make science-based management and conservation decisions for the species, including research on hydrology, nesting success, predation, and habitat use. Recently, NCWRC has advanced knowledge about nest success and egg survivorship, which has informed population management activities, including nest protection, predator deterrence, and head-starting methods.

Interest in conservation and management of mountain bogs has broadened and intensified. In 2015, the Mountain Bogs National Wildlife Refuge was established, with most of the refuge's footprint in North Carolina. The refuge will complement and expand existing conservation efforts by offering additional opportunities to protect sites via fee title or conservation easement and other avenues such as landowner stewardship agreements. Around the same time, a new partnership, the Bog Learning Network, was formed. The Bog Learning Network is a consortium of scientists and land managers working to advance the restoration and management of Southern Appalachian Bogs. In North Carolina, biologists with the USFWS and NCWRC have begun working more closely with biologists who work in the northern range of the species. This group may develop a regional bog turtle conservation plan for the southern population like the Conservation Plan written for the northern population (Erb 2019), which could be helpful in gaining additional funding for bog turtle conservation. Going forward, collaboration and communication with these partners will be essential to meeting conservation goals for the bog turtle in North Carolina.

Cordie Diggins, a wildlife diversity technician with the NCWRC, probes the ground searching for bog turtles in Ida's Bog. (NCWRC)

THREAT ASSESSMENT

Reason for Listing

The USFWS listed the northern population of bog turtles as federally Threatened on November 4, 1997, noting that the species "is threatened by a variety of factors including habitat degradation and fragmentation from agriculture and development, habitat succession due to invasive exotic and native plants, and illegal trade and collecting." The southern population was simultaneously listed due to Similarity of Appearance to the northern population of this species (USFWS 1997). In the Federal Register, the USFWS identified its reasons for not proposing the southern population for listing: "(1) the recent discovery of bog turtle sites in the Piedmont physiographic province of North Carolina, well outside the species' previously known Appalachian Mountains range; (2) limited information regarding threats; and (3) inadequate survey coverage within the southern range" (USFWS 1997). Further, the USFWS stated that "A comprehensive status survey of the southern population is currently underway and is anticipated to be completed by December 1999. The Service agrees that it is premature to draw any conclusions regarding the status of the southern population until additional survey and threat information becomes available" (USFWS 1997). In 2003, a status report on the southern population was completed (Herman 2003). In North Carolina, an additional 36 records in 10 counties were discovered — three of which were new county records (Herman 2003). At the time, the author estimated that there were 53 populations in the state, with 30 designated as "viable or potentially viable," distributed across 21 counties in North Carolina (Herman 2003).

> There is significant concern for the bog turtle in North Carolina as relatively few populations remain, and most appear to be in decline.

In the "Bog Turtle Northern Population Recovery Plan," which officially applies only to the northern population, the following are cited as reasons for listing the species: (1) Continued loss, alteration, and fragmentation of habitat, (2) Illegal trade and collection, (3) Inadequacy of existing regulatory mechanisms to protect bog turtle habitat, and (4) Disease and predation (USFWS 2001). The species faces the same threats in the southern United States (Tutterow et al. 2017). In fact, the USFWS recently completed a 90-day finding for a petition to list the southern population and will initiate a status review (Federal Register 2022). There is significant concern for this species in North Carolina as relatively few bog turtle populations remain, and most appear to be in decline (Knoerr 2018, NCWRC unpublished data 2021). North Carolina General Statute (G.S.) 113-334 (a) gives all native or resident wild animals which are on the federal lists of endangered or threatened species pursuant to the Endangered Species Act, the same status on the North Carolina protected animals lists.

(Jeff Hall)

Present and Anticipated Threats

Threats to bog turtles include habitat loss and degradation, altered hydrology, vegetative succession within the wetland, inappropriately managed grazing, invasive species, increased predation, vehicles, barriers to movement, disease, climate change, and illegal collection and trade. Many of these threats influence or are somehow interconnected with others, some are long-term and may affect all bogs (e.g., climate change, invasive species), and others are immediate and vary in intensity depending on the specifics of each site. The impacts of some threats on the population and bog habitat are largely unknown, but research and monitoring are beginning to elucidate the significance of various threats and identify new ones. Presently, NCWRC and partners are taking conservation and management actions with the best available data and information and using an adaptive management approach to continually improve these efforts.

Wetland Loss and Degradation

About 80-90% of bog habitats have been lost over decades of land-use conversion (Weakley and Schafale 1994, Noss et al. 1995). Wetland loss and degradation occur when bogs are converted to another use such as a pond, agricultural field, or urban area or when only a remnant of the habitat remains. Remaining bogs are subject to a myriad of side effects of changes in the surrounding landscape. For example, an increase in impermeable surface area generally leads to increased stormwater run-off and erosion, as well as increased loads of nutrients and pollutants from urbanized landscapes. Similarly, agricultural activity within the watershed of a bog can result in runoff of nutrients, toxins, and sediments (Torok 1994, Gustafson and Wang 2002, Feaga 2010, USFWS 2014). Even when some wetland remains, it is often reduced in size and/or ecological integrity, with the habitat quality diminished, which may have impacts on bog turtle occupancy and abundance (Stratmann et al. 2019). Almost every remaining mountain bog shows evidence of past human manipulation. Many sites were ditched and drained for agriculture or livestock or flooded to form ponds or lakes and these activities are still occurring. Most known wetlands with bog turtles in North Carolina are privately owned with no long-term protective measures in place. Lack of land protection leaves many sites vulnerable to future habitat loss through ditching, draining, and other harmful activities. However, good landowner stewardship can maintain or improve habitat while in that individual or family's ownership.

Mountain bog (Jeff Hall)

Altered Hydrology

Changes in a watershed and within a bog can have detrimental effects on the hydrology of a bog and the resident bog turtles (Torok 1994, Brennan et al. 2001, Feaga 2010). Flooding occurs due to poor stream bank condition, human-made barriers that hold back or alter water flow (e.g., driveways, berms, ditches), increases in storm flow volumes due to development, and sometimes due to beaver activity, and can be exacerbated by extreme storm events. Flooding affects bog turtle nesting and hatching success, and specifically, studies in NC and elsewhere found that inundation from flooding caused egg failure (Zappalorti et al. 2015, Knoerr et al. 2020). In a relatively unaltered landscape and watershed, beaver activity may benefit bog turtles (see Conservation Actions). However, beaver activity can be detrimental to a bog turtle population if a site is very small and the entire wetland is flooded for long periods of time (Sirois et al. 2014). This scenario is typically observed when a wetland has been reduced in size due to human activities and the surrounding landscape is altered. In this case, when the beavers flood the wetland, turtles may have no suitable habitat available and thus, very little nest success. In addition to flooding, draining of wetlands can be a side effect of increased storm flows that create head cuts which increase the amount of outflow from the bog. Indirect draining occurs when changes in the watershed affect groundwater recharge, such as residential and commercial wells or impervious surfaces, and thus impact the spring heads that supply the bogs.

Bog turtle habitat with overgrown vegetation (NCWRC)

Wetland Vegetative Succession

Diminished natural disturbance factors, increased nutrient input, and altered hydrology result in natural vegetative succession within bogs, whereby herbaceous grasses, forbs, and shrubs are replaced over time by large shrubs, saplings, and eventually trees. Because bog turtles and other species that require direct sun struggle to nest and produce young successfully, and do not have adequate sunlight for thermoregulation and other activities, they may leave these sites or perish.

