Interim Species Status Assessment/Biological Report

for the
Northern Population of the
Bog Turtle
(*Glyptemys muhlenbergii*)

Photo Credit: Todd Pierson

Version 1

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Note: Wetland/site names are redacted/modified to protect sensitive species locations.

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Executive Summary

This report summarizes the results of the first two stages of a Species Status Assessment (SSA) for the northern population of the bog turtle (*Glyptemys muhlenbergii*). In stage 1, we described the species' ecology in terms of its resiliency, redundancy, and representation (collectively the "3Rs") (Shaffer *et al.* 2002, pp. 139–140; Wolf *et al.* 2015, entire; Smith *et al.* 2018, entire); specifically, we identified the ecological requirements for survival and reproduction at the individual, population, and species levels. In stage 2, we assessed the species' historical and current condition in relation to the 3Rs and identified past and ongoing factors (beneficial and risk factors) that led to the species' current condition. Stage 3, assessing the species' future condition and viability, will be completed in the near future to aid in possible Recovery Plan revisions.

Background

The U.S. Fish and Wildlife Service (Service) listed the northern population of the bog turtle (Connecticut, Delaware, Maryland, Massachusetts, New Jersey, New York, and Pennsylvania) as a threatened distinct population segment in 1997. Since that time, the Service and our partners have focused our efforts on finding additional individual populations, restoring and managing habitat, and minimizing impacts from activities within or near bog turtle wetlands. The Service finalized a Recovery Plan (Service 2001, entire) which included recovery criteria for 5 recovery units (RU) (Delaware, Hudson-Housatonic, Outer Coastal Plain, Prairie Peninsula-Lake Plain, and Susquehanna-Potomac). Recently, states throughout the range developed a Conservation Plan to assist with prioritizing individual populations and conservation strategies to implement towards achieving recovery of this species (Erb 2019, entire).

The bog turtle is the smallest member of the genus *Glyptemys* and one of North America's smallest turtles (Service 2001, entire). The bog turtle's life cycle is similar to other northeast freshwater turtles. Depending on latitude and weather conditions, bog turtles generally brumate from October to March. Upon spring emergence, individuals begin traveling to their nesting grounds. Mating takes place between March and June, with females, on average, laying between 3–4 eggs in June to early July. Eggs hatch from August to October. See chapter 2 for additional life history information.

Within a watershed, bog turtles inhabit a variety of wetland types that are generally small, spring/seepage-fed, open-canopy, herbaceous sedge meadows and fens[1] bordered by more thickly vegetated and wooded areas. These areas are primarily used by bog turtles for nesting, basking, and foraging activities, and contain native sedges, grasses, forbs, scattered shrubs, saturated mud/muck-like soils, and shallow to deep rivulets/watery trails created by naturally flowing water or by wildlife. However, bog turtles use more densely vegetated or sparsely forested areas for hibernation and will occasionally be found using upland habitat adjacent to wetland edges. Bog turtles are known to occasionally disperse through uplands or via streams and travel to adjacent wetlands to seek out other areas of suitable habitat; indicating the

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[1] Mitsch and Gosselink (2000, p. 41) define a fen as "a peat-accumulating wetland that receives some drainage from surrounding mineral soil and usually supports marshlike vegetation."

importance of metapopulation dynamics where connective corridors[2] and genetic exchange help to maintain healthy and resilient individual populations.

Prior to listing, there were range reductions, with at least 40 individual populations extirpated (bog turtle wetlands no longer contain suitable habitat) and an additional 37 individual populations considered historical (no bog turtle observations within the last 30 or more years; of which the majority are likely extirpated), from 18 counties in western Pennsylvania, northern, central and eastern New York, western Connecticut, and northern and southern New Jersey. At the time of the listing, the bog turtle was thought to be extant in 191 individual populations in the northern range. Significant survey efforts since the time of the listing have resulted in 508 extant individual populations comprising 330 metapopulations, of which 244 are single, isolated individual populations. For simplicity, we use the term metapopulation throughout even if the population has only one individual population. Currently, the northern range distribution is stable. Pennsylvania is the only state in the northern range where new individual populations are regularly being discovered.

Extant individual populations in many locations are highly fragmented primarily due to external factors resulting from encroachment of residential and commercial development that eliminates corridors to other extant wetlands. Individual populations also face threats from habitat alterations due to vegetation succession, hydrology changes, and introduction of invasive plant species. In chapter 4, we describe how these factors influence the current condition of the species.

Methods

We used individual population-level condition metrics originally provided from the Conservation Plan (Erb 2019, pp. 10–12) and converted them to metapopulation-level condition metrics. The metrics were then combined into a single resiliency score (good, fair, or poor) for each known extant bog turtle metapopulation. The foundation of this assessment uses a combination of field data, observations, and expert judgements to arrive at the current condition of the 330 extant metapopulations through 2020. The ranking of condition metrics was organized into two general groups that evaluated the individual population quality (demographic needs) and habitat quality (table E.1).

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[2] Connecting corridors for bog turtles are defined as habitat connections between individual populations that can consist of vegetated upland, wetlands, and streams.

Table E.1. The metapopulation condition category (unknown, good, fair and poor) for each demographic and habitat condition metric. Population size and recruitment were categorized as poor or good condition, while interconnectedness, succession, hydrology, and development were categorized as poor, fair, or good condition. Unknown condition categories were used when data were not available, or population-level data were insufficient for determining metapopulation-level.

	Unknown	**Poor**	**Fair**	**Good**
Demographic Condition Metrics[1]				
Population Size	Unknown	< 30 individuals	NA	≥ 30 individuals
Recruitment	Unknown	No or potential evidence of recruitment[3]	NA	Some evidence of recruitment[4]
Interconnectedness	Unknown	Isolated, single population	Some interconnectedness	Strong interconnectedness
Habitat Condition Metrics[2]				
Succession	Unknown	High level of woody succession	Moderate level of woody succession	Low level of woody succession
Hydrology	Unknown	High disturbance	Moderate disturbance	Low disturbance
Development	Unknown	High development	Some development	No development

[1]Descriptions of each demographic condition metric category are in the sections below (see tables A3, A5, and A7, respectively).

[2]Descriptions of each habitat condition metric category are in the sections below (see tables A9, A11, and A13, respectively).

Scores for each metapopulation metric were then normalized on a scale of 0 (poor condition) to 1 (good condition) before each could be weighted by its relative importance and combined into a single resiliency score. Unknowns were not included in the normalizing process, rather, they were assigned either a good or poor condition during the sensitivity analysis to explore the influence of resolving unknowns on the assessment of resiliency for each metapopulation. Then a relative importance weighting method was used to combine metapopulation metrics into a single resiliency score for each metapopulation. Resiliency was then calculated for each metapopulation using all normalized demographic and habitat scores, weighted by their relative importance (*i.e.*, weighted average).

Results

A total of 119 metapopulations had known conditions for all six metapopulation metrics (no unknowns). Among these metapopulations, the average resiliency score was 0.41 (median=0.36), with higher average resiliency in the Hudson-Housatonic (0.48) and Prairie Peninsula-Lake Plain (0.43) Recovery Units, and lower average resiliency in the Delaware (0.40) and the Susquehanna-Potomac (0.38) Recovery Units. Resiliency could not be calculated for the Outer Coastal Plain Recovery Unit because there were too many unknowns. Over half (N=79) of