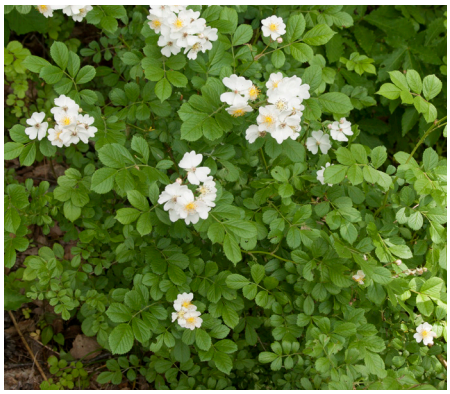
Inappropriately Managed Grazing

The presence of grazers can provide many benefits to bog turtles and their habitat via bioturbation and grazing (see Vegetation Management in the Conservation Actions section). However, inappropriately managed cattle or other livestock may impact bog turtle populations. Bog turtle nests may be trampled and eggs destroyed by cattle (Knoerr 2018). NCWRC biologists and partners have documented 18 injuries and three deaths of bog turtles that were attributed, because of the shape of the injury, to being stepped on by livestock (NCWRC unpublished data). Although we have documented injuries and deaths that appear to be from livestock, we know very little about the frequency of occurrence and population-level effects.

Inappropriately managed grazing can negatively affect bog conditions. Significant increases in nutrient concentrations can occur when cattle are stocked at high densities (Line et al. 2000). An increase in nutrient load to an otherwise nutrient-poor system, in conjunction with soil disturbance, can facilitate invasion of the habitat by exotic vegetation, altering the plant community (USFWS 2001). Inappropriately managed grazing can also cause excessive soil exposure, soil compaction, denuding of sphagnum moss and herbaceous vegetation, and destruction of rare plants (USFWS 2001, 2010). Similarly, inappropriately managed livestock grazing can result in destabilized streambanks and worsening headcuts, thereby threatening habitat quality (Yochum 2018). More research and adaptive management are needed to inform decisions about appropriate timing and intensity of grazing under different scenarios and to strengthen current recommendations (USFWS 2019). When under conservation ownership or a private landowner is interested, much of this threat can be turned into a conservation tool with site-specific management plans that have appropriate grazing management.

Invasive Species

In general, wetlands are especially vulnerable to invasions by aggressive plants. Less than 6% of the land on Earth is classified as wetlands, but 24% of the most invasive plant species are wetland obligates (Zedler and Kercher 2004). The accumulation of debris, sediments, water, and nutrients in wetlands helps facilitate invasions by creating canopy gaps, accelerating the growth of opportunistic plant species, and through direct input of invasive seeds (Zedler and Kercher 2004). Furthermore, many invasive wetland species grow as a monotype, resulting in lower biodiversity, altered habitat structure, and modified food webs (Zedler and Kercher 2004). NCWRC staff have documented many non-native invasive plant species in or adjacent to bogs, including autumn olive (*Elaeagnus umbellata*), Chinese lespedeza (*Lespedeza cuneata*), Chinese privet (*Ligustrum sinense* and *L. vulgare*), Chinese silvergrass (*Miscanthus sinensis*), common reed (*Phragmites australis*), Japanese barberry (*Berberis thunbergii*), Japanese honeysuckle (*Lonicera japonica*), Japanese knotweed (*Polygonum cuspidatum*), Japanese stiltgrass (*Microstegium vimineum*), murdannia (*Murdannia keisak*), multiflora rose (*Rosa multiflora*), oriental bittersweet (*Celastrus orbiculatus*), purple loosestrife (*Lythrum salicaria*), reed canarygrass (*Phalaris arundinacea*), and yellow flag iris (*Iris pseudacorus*), among others. There are several documented cases of invasive plant species, such as reed canary grass, common reed, and purple loosestrife, forming a monotype in a bog and adversely affecting the habitat quality for bog turtles and other wildlife (e.g., Blossey 2002; Warwick 2014).



NCWRC staff have documented many non-native, invasive plant species in bogs, including (from left to right) purple loosestrife (Shutterstock) and reed canarygrass (Simona Pavan), as well as multiflora rose (Wikipedia) adjacent to bogs.

Wildlife not native to the bog may also pose a threat to bog turtles, especially any species that affects nest success and juvenile or adult survivorship. One animal of particular concern is the red imported fire ant (*Solenopsis invicta*). This species has been documented in 75 of North Carolina's 100 counties, including 11 counties with bog turtle records (Burke, Catawba, Cherokee, Clay, Gaston, Graham, Iredell, Macon, McDowell, Polk, and Rutherford) (NCDA&CS 2021). Fire ants have been documented preying upon nests of gopher tortoises (*Gopherus polyphemus*), snapping turtles (*Chelydra serpentina*), Florida cooters (*Pseudemys floridana*), and yellow-bellied sliders (*Trachemys scripta scripta*) in the wild (Allen et al. 2004; Aresco 2004). To our knowledge, the fire ant has not been documented within a bog turtle wetland in North Carolina. Given what we know about their aggressive behavior and their proclivity to invade newly disturbed areas, fire ants should be of great concern when it comes to these fragile ecosystems, especially considering the vulnerability of bog turtle nests and the small size of juvenile turtles.

Although not yet documented in a bog turtle wetland in NC, the fire ant is of great concern to the viability of bog turtle nests and survival of juvenile bog turtles. (Shutterstock)

Increased Predation

Data suggest that low nest success and juvenile survival are important limiting factors for turtles in general (Congdon et al. 1983) and specifically for bog turtles in North Carolina (Tutterow et al. 2017; Knoerr et al. 2020). We have very few bog turtle populations in the state with all age classes represented (i.e., many have only adults), so something is out of balance. Also, we have documented high predation rates at some sites over multiple years. A recent study on nest success in four populations in North Carolina found that only 28% of eggs hatched, with the highest egg survival being 60% at one site and predation accounting for much of the nest failure (Knoerr et al. 2020). Mesopredators accounted for 68% of egg predation and small mammals were responsible for 31% of egg predation (Knoerr et al. 2020). A recent Maryland predation study observed approximately 40% of eggs preyed upon at one site and as many as 74% at another over a 2-year period (Byer 2015). Additionally, Macey (2015) documented a 62% predation rate over a 4-year period at 24 unprotected nests across nine sites in southeastern New York. One study demonstrated that even with 100% mitigation of road mortality effects, a population of semi-aquatic turtles would still be declining due to increased predation (Crawford et al. 2014), demonstrating the large impact predation can have in some systems.

Recently hatched bog turtle (Mike Knoerr)

Several studies have linked turtle nest predation rates to the landscape matrix (Kolbe and Janzen 2003, Marchand and Litvaitis 2004). Human-commensal predators such as raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), and red foxes (*Vulpes vulpes*), often termed mesocarnivores or mesopredators, often represent the largest sources of increased predation in altered habitats (USFWS 2001).

Although predation is a natural part of the ecosystem that bog turtles inhabit, some areas have a higher abundance of mesopredators now due to human-caused food supplementation, as well as reduced or absent top predators (Prugh et al 2009; Newsome et al 2014). However, mesocarnivore use of altered landscapes varies depending upon local environmental and social factors and management actions are likely to be most effective when decisions are based upon locally derived data (Rodriguez et al. 2021).


(Shutterstock)

Domesticated pets may also be threats to bog turtles, primarily house cats (*Felis catus*) and dogs (*Canis familiaris*). With their small size and lack of a hinge on the plastron, it is likely that adult bog turtles are more vulnerable than many other turtle species to predation by domesticated pets. Many bogs are located within a fragmented and developed landscape with residential areas, and thus, a source of cats and dogs that may be allowed to roam. Loss et al. (2013) estimated that annually 86-320 million amphibians (median 173 million) and 228-871 million reptiles (median 478 million) are killed by house cats in the continental United States. The North Carolina bog turtle database documents 24 injured and two dead turtles from bites, presumably a mix of native predators and domesticated pets (2017). Although the degree of impact is unknown, dogs have been documented to injure and kill bog turtles in North Carolina and Virginia (McCoy et al. 2020).

Vehicles

Roads present a major threat to small animals, including turtles (Gibbs and Shriver 2002, Aresco 2005, Marsh and Jaeger 2015). Beyond direct mortality, roads can have numerous other deleterious effects, including behavioral effects, decreased dispersal between habitats, reduced abundance, and loss of genetic diversity (Marsh and Jaeger 2015). Turtles are slow-moving animals and mortality risks as high as 95% per crossing attempt have been documented for turtles (Aresco 2005). The NC bog turtle database has 62 records of bog turtles found on roads in the state (43 alive, 20 dead) from 1951 to 2020 (Project Bog Turtle, NC Museum of Natural Science, NCWRC unpublished data). Long-term demographic studies of turtle populations have indicated that a 2-3% annual road mortality rate is likely to cause population declines (Gibbs and Shriver 2002). Likewise, at a landscape scale, reduction of a population's dispersal ability can slowly drive a metapopulation to extinction (Marsh and Jaeger 2015). Other vehicles and equipment, such as tractors, mowers, and other farm machinery can injure and kill turtles (Saumure et al. 2007, USFWS 2019). Bog turtles have been documented spending time in the fields surrounding some wetlands (Pittman and Dorcas 2009) and NCWRC biologists and partners have captured three injured and two dead bog turtles over the years that have long, deep injuries to the shell that appear to be caused by a blade (NCWRC unpublished data). It seems likely that some bog turtles are crushed and injured, but little is known about the population effects of this type of machinery.


Studies have shown tractors, mowers and other farm machinery can injure and kill bog turtles. (Wikipedia)

Barriers to Movement

Roads, railroad tracks, and other anthropogenic habitat alterations can serve as barriers to movement and cause entrapment for turtles (Aresco 2005, Kornilev et al. 2006, Pittman and Dorcas 2009). Presumably, perched culverts would prevent bi-directional use of streams as travel corridors. A telemetry study of bog turtles at a site in North Carolina led to the discovery of the death of a bog turtle in a puddle adjacent to a railroad track, with the authors proposing that the turtle perished due to difficulty with crossing the railroad tracks to get back to the bog (Pittman and Dorcas 2009). It is likely that anything within the landscape that is a barrier to movement or entraps bog turtles in place could increase stress, affect thermoregulation, and lead to death. Additionally, the isolation of populations due to barriers and loss of habitat limits gene flow and removes the benefits of a functioning metapopulation, which in turn makes them susceptible to local extirpations (Frankham et al. 2002, Pittman et al. 2011, Apodaca et al. 2012).

Disease

The possibility of disease having detrimental effects on the species is of great concern, especially given the small size of these populations. Although we do not have evidence of disease being a significant cause of declines in bog turtles, they have been documented with various diseases, including bacterial pneumonia in North Carolina and Virginia (e.g., *Pseudomonas* spp. and *Aeromonas* spp.), herpesvirus in wild turtles in the northeast, and mycoplasma in wild bog turtles (Carter et al. 2005; Ossibof et al. 2015; Erb 2019). Moreover, there is plenty of evidence of disease having detrimental effects on other turtle species (e.g., Turtle fraservirus 1 affecting multiple turtle species in Florida, Waltzek et al. 2022; mystery disease affecting the Bellinger River Snapping Turtle in Australia, Spencer et al. 2018; Helicobacter bacteria affecting gopher tortoises; Desiderio et al. 2021). Thus, it is important to monitor the health of bog turtles and conduct disease testing of sick or dead turtles. We must also be diligent with disinfection procedures to minimize chances of spreading disease during fieldwork activities. This is especially true due to the potential for the rapid spread of diseases via human movement around the globe.

> The largest bog turtle die-off ever documented in the state occurred in 2019 when more than 50 turtles were found dead. Despite extensive disease testing and investigations into other potential causes, biologists were unable to determine conclusively how the turtles died.

In 2019, we discovered the largest bog turtle die-off ever documented for the species in a North Carolina site, with more than 50 turtles found dead. Despite extensive disease testing (*Ranaviruses*, *Mycoplasma*, *Herpesvirus*) and investigations into other potential causes, including predation and toxins, the results were inconclusive. This die-off could have been a result of disease or toxins, increased stress and vulnerability due to drought conditions, or predation, or some combination of these causes. Similarly, a Health Bulletin published by the USFWS (2014) reported 14 bog turtles found dead at one site in May 2014 in Pennsylvania and outlined protocols for decontaminating gear and submitting specimens for testing (USFWS 2018). In the Pennsylvania case, test results did not indicate one causative agent, but a variety of potential factors include injury, infection, pneumonia, and carcinoma. The USFWS warns biologists to be aware and take necessary precautions.

Climate Change

Climate models predict various outcomes for North Carolina (DeWan et al. 2010, NCWRC 2015). For example, the timing, amount, and type of precipitation are expected to change, but precipitation predictions are unclear for North Carolina (NCWRC 2015). Some models indicate that the amount of precipitation may not change, but the intensity and duration of both storms and droughts will increase (NCDENR 2010, Schultheis et al. 2010, NCWRC 2015). When a drought occurs, the amount of suitable habitat in a bog can shrink and result in increased water temperatures, both potential stressors for bog turtles. The large bog turtle die-off in North Carolina in 2019 may have been partially due to drought conditions. The impacts of climate change have been documented in other turtle species, including the Murray River turtle and ornate box turtles (Spencer et al. 2018; Rodriguez et al. 2022).

Changes in storm intensity can increase the soil erosion potential and decrease the frequency of groundwater recharge (Karl et al. 2009). Intense rainfall events would likely flood many bogs, leading to scouring and head-cuts, and further increasing nutrient loads (NCDENR 2010). A study to predict effects of climate change on Southern Appalachian bogs indicated that future climates are likely to affect them through the combined impacts of temperature and precipitation (Schultheis et al. 2010). Dominant vegetation is likely to shift from sphagnum moss to woody shrubs because shrubs are better able to handle drought and higher nutrient levels (Schultheis et al. 2010). Thus, climate change may intensify the need for management. Likewise, invasive plants are likely to become increasingly prevalent in bogs as vegetation dominance shifts away from sphagnum (NCDENR 2010). Impacts from climate change may exacerbate many of the threats that bog turtles face, including altered hydrology, invasive species, disease, and increased predation.

Illegal Collection and Trade

Collection of turtles in North America for illegal trade has become a lucrative business. There are documented instances of many species of turtles being illegally harvested for the purpose of sale into the black market (Christy 2008; Todd et al. 2010; Sevin et al. 2022). There is evidence that people who seek to purchase wild-caught or captive-bred bog turtles as pets are not dissuaded by high prices (Turtle Survival Alliance pers. comm.; Grover Brown pers. comm.). Illegal collection of bog turtles poses a serious potential threat, although we do not know how often it occurs in North Carolina or which sites have been targeted in the past, with two exceptions. In 1989, a presumably large number of bog turtles was collected from two sites in Henderson County, and turtles were offered for sale in Ohio soon after (D. Herman pers. comm.). These populations have not yet recovered to their original abundance, and we attribute that, in part, to the loss of many breeding individuals to this collection event (NCWRC unpublished data). In 2006, a bog turtle was taken illegally in North Carolina and confiscated by law enforcement. A simulation model examining the impact of removal of one adult turtle per year indicated that the study populations in New York would be devastated by such loss and thus, anti-poaching measures would be warranted (Shoemaker 2011).

> A large number of bog turtles collected from Henderson County in 1989, and subsequently sold in Ohio, continues to have a detrimental effect on today's populations, due in part, to the loss of many breeding individuals collected.

Summary of Threats

Although all these threats likely impact bog turtles to some degree, the main threats are wetland vegetative succession, altered hydrology, wetland loss and degradation, increased predation, vehicles, and barriers to movement. However, each site is affected by the range of identified threats differently based upon proximate historic and current land uses, state of ownership, and other local conditions and should be considered and incorporated into any action plans. Threats to monitor closely include illegal collection and trade, disease, and invasive species because these could quickly result in devastating impacts. Climate change could have a large long-term negative impact, especially if wetland hydrology is altered, and it should be considered in all conservation planning for bog turtles and their habitat. Lastly, more research is needed to better understand how extensive these threats are and the most effective methods to address them.