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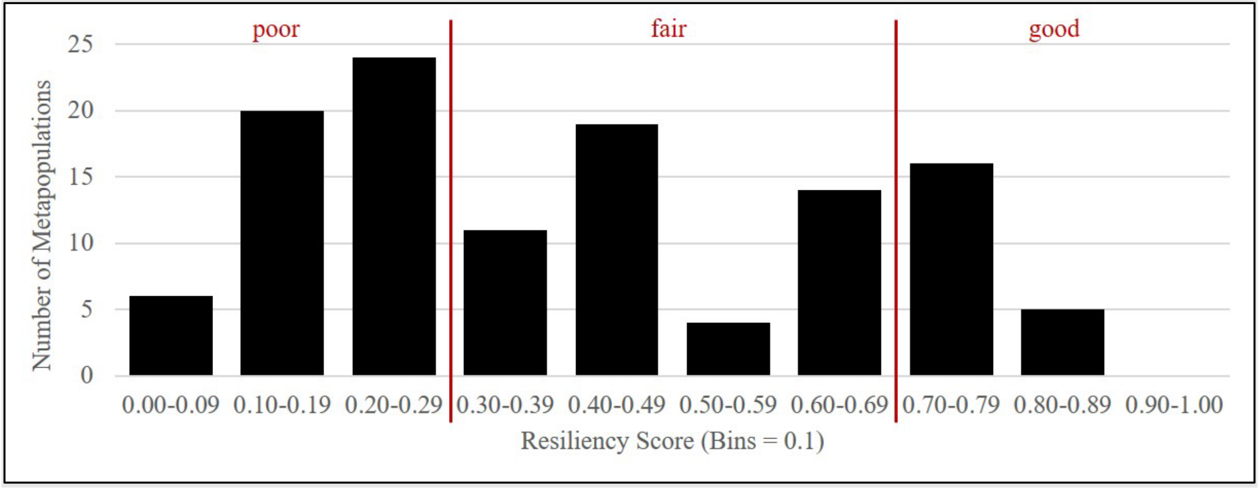
[3] "No or potential evidence of recruitment" means that either there is no recruitment found based on extensive survey efforts or gravid females, eggs, or nests have been observed.

[4] "Some evidence of recruitment" means hatchlings, yearlings, juveniles, or multiple age classes have been observed.

all metapopulations (without unknowns) had resiliency scores less than 0.5, with only 24 metapopulations exceeding a resiliency score of 0.7 (figure E.1 [figure A7 in appendix A]; table A26).

Figure E.1. Resiliency scores (range 0.00 to 1.00; bin size=0.1) for each metapopulation (N=119) with known condition for all demographic and habitat metrics (see "Resiliency" tab), for poor (0.0–0.29 scores), fair (0.30–0.69), and good (0.70–1.00) condition.



Due to the large number of unknowns across each metapopulation condition metric (153 had unknown metapopulation size, 138 had unknown recruitment, 17 had unknown interconnectedness, 65 had unknown succession, 53 had unknown hydrology, and 9 had unknown development), it was not possible to calculate resiliency scores for a majority of metapopulations (64%; 211 of 330). To evaluate the range in *possible* resiliency scores if unknowns were resolved, we developed two scenarios. The first scenario represented if all unknown conditions were resolved and found to be in good condition. The second scenario represented if all unknown conditions were resolved and found to be in poor condition. These two scenarios provided a range of plausible resiliency scores for all metapopulations given unknowns are resolved through additional field surveys.

We assigned resiliency categories of good, fair, and poor to each metapopulation based on the corresponding resiliency score. Resiliency scores less than 0.3 were considered poor and represented metapopulations that are lacking many of the conditions needed for persistence (*e.g.*, individual population size, recruitment, and/or hydrology). Resiliency scores between 0.3 and 0.7 were considered fair and represented metapopulations lacking many of the conditions needed for persistence (*e.g.*, interconnectedness, suitable vegetation, or suitable hydrology). Resiliency scores equal or greater than 0.7 were considered good and represented metapopulations that had most of the conditions needed for persistence (but could still have performed poorly in at least three of the less important condition metrics).

Across recovery units, a range of 21–98 metapopulations have good resiliency (6–30%), 87–166 metapopulations have fair resiliency (26–50%), and 66–222 metapopulations have poor resiliency (20–67%) (table E.2 [table A27 in appendix A]). Approximately 153 (46%)