CONSERVATION GOAL AND OBJECTIVES

Conservation Goal

The conservation goal for *Glyptemys muhlenbergii* is to protect and restore the populations and habitat of this species to prevent extirpation and ensure long-term viability across its current range in North Carolina for the next 100 years.

Conservation Objectives

A. Further our understanding of bog turtles by filling information gaps about distribution, improving knowledge of site-specific threats, monitoring status and trends, and conducting research to improve conservation outcomes.
B. Maintain existing populations and metapopulations and maximize the number of viable populations by working with partners to address site-specific threats through habitat management and restoration, population management, and habitat protection.
C. Expand outreach efforts by involving more collaborators and more effectively reaching landowners with a range of options that conserve bog turtles.

(Jay Ondreicka)

CONSERVATION ACTIONS

The following actions are all considered essential to meet the three conservation objectives listed on page 21 and efforts must be immediate and concurrent. These actions are equally important and not listed in order of priority.

Inventory, Monitoring, and Research

We have learned much about bog turtles in North Carolina over the last 40+ years, but specific knowledge gaps remain. We need to identify and survey for bog turtles at new locations that have a high potential for suitable habitat so we have a more complete understanding of the species' status and distribution in North Carolina. Likewise, we need to continue monitoring bog turtle status and trends at known sites. New survey and monitoring tools are being developed and we need to create a more robust monitoring plan that incorporates these and traditional survey techniques. Lastly, additional research is needed to address specific questions to inform management and conservation. All work will be conducted in a manner that minimizes negative impacts from the work itself. With regard to disease, we will use existing protocols for handling disease cases and preventing spread of parasites and pathogens from one site to another (e.g., SEPARC disease task team reports, Bog Learning Network Decontamination Protocols, Health Bulletins from the northern population of bog turtles). A full accounting of possible techniques for inventory, monitoring, and research can be found in the Partners in Amphibian and Reptile Conservation's Inventory and Monitoring Handbook (Graeter et al. 2012). To find turtles, we will use several visual and tactile active survey methods, as well as several passive methods, including trapping (Somers and Mansfield-Jones 2008).

Counting scutes (top left) and measuring shells (bottom left) of each individual turtle captured during surveys help biologists keep track of bog turtle status and trends at known sites. (Meliissa McGaw/NCWRC)

Fill Information Gaps about Distribution

Recently, through concerted efforts, NCWRC biologists, members of Project Bog Turtle, and others have found several previously unknown bog turtle populations, but there are likely more to discover. With limited time and resources, we have focused more effort on known populations and had less time to dedicate to surveying habitat with potential for bog turtles. Through GIS technology, use of small airplanes and drones, and outreach, we can focus on locations with high potential for bog turtles. Many small wetlands are not easily accessed or seen from public roads. Because bog turtles are cryptic and most humans are averse to getting deep into a muddy place, many landowners do not know they have bog turtles on their property.

Bog turtle populations can be discovered both on a small scale using aerial images to locate places with potential for bog habitats and on a larger scale by creating predictive GIS models to locate places with a high likelihood of having suitable bog turtle habitat (e.g., Stratmann et al. 2016). Layers that may go into these models include soil maps, topography, aspect, and LIDAR, among others. This model could also help locate bogs that need restoration and/or habitat management. Historical imagery is another valuable resource for researching the land-use history of a site, such as past efforts to ditch, drain, or pond a site, whether it was forested or open, and how the land cover has changed over time. It may also prove helpful to reach out to private landowners through news releases, newspaper articles, and through Natural Resources Conservation Service (NRCS) offices, especially in counties with extant populations, to encourage them to contact NCWRC and consider allowing us to survey wetlands on their property.

Lastly, we need to increase our on-the-ground habitat assessments and survey efforts to determine presence-absence and population viability at the locations identified as having high potential. It is important to have complete information of how many bog turtle populations exist, their geographic distribution, and their status. With this information, we can make more informed conservation decisions.

Wildlife Diversity Biologist Lori Williams sets a bog turtle trap. On-the-ground assessments and survey efforts will help NCWRC staff determine viable populations of this tiny turtle. (NCWRC)

Monitor Populations to Determine Status and Trends

Regular monitoring is important so we can continue, or in some cases begin, to assess the status of populations over time. Monitoring can detect positive or negative changes that occur in response to our efforts or other factors. Although NCWRC biologists and partners have monitored bog turtles for many years, the project would benefit from long-term strategic planning and a structured monitoring plan. Monitoring will need to be multi-faceted, where some populations have more intensive mark-recapture monitoring and others are monitored via site-occupancy or presence-absence (Graeter et al. 2012). Numerous methods should be included in a structured monitoring plan, from mark-recapture and conventional trapping to newer techniques such as camera traps and eDNA. We also need to gain a better understanding of detectability of bog turtles in North Carolina's varied bog habitats.

Conduct Research to Improve Conservation of Bog Turtles

Research is needed on multiple topics to better understand the ecology, habitat use, and appropriate habitat management actions to implement. We must identify limiting factors of declining populations so conservation actions are targeted and effective. In addition to identifying major threats to bog turtle survival, NCWRC and partners will evaluate the success of conservation efforts. Adaptive management will be important for refining and improving conservation actions and outcomes.

Some prioritized research topics we need to address are listed below, but this list is not exhaustive, nor is it in order of priority. As we learn more and begin working toward the objectives in this Plan, different questions may arise that need to be answered.

1. **RECRUITMENT**: Demographic research to determine life stages that are limiting factor(s) to population stability or growth.
2. **ADDRESSING THREATS**: Improve understanding of which threats are playing significant role(s) in which populations, and which management actions may be most effective and economical to address these issues.
3. **POPULATION MANAGEMENT and DECISION MAKING**:
   1) Develop a predictive population model that aids conservation and management decisions.
   2) Using different population management techniques, including population augmentation via head-starting, investigate differences in survivorship of turtles.
   3) Conduct genetic studies to determine gene flow and population health and to guide population management actions such as reintroductions, augmentations, relocations, and captive-breeding.
4. **HABITAT USE and MANAGEMENT**:
   1) Examine efficacy of different vegetation management techniques, such as grazing studies focused on evaluating the ideal density and timing of grazers, effects of grazing on bog turtle detectability, and if (and under what conditions) bioturbation improves habitat.
   2) Improve understanding of landscape ecology and metapopulation dynamics.
   3) Improve understanding of bog hydrology (e.g., variation between bogs, inter- and intra-annual differences, influence of disturbances and management, relationship of bog hydrology to habitat use) and water quality (e.g., baseline conditions, effects of agriculture and development).

4) Conduct occupancy modeling to determine what qualifies as suitable habitat and adequate habitat size.

5) Bog turtle ecology: 1) Examine differences in food availability across bogs, 2) Study overwintering locations and determine if they are limiting.

5. **SURVEY/DATA COLLECTION METHODS**: Estimate detection probability, including (but not limited to) individual detectability, site-specific estimates, survey methods, and effect of different habitat features (e.g., vegetation structure and composition, soil saturation, microtopography, wetland size).
6. **BOG TURTLE HEALTH**: Conduct baseline health assessment. Identify diseases and health issues that may affect bog turtles.
7. **CLIMATE CHANGE**: Investigate effects of climate change on bogs (e.g., hydrology, vegetation, resiliency of bogs over long-term) and bog turtles.

Habitat Management and Restoration

Although the habitat at some bog turtle sites appears to require little effort to maintain, this is certainly the exception. Many of the bog turtle sites that appear to have the most robust populations have had some form of repeated disturbance that maintained open areas. Many factors that are believed to have kept some wetlands open historically are gone or diminished, such as bison, elk, beavers, and natural fire or fires set by American Indians (NCWRC 2015).