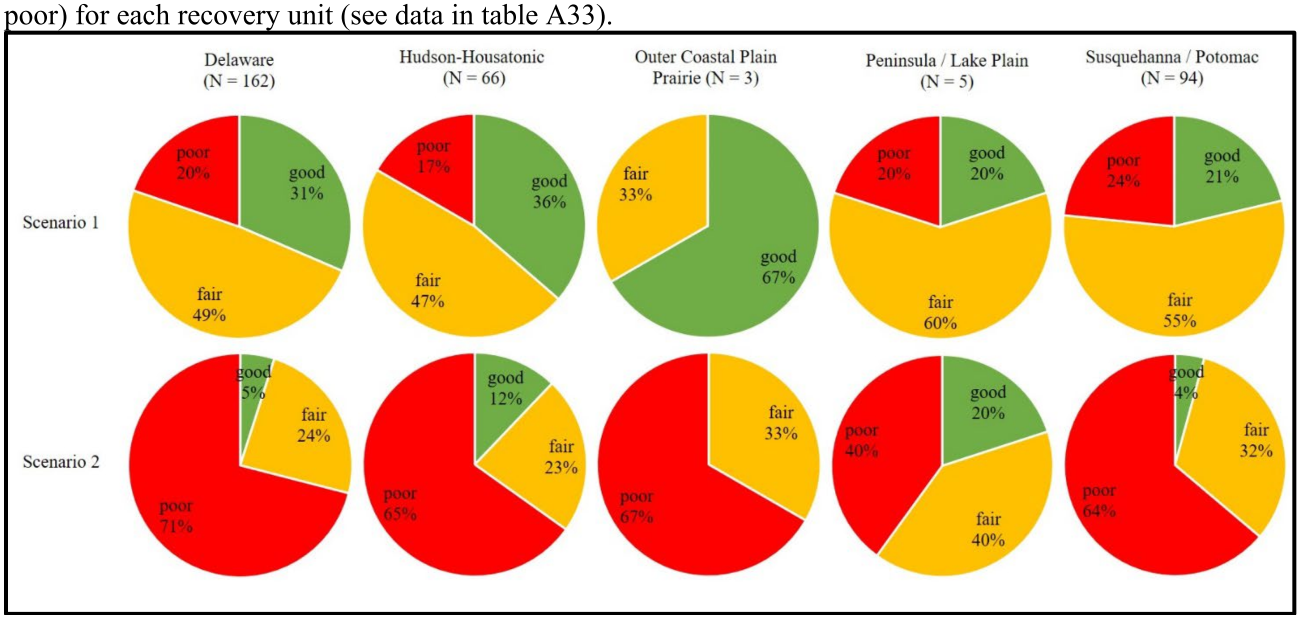
metapopulations have resiliency categories that were insensitive to unknowns (the category did not change based on if unknowns were potentially good [scenario 1] or poor [scenario 2]; table A28; table A34). The remaining 78 (54%) of metapopulations have resiliency scores that were sensitive to the potential condition of one or more unknown metrics (table A28; table A35). Twenty-one (6%) metapopulations have good resiliency regardless of the potential condition of unknown metrics, 65 (20%) had fair resiliency regardless of the potential condition of unknown metrics, and 66 (20%) have poor resiliency regardless of the potential condition of unknown metrics (grey boxes in table A28). Figure E.2 depicts the proportion of metapopulations in each resiliency category under scenarios 1 and 2.

Table E.2. The number of metapopulations in each resiliency category under scenario 1 (unknown condition metrics hypothesized as good) and scenario 2 (unknown condition metrics hypothesized as poor) for each recovery unit.*

	Recovery Unit					
Resiliency Category	**Delaware**	**Hudson-Housatonic**	**Outer Coastal Plain**	**Prairie Peninsula-Lake Plain**	**Susquehanna-Potomac**	**Total**
Scenario 1 (unknown condition metrics hypothesized as "good")						
Good	51	24	2	1	20	98
Fair	79	31	1	3	52	166
Poor	32	11	0	1	22	66
Scenario 2 (unknowns condition metrics hypothesized as "poor")						
Good	8	8	0	1	4	21
Fair	39	15	1	2	30	87
Poor	115	43	2	2	60	222

*Resiliency categories are summarized in the "ResiliencybyRU" tab, using the columns with "_Resiliencycategory_Scenario1" and "_Resiliencycategory_Scenario2" from the "MetaPopData" tab.

Figure E.2. The proportion of metapopulations in each resiliency category under scenario 1 (unknown condition metrics hypothesized as good) and scenario 2 (unknown condition metrics hypothesized as poor) for each recovery unit (see data in table A33).



Summary

Since the species was listed, progress has been made in finding new bog turtle wetlands (primarily in Pennsylvania) and managing the primary threat of habitat loss or alteration from altered hydrology and/or changes to vegetation (succession and invasive plants). We are now aware of 330 extant bog turtle metapopulations (made up of 508 individual populations; 244 of the metapopulations are single, isolated populations) across the range. Thirty-seven additional individual populations are considered historical as bog turtles have not been found in these populations for at least 30 years; however, state biologists consider these as likely to be extirpated. Finally, 40 additional individual populations are considered extirpated (due to habitat no longer being present) across the range.