NCWRC staff will collaborate with partners to evaluate needs and develop and implement adaptive management plans for bog turtle sites, prioritizing state-owned sites and others that have complex and immediate management needs. The full suite of management and conservation tools that are available will be considered in development of these plans. Habitat management tools to be considered include mechanical removal of vegetation, treatment of invasive species, addition of desirable native plants, prescribed fire, use of grazers/browsers (e.g., cattle, goats, bison), hydrologic restoration (e.g., plugging ditches, fixing head-cuts, breaking up drain tiles, removal of fill dirt), co-existing with beavers when possible, creating turtle passages, and any other management tool that helps staff accomplish objectives. The habitat, land-use history, and threats that each population faces are site-specific, and thus, different tools and techniques will need to be appropriately applied. These plans will need to be adaptive and allow for flexibility when ecological conditions and/or threats to a population change.

One habitat management tool biologists can use is mechanical removal of vegetation; however, habitat management tools are site specific and depend on the habitat, land-use history, and threats that each bog turtle population faces. (NCWRC)

As these management plans are developed, mapping of known and desired features and sensitive areas (e.g., erosion, rare plants), and consultation of the scientific literature, will be crucial in determining the most appropriate management technique to use (e.g., grazers, mechanical vegetation removal, prescribed fire). NCWRC staff will establish a prioritized schedule for habitat management of all extant bog turtle populations. Staff will identify needs related to that schedule, including staff capacity, partners, budgets, funding, and anything else required to carry out a management plan. After habitat management has been conducted, NCWRC staff will evaluate the management efforts through subsequent population and habitat monitoring. Furthermore, this will require a system of tracking management actions taken at each site to ensure effective adaptive management and accurate accounting of site histories.

Vegetation Management

The aim of vegetation management is to create and/or maintain high quality habitat for bog turtles. One method of setting back vegetative succession is to enter the bog on foot and use hand-held equipment, such as chainsaws, loppers, clippers, and hand saws to mechanically cut and then remove woody vegetation. Vegetation management may also include the addition of native plants to improve habitat, to fill a void when non-native invasive plants have been removed, to add structure when no shrubs are present within a bog, or to minimize erosion when restoration efforts have resulted in bare soil areas. Botanists in the N.C. Natural Heritage Program and members of the Bog Learning Network will be consulted to establish an appropriate plant list, considering the likelihood of each species to occur naturally on the property and the propensity of a species to spread invasively, among other factors.

(Shutterstock)

Vegetation management may also include the addition of native plants to improve habitat, such as sphagnum moss (top) and bulrush (bottom).

(University of Mississipi Field Station)

NCWRC staff and partners often document the presence and general abundance of non-native invasive species at sites. Because some invasive plant species can form monotypic stands and affect habitat suitability, we will incorporate treatment and removal of invasive species into Management Plans. When an invasive plant species that significantly alters bog turtle habitat (e.g., reed canary grass, purple loosestrife) is found, we will respond rapidly with treatment before it spreads further. The goal for some invasive plant species may be elimination. For other invasive plant species, elimination may be unrealistic goal; therefore, the focus will

be on control and reduction. NCWRC staff should be prepared to increase the frequency of management activities targeted at woody stems and invasive plants, because these are likely to fare better under most predicted climate change scenarios. We should also determine a treatment plan in preparation for the potential discovery of fire ants at a bog turtle wetland.

Prescribed fire can be used in some cases as a vegetation management tool, but managers should proceed with caution as very little is known about its ecological effects within bogs. Prescribed burning has been used minimally for vegetation management in bog turtle habitat and it is most appropriate when used in conjunction with other management techniques. In fact, there are very few studies that have investigated the role of fire in wetland ecosystems in general (Osborne et al. 2013). We do not know the role or extent to which wildfires in precolonial times would have helped slow succession in bogs. In some bogs, a fire may not be able to burn across the bog due to too much moisture and/or a lack of material to burn. At other sites, it may be able to burn across the wetland under ideal conditions and be a useful management technique. Research is needed to understand better the ecological effect and utility of this method, and to determine general guidelines for using prescribed fire in bogs. Consultation and collaboration with NCWRC Land and Water Access staff and other partners will improve adaptive management using prescribed fire.

Prescribed fire can be used in some cases as a vegetation management tool, but managers should proceed with caution as very little is known about its ecological effects within bogs. (NCWRC)

Grazing is another technique available to aid vegetation management at bogs. We will take a site-specific approach of weighing the risks and benefits before deciding whether grazing is suitable and if so, at what intensity. In many bogs with a history of grazing, low and moderate intensity grazing is beneficial to maintaining relatively open habitat (Tesauro 2002, Tesauro and Ehrenfeld 2007, USFWS 2019). Moreover, Tesauro and Ehrenfeld (2007) found higher population abundances and densities, and more juvenile bog turtles in grazed sites. Grazing is an important tool for managing many bog turtle sites and while there are some risks, benefits of light to moderate intensity grazing typically outweigh potential risks. At sites with no history of grazing, and/or when the plant community and/or topography of a site is deemed too sensitive for grazers, we will use other habitat management techniques. Whenever appropriate and feasible, NCWRC staff will use grazing at sites with a history of grazing so they can continue to provide suitable habitat for bog turtles. When possible, NCWRC staff will accomplish grazing treatments via agreements with appropriate terms and conditions, including species, breed, duration, timing, and areas to exclude. When NCWRC biologists have determined that grazing is a desirable technique for a given site, we will take steps to ensure the grazing intensity is adequate to meet conservation goals but not excessive. We will consult recommendations from the USFWS (e.g., USFWS 2019, Appendix H) and peer-reviewed articles to guide decisions about grazing, and work with willing landowners to schedule the appropriate amount of grazing in the wetland,

especially during the bog turtle nesting season (June 1-September 30). We will consider installing temporary or permanent fencing that makes it possible to limit grazing in known or suspected nesting areas during and after nesting each year. Conservation partners such as USFWS and NRCS may be able to assist with funding and implementation.

Hydrology Management and Restoration

Many of restoration needs of wetlands with bog turtles include hydrology. Most wetlands have experienced human influence involving an attempt to minimize the wetland extent and increase rate of drainage out of the wetland area, including ditching, installing drainage tiles/pipes, and filling wetland areas (Biebighauser 2007). Much of this work was done to improve agricultural and pasture lands. Landowners have also taken advantage of the constant flow of water from springs in the wetlands and created ponds on their property where bogs existed. To restore hydrology, we are often attempting to reverse past efforts by removal and/or breakage of drainage tiles and other similar drainage materials, filling or plugging old ditches, and removal of fill dirt (Biebighauser 2007). Other hydrological restoration actions include addressing problems with head-cut erosion within or adjacent to the wetland, restoration of streams adjacent to bog, addressing problematic flooding, and activities to improve natural movement of water within a wetland. Restoration can also occur by allowing a ponded area to fill slowly over time so it becomes a bog.

In a relatively unaltered landscape and watershed, beaver activity helps bog turtles because it keeps some sections of a wetland complex open with mostly herbaceous and shrubby vegetation, and areas are periodically flooded and opened back up so there is always some suitable habitat for bog turtles. Bog turtles are adapted to adjust their habitat use based on changing hydrology (Sirois et al. 2014, McCoy 2016). A geomorphic study of a bog with extensive beaver activity in western North Carolina indicated that the wetland has existed since the terminal Pleistocene, although it has changed in form over time (McDonald 2010). If habitat is limited and beavers are causing damage to bog turtle sites, we will determine best action(s) to take, which may include using devices such as the Clemson Pond leveler to reduce problems associated with flooding (CUCES 1994), trapping and removal of beavers, and/or regular manual removal of beaver dams to prevent flooding, among other tactics. We will work with private landowners to find a balance between their needs and allowing beavers to remain and provide ecological benefits.

Jamie Espinosa

Habitat Connectivity

We will form a working group to address issues associated with roads and other barriers to movement and determine a multi-faceted plan. An important partner in this working group will be the N.C. Department of Transportation (NC DOT). To decrease road mortality of bog turtles, fencing and turtle passages under roads to allow safe subterranean movement can be built when resources allow. In some cases, existing culverts and bridges may be retrofitted to improve connectivity and decrease mortality of turtles on roads.

Broader Habitat Efforts

While management and restoration work should be prioritized at important bog turtle sites, work at other sites is important to increase species viability and habitat connectivity. Bog turtle sites with highly degraded habitat, habitat with historic records, and locations within the bog turtle range that lack bog turtles but have the potential to be high-quality habitat, should be targeted for restoration whenever feasible. Restoration work may include sites that need significant changes due to past land-use activities such as ditching, drainage, filling, and other soil movement activities. Sites that are within a metapopulation should be given additional attention in planning and management activities to enhance landscape connectivity and potential for movement between populations. Even when a wetland in a metapopulation does not have records of bog turtles, those habitats should be managed and restored whenever possible with bog turtles' needs in mind. There may also be opportunities to create habitat in high-priority watersheds and metapopulations. These actions will consider the existing plant community with the aim of improving habitat for other wildlife and rare plants. Wetlands that are not occupied by bog turtles now may be colonized in the future or used periodically during movements across the landscape.

(Mike Knoerr)

NCWRC staff will collaborate closely with partners and private landowners to accomplish habitat management and restoration. Partners will include agencies with programs that facilitate habitat management to benefit bog turtles on private property, including the NRCS and USFWS. Such habitat management may also help reduce agricultural runoff into wetlands. To improve management and restoration decisions related to bog hydrology, NCWRC staff will partner with hydrologists, soil scientists, and other wetland experts. It is also essential that we continue to nurture good relationships with private landowners and expand these efforts to optimize bog turtle conservation on these lands (see Outreach section).

Population Management

To help this species persist under the pressure of so many threats, we must employ multiple conservation tools simultaneously (Crawford et al. 2014). The NCWRC and partners are focusing on the importance of adequate quality habitat and addressing other threats, but some populations are so small that we need additional techniques to help give them a boost in numbers. Population management methods will be used simultaneously with many other conservation activities, including habitat management and restoration, threat abatement from predators and road mortality, and others. We need to use these population management techniques to buy some time to avoid losing these populations while we are addressing other issues. It is also possible that past events have reduced populations to such low numbers that recovery without a boost in numbers may be impossible given ongoing low-level threats such as loss of adults to road mortality, flooding due to climate change, and reduced wetland size due to overland flow of sediment during storms.

> The objective of bog turtle population management is to increase the number of viable populations, maintain existing genetic diversity, and create Resiliency, Redundancy, and Representation (USFWS 2016) of the species throughout its range in North Carolina.

NCWRC staff and permitted partners should continue with in-situ population management techniques, such as protecting nests and hatchlings from predation and other threats, whenever necessary and likely to be effective as resources allow. Nest failure has multiple potential causes, including predation, inundation from flooding, getting crushed, and in some cases, these can be addressed in-situ. When increased predation is identified as a threat to a bog turtle population, an action plan should be devised. Although predation is a part of the ecology of bog turtles, predators can be at higher abundance due to human subsidies and some turtle populations are in such peril that action is needed. When adult and juvenile survival rates are lower, which is the case in NC (Tutterow et al 2017; Knoerr et al 2021), and the threat cannot be addressed directly or quickly (e.g., road mortality, diminished hydrology conditions), increasing nest survival can help mitigate population declines until the root causes of low age-class-specific survivorship rates can be managed. One way to directly influence the bog turtle population at a site is through various types of in-situ activities to protect nests and turtles from predators or other threats, such as use of electric fences surrounding a wetland and/or a nesting area, use of predator excluder cages over nests during incubation, and removal of meso-predators through trapping or other means (Macey 2015; Zappalorti et al. 2017; Knoerr 2018). Predator removal is not always appropriate and may not be effective in some situations. It will be necessary to monitor the situation after taking action to see if the problem has been addressed fully or whether the plan needs to be adapted. In some instances, these efforts to protect hatchling and yearling bog turtles from predators may also extend benefits to older juveniles and adults. Moving nests to safer locations (Burke 2015) is another technique used to improve nest success in situations where flooding is likely or other threats exist in a portion of a site.

To recover bog turtles in North Carolina and avoid extirpation, NCWRC should continue to expand our ex-situ population management activities. These tools include, but may not be limited to, population augmentation (at sites with extant populations), repatriation (to sites that historically had the species), and population introduction (with no record of the species in past), through various means including ex-situ egg incubation, head-starting, translocation, and captive breeding. Population management techniques, such as population augmentation through head-starting, offer a direct route to restoring Resiliency and Redundancy and bolstering populations. A bog turtle population in Tennessee was established via captive-breeding and head-starting over a 30+ year period, with successes including an 84% survival rate, relatively high genetic variation, and the recent discovery of several nests and hatchlings on-site (Dresser et al. 2017; Zoo Knoxville unpublished data).

NCWRC biologists recently completed a small short-term (2-year) head-starting effort at a NCWRC owned site in North Carolina with Zoo Knoxville to develop and refine our procedures and methods. Recent studies of freshwater turtles have concluded that these types of initiatives are valuable tools to address recruitment problems, increase turtle numbers, and stave off extinction threats (Spinks et al. 2003; Kuhns 2010; Riley and Litzgus 2013; Buhlmann et al. 2015; Spencer et al. 2017). Importantly, modeling has shown that population management efforts, especially head-starting, can help stabilize declining North Carolina bog turtle populations (Knoerr et al. 2021).

Head-starting efforts on bog turtles could be a valuable tool to address recruitment problems, increase turtle numbers and stave off extinction threats. (Mike Knoerr)

For these ex-situ population management activities, we will collaborate with conservation partners and experts to develop an objective, science-based decision framework that will help guide decisions for population management with this species in North Carolina, similar to a reintroduction program for Blanding's turtle (*Emydoidea blandingii*; Buhlmann et al. 2015). Given how dire the situation is (see *Distribution and Population Status* section), until this decision framework is developed, it is imperative that we act now and begin using these population management techniques using the best, current information and adapt as we learn more in the future (i.e., adaptive management). Depending on the situation at a given site, the objective of using population management may vary, ranging from buying time while other threats are addressed, increasing genetic diversity, to helping a population become viable and stable.

Examining conservation genetic parameters, such as genetic diversity, inbreeding level, and bottlenecks, is important to bog turtle population management. Because long-range movements are rare and difficult to document in bog turtles (Shoemaker and Gibbs 2013), exploring genetic patterns will give us a broader landscape scale perspective for this species. Landscape scale genetics can also help us infer metapopulation factors, such as rates of migration, effective population sizes, and indices of inbreeding. Results can inform conservation decision making as it pertains to landscape features that may inhibit or enhance

migration (Apodaca et al. 2012). Both the genetic parameters and metapopulation factors are valuable for decision-making about the use of potential population manipulation techniques. A genomic assessment can also be a useful tool for examining the success of a population management program at a site, such as introduction of bog turtles to a novel location (Dresser et al. 2017).

We will develop requirements for facilities involved in handling or holding turtles for population management purposes (e.g., secure from illegal collection, ability to follow protocols for rearing/head-starting, disease concerns, genetic concerns). NCWRC has developed a partnership with Zoo Knoxville for incubation and head-starting of bog turtles, but it may be necessary to explore additional partnerships, and/or use NCWRC facilities for rearing and head-starting North Carolina bog turtles. We will also work with conservation partners to establish a detailed plan for each site, including goals, methods, and a monitoring protocol for evaluating population management efforts at each site over time. We will continue our mark-recapture efforts using several survey methods. As part of this monitoring plan, we will establish measures of success and the time scale at which they can each be evaluated. Furthermore, we will develop NC-specific genetics guidelines on the use of these population management techniques. NCWRC biologists will work closely with a variety of experts to help make optimal conservation decisions about population management for bog turtles in North Carolina.

Land Protection

While portions of some bogs have permanent land protection and a few bogs are protected entirely, most sites are in private ownership and lack permanent land protection, which puts them at risk to ditching, draining, ponding, and filling activities. Additionally, it has become apparent through bog conservation efforts over the years, that protecting the watershed of the bog, or “bog-shed,” including underground aquifers, is important and in some cases critical to addressing the threat of altered hydrology. Land protection can minimize heavy equipment in or near bogs, address road mortality issues via installation of road crossings, and reduce the risk of further habitat fragmentation, etc. Without some form of land protection, all other efforts for the population and its habitat may be in vain because the habitat can be destroyed in a day via activities such as ditching.

Land protection may take many forms, from ownership by a conservation entity, a permanent conservation easement, registration under the NCNHP Registered Natural Area program, as well as temporary protection through programs such as the Wildlife Conservation Land Program (WCLP) with NCWRC or farm bill programs with USDA NRCS. Partnerships with non-governmental conservation organizations are essential for many reasons, including their skills in grant writing and working with landowners, as well as their ability to purchase property quickly. Short-term protection programs do not lend the degree of protection that conservation ownership or a permanent conservation easement provide, but they are important tools to have in the conservation toolbox for working with private landowners to aid land protection and improve stewardship of the habitat. See the Outreach section on page 34 for more information on short-term protection of habitat on private lands.

Of the 65 wetland sites with at least one bog turtle captured in the last 20 years (2001-2020), more than half (34) are not protected (i.e., under conservation ownership or easement). Of the 23 sites that have had 10 or more individual turtles captured over the last 20 years, only 12 have permanent land protection, leaving the remainder (11) without any protection. Our strategy will involve collaborating with the Bog Learning Network's Protection Committee to enhance their site-specific planning actions, coordinating with our conservation partners, and reaching out to landowners about protection options and incentives. When conservation agreements and easements are created, we will ensure that the language in the easement document allows for appropriate management of the bog turtle habitat.

Protecting the wetland is the first priority, but NCWRC will also strive to protect the land immediately surrounding the wetland, the watershed of the wetland, the land and streams between wetlands, and any other lands and wetlands that would benefit the bog turtle population or metapopulation. Protecting the watershed is critical. The value of watershed protection is acknowledged in the Mountain Bogs National Wildlife Refuge Land Protection Plan and Final Environmental Assessment as one of the four factors used in delineating Conservation Partnership Areas (USFWS 2014). Key components of watershed protection are inclusion of riparian buffers, minimization of impervious surfaces, and limiting activities that involve water extraction. Further, protecting the landscape surrounding bogs will lessen impacts of intense rainfall events via water infiltration and will attenuate runoff concerns as climate changes. Protecting the surrounding landscape of a metapopulation will help maintain or improve movement corridors, habitat connectivity, and gene flow. NCWRC staff, land trusts, and other conservation partners such as NRCS will play a critical role in developing relationships with additional landowners and developing an educational campaign in communities closest to these metapopulations.

Protecting the wetland and surrounding land will help maintain and improve bog turtle movement corridors, habitat connectivity and gene flow. (USFWS)

Outreach

We have a strong network of collaborators and solid relationships with many private landowners, but more needs to be done. NCWRC's involvement needs to expand to an agency-wide effort, we need to work with additional key partners, and we need to have a more robust outreach program to landowners. These actions would bring increased funding, programs, private landowner involvement, and protection of the species, thereby making a significant difference in the conservation of bog turtles.

Increased Collaboration

Collaboration efforts at the Agency level should be focused on the variety of opportunities multiple divisions can contribute to bog turtle conservation. Staff expertise exists within the Wildlife Management, Wildlife Education, Land and Water Access, Law Enforcement, Engineering, and Communications, Marketing and Digital Engagement divisions. For example, the Wildlife Management Division's Operations Program can assist with landowner education and outreach as well as identification of new bog locations, and program biologists can develop and disseminate tools and incentives that get landowners more engaged in practices that benefit bog turtles. The Land and Water Access staff's expertise in habitat management is integral to habitat management efforts on NCWRC-owned bogs, and the expertise of staff from Engineering will help develop and conduct wetland restoration projects beneficial to bog turtles. The Wildlife Education and Communications, Marketing, and Digital Engagement divisions can help develop and implement stronger education and outreach programs focusing on bog turtles and bogs. However, increasing directed efforts toward the conservation needs of this species could require additional personnel resources or a reprioritization of activities.

Staff from the Wildlife Management and Law Enforcement divisions should collaborate and share information on mountain bog ecosystems and bog turtles and enhance efforts to educate the public about the importance of protecting these habitats and species. Specifically, Division of Wildlife Management staff will work closely with law enforcement officers who have bog turtle populations in their districts, so they can focus antipoaching efforts as needed.

Building relationships with entities that can provide habitat management and land protection assistance to landowners, including NRCS and land trusts, will continue to be important to long term conservation. Cooperative work with NRCS staff to identify possibilities and encourage interest in new programs and funding designed for bog turtle conservation will continue. Agency staff can provide educational programs for NRCS staff regarding mountain bogs and bog turtles. Opportunities may exist through current NRCS incentive programs for private landowners, such as the Wetlands Reserve Easement (WRE) program and Environmental Quality Incentives Program (EQIP), as well as future NRCS programs. Agency staff currently maintain strong relationships with many land trusts in the region and further steps to strengthen relationships with land trusts that have not been as active in bog turtle conservation efforts should be considered.

A need exists to improve communication with staff at organizations and businesses that may impact known and potential bog turtle wetlands. For example, Utility Right-of-Way managers (e.g., Duke Energy, Tennessee Valley Authority) often unintentionally use management techniques that damage bogs and bog turtles. Agency staff should develop and disseminate information that will provide alternative management techniques that will not harm bog turtles and alter habitat, and maintain open communication with managers. Finally, efforts toward expanding our conservation partners' understanding of the risks of poaching and the importance of safeguarding location information is paramount.

Work Closely with Private Landowners

In collaboration with partners, NCWRC staff will develop and implement an effective outreach and education program that is designed for both the public and for landowners within the range of the bog turtle who have wetlands on their property. We will work with Wildlife Education and Marketing staff to develop an outreach strategy to gain awareness, compassion, and support for bog turtles and their habitat. We also need to identify strategies to help maintain existing relationships and consider how to reach additional private landowners. Due to the time-consuming nature of maintaining landowner relationships and providing meaningful education and outreach, we need to increase NCWRC staff capacity to meet this need better.

Working closely with private landowners is paramount to our success in studying, managing, and protecting wetlands that bog turtles inhabit. We need to expand our outreach, guidance, and assistance for private landowners to encourage them to manage their property with bog turtle conservation in mind. We need to identify, develop, and implement incentive programs for landowners to implement habitat management practices (e.g., fencing rental program, NRCS programs such as Working Lands for Wildlife, USFWS Partners for Fish and Wildlife, WCLP). These programs can provide money to willing landowners to reduce their tax burden and contribute funds to do projects on their land. State Wildlife Grants also yield benefits to interested landowners because their wetlands may be managed at no cost to them. We must also provide tangible and helpful guidance on how best to manage their properties and what conservation programs are available to them.

Working closely with private landowners is paramount to the success in studying, managing, and protecting wetlands that bog turtles inhabit. (Jeff Hall)

This guidance includes determining products (e.g., information packet, brochures) and/or educational programs that are needed. Project Bog Turtle and the USFWS each have some materials that may be useful, but they need to be updated. For example, one product would be to develop "bog turtle best management practices" to educate landowners (e.g., use of livestock, mowing/bush-hogging practices, pesticide and fertilizer use, feral pets) with the aim of improving bog turtle habitat and minimizing habitat loss and injuries or death of turtles. Likewise, when private landowners express an interest, we can assist by developing management plans for their property.

Regulations and Enforcement

The bog turtle was listed as Threatened in 1997 by the USFWS and has been listed in CITES Appendix I (Convention of International Trade in Endangered Species) since 1975. However, the Threatened by Similarity of Appearance designation for the southern population limits some protections afforded by the Federal ESA, including incidental take. In North Carolina, take or possession of this species without a valid permit is currently prohibited under NC law and administrative code (15A NCAC 10I .0102) and is considered a Class 1 misdemeanor (NCGS § 113-337(b)). We will address threats from illegal collection by continuing and expanding training and communication with enforcement officers and land managers. We will work with state and federal enforcement officers to increase surveillance at sites deemed most vulnerable to illegal collection. We will also follow the progress of larger turtle anti-poaching groups such as the Collaborative to Combat the Illegal Trade in Turtles and will implement guidance developed by these groups.

Reviews of permit applications (e.g., NCWRC, USFWS) and enforcement of current regulations (e.g., Section 404 of the Clean Water Act) protect bogs from further destruction and degradation (e.g., filling, ditching, flooding to create ponds). However, the Clean Water Act protects jurisdictional wetlands from filling or draining, but small wetlands, including many bogs, are not protected and most agricultural activities are exempt from these restrictions. NCWRC biologists will provide conservation recommendations during reviews of permit applications that will reduce negative impacts to bogs, including reduction of stormwater runoff, decreased impermeable surface area, and support of measures that increase infiltration into the groundwater.

Summary of Actions Needed

The Conservation Actions needed to recover bog turtles are numerous and reflect the wide range of threats the species faces. Central to this long list are surveys and monitoring that are critical to continue assessing populations, discovering new populations, evaluating site-specific threats, and evaluating the success of conservation actions taken in an adaptive management framework. These core actions provide the foundation for targeted, intensive research that is needed to provide the information necessary to make decisions about the most effective conservation actions for specific populations. Some sites or populations may only need vegetation management to ensure population viability, whereas many others could require working with NCDOT, enforcement, implementing hydrologic restoration, population management, subsidized predator trapping, outreach, land protection or landowner technical guidance, and many other actions. It may seem overwhelming considering the site-specific nature of the threats and conservation actions needed to address those threats, but by prioritizing populations and conservation actions through the development of management plans and addressing threats in a timely manner, progress is being, and will continue to be made recovering bog turtle populations in North Carolina.

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GLOSSARY

Bioturbation: The reworking of soils and sediments by animals or plants.

Captive-breeding: The process of breeding animals in controlled environments by experts within well-defined settings, such as wildlife reserves, zoos, and other commercial and noncommercial conservation facilities.

Conservation easement: A conservation easement is a restriction placed on a piece of property to protect specific resources. The easement is either voluntarily donated or sold by the landowner and constitutes a legally binding agreement that limits certain types of uses or prevents development from taking place on the land in perpetuity.

Conservation ownership: When a property is owned by a government agency focused on conservation (e.g., NPS, USFS, NCWRC, NC Parks) or a conservation NGO (e.g., land trust, The Nature Conservancy).

eDNA: Environmental DNA is organismal DNA that can be found in the environment. Environmental DNA originates from cellular material shed by organisms (via skin, excrement, etc.) into aquatic or terrestrial environments that can be sampled and monitored using new molecular methods.

Extirpation: Local extinction or extirpation is the condition of a species (or other taxon) that ceases to exist in the chosen geographic area of study, though it still exists elsewhere. Local extinctions are contrasted with global extinctions.

Fecundity: The actual reproductive rate of an organism or population, measured by the number of gametes (eggs), seed set, or asexual propagules.

Fee-simple purchase: A fee-simple purchase transfers full ownership of the property, including the underlying title, to another party.

Fertility: The quality of an organism's ability to produce offspring, which is dependent on age, health, and other factors.

GIS: A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, man- age, and present spatial or geographic data.

Head-starting: The act of rearing wild hatchlings in protective enclosures before release at less susceptible size/ age, thereby avoiding the heavy mortality of young age classes in the wild.

High-quality habitat: This habitat is of adequate size and has the components of "suitable habitat," plus the following characteristics: areas with deep, loose, low-strength soils (Feaga et al. 2013), 2) presence of sphagnum mosses, rushes, sedges, and some wetland shrub species, 3) mosaic of low and shrubby vegetation with one or more relatively large areas with very low vegetation (ideally sphagnum, but also rushes and sedges) that receive full sun, 4) relatively unaltered hydrology with stable groundwater levels that are 8 cm ± 1 cm (3.1 in ± 0.4 in) average depth from sur- face over multiple years, without flooding and inundation

(Feaga 2010), 5) presence of subsurface root structures and/or tunnels, 6) adequate vegetation to conceal turtles when basking on surface, 7) minimal threats within habitat and/or adjacent to property (e.g., busy roads, overabundance of predators).

Hydrology: The science dealing with the properties, distribution, and circulation of water on and below the earth's surface and in the atmosphere.

Invasive species: Is a species 1) that is non-native (or alien) to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health. Land Protection: Permanent protection of a piece of property through fee-simple purchase, donation, or a conservation easement.

LIDAR: This term stands for "Light Detection and Ranging" — a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.

Mesocarnivore: an animal whose diet consists of 50–70% meat with the balance consisting of non-vertebrate foods which may include insects, fungi, fruits, other plant material and any food that is available to them.

Mesopredator: Mesocarnivore that is often outcompeted by top predators such as wolves and cougars but can become the dominant predator in ecosystems where top predators are absent.

Metapopulation: Consists of a group of spatially separated populations of the same species that interact at some level.

Mountain bogs: See "Southern Appalachian Bog".

Mycoplasma: Any of numerous parasitic microorganisms of the class Mollicutes, comprising the smallest self-reproducing prokaryotes, lacking a true cell wall and able to survive without oxygen.

Occurrence record: A location with a record of a bog turtle is an occurrence.

Population: A group of bog turtles that interact and share the same habitat.

Population Augmentation: The addition of animals to an existing population, usually a small population that has habitat that can support a larger population that has not been expanding on its own due to impacts from threats, stochastic events, or demographic limitations. Animals can be translocated from a source population or may be added through captive breeding or head-starting of individuals that originated at the site.

Population Introduction: The intentional movement and release of animals to a location with no prior records of bog turtles (within or outside the species' range).

Population Management: Refers to population augmentation, population repatriation, and population introduction via various methods, including but not limited to head-starting, captive rearing, and translocation.

Population Repatriation: The intentional movement and release of animals to a site that historically had bog turtles.

Ranavirus: *Ranavirus* is a genus of viruses in the family *Iridoviridae* that includes viruses that are infectious to amphibians and reptiles.

Recruitment: Occurs when juvenile organisms survive to be added to a population, by birth or immigration — usually a stage whereby the organisms are settled and able to be detected by an observer.

Restoration: An intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity, and sustainability.

Site: A location that harbors a bog turtle population. It could be composed of one wetland with a population or a complex of wetlands in close proximity.

Southern Appalachian Bog: Includes open, acidic, permanently saturated wetlands of flat stream bottoms or gentle slopes, with a distinctive bog flora, with varying amounts of shrubs and sometimes with moderate amounts of tree cover, but with a well-developed, dense herbaceous layer and, generally, extensive Sphagnum cover. These wetlands generally appear to have a substantial amount of groundwater input, and therefore would be considered poor fens.

Suitable habitat: Habitat composed of the following at a minimum: 1) soft, saturated soils, 2) spring-fed hydrology, and 3) an area with low vegetation (no canopy) that gets full sun.

Threatened due to Similarity of Appearance: A species that is threatened due to similarity of appearance with another listed species or the same species in another geographic area and is listed for its protection. Species listed as T(S/A) are not biologically endangered or threatened and are not subject to Section 7 consultation with USFWS.

Viable Population: A population will be considered viable if it is estimated to have 1) at least 15 individual female adult turtles found within past 10 years (Shoemaker et al. 2013) AND all age classes have been observed in the past 10 years (eggs, hatchlings, juveniles, and adults). If enough data exist to assess population status, the population must also be stable or increasing, rather than in decline. We propose the following categories related to viability: non-viable, unknown viability, potentially viable, and viable.

Watershed: A drainage basin or 'catchment area' is any area of land where precipitation collects and drains off into a common perennial body of water, such as a wetland or stream.

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