Bog turtles continue to occur throughout the northern population range with the majority of metapopulations found within the Delaware and Susquehanna-Potomac RUs. There was an historical range reduction, primarily in New York. There have been no discernible range reductions throughout the northern range since the time of the listing. Instead, there has been an increase in the discovery of extant individual populations since the Federal listing with 317 new individual populations located throughout the northern range. For example, Pennsylvania has new individual populations in new WBDHU 12-level watersheds[5]

Table E.3 summarizes the resiliency at the species-level across the northern range of the bog turtle. Of the known extant metapopulations, 6–30% are considered to have good resiliency and should be able to continue to respond to environmental stochasticity. The remaining

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[5] See the following link for Watershed Boundary Data for Hydrologic Units (WBDHU): *https://www.usgs.gov/national-hydrography/watershed-boundary-dataset?qtscience_support_page_related_con*

metapopulations are considered to have poor to fair resiliency due to their small individual population size or degradation of habitat and/or isolation. Many of these metapopulations have the potential for higher resiliency in the future if habitat is restored and managed.

Smaller individual populations or populations with reduced reproductive success due to degraded habitat conditions are at greater risk of extirpation as a result of additional development (includes many types) on the landscape (includes in uplands and within wetlands), predation, pollution and contaminants, and from flooding and drought events. They are also at greater risk of extirpation associated with illegal collection or disease, although these kinds of catastrophic events could occur at larger wetlands as well. Any future loss of metapopulations can reduce overall genetic and ecological diversity of the species, further limiting the species' representation. Small, isolated metapopulations of bog turtles have the potential to retain sufficient genetic diversity; therefore, preservation of these metapopulations may be important to maintaining range-wide genetic diversity (Sirois *et al*. 2014, p. 459).

Due to their specific habitat requirements and limited dispersal capacity and behavior, it is unlikely that bog turtles will frequently be able to move from current wetland locations to other wetlands. In addition, it is likely that if they moved to another wetland that it would also be in a degraded condition given the high percentage of wetlands in that situation.

Table E.3. A summary of bog turtle current condition.

3 Rs	Requisites	Description	Current Condition
Resiliency *(able to withstand stochastic events)*	Healthy populations	Populations with: • sufficient number of adults • presence of males and females • high adult survival • sufficient recruitment and age structure • interconnectedness of habitat (part of metapopulation) • suitable soils and associated vegetation • intact hydrology and ecological processes • intact upland buffer	Rangewide, 6–30% of metapopulations have good resiliency 26–50% have fair resiliency, and 20–67% have poor resiliency 37 historical (individual populations) 40 extirpated (individual populations)
Representation *(to maintain evolutionary capacity)*	Maintain adaptive diversity	Healthy populations distributed across areas of unique adaptive diversity (*e.g.*, across latitudinal gradients) with sufficient connectivity for periodic genetic exchange.	Metapopulations occur throughout the range. However, most are in poor to fair condition within each recovery unit (RU). **Delaware RU** 162 metapopulations poor (20–71%) fair (24–49%)

			good (5–31%) **Hudson-Housatonic RU** 66 metapopulations poor (17–65%) fair (23–47%) good (12–36%) **Outer Coastal Plain RU** 1 metapopulation=fair 2 metapopulations=poor or good (too many unknowns) **Prairie Peninsula-Lake Plain RU** 1 metapopulation=poor 2 metapopulations=fair 1 metapopulation=good 1 metapopulation=poor or fair (too many unknowns) **Susquehanna-Potomac RU** 94 metapopulations poor (23–64%) fair (32–55%) good (4–21%)
Redundancy *(to withstand catastrophic events)*	Sufficient distribution of healthy populations	Sufficient distribution to guard against catastrophic events (*e.g.*, novel disease, drought, and floods) significantly compromising species adaptive diversity.	Bog turtles continue to have a large distribution with extant metapopulations known throughout the range and within each RU. However, most are in poor to fair condition. In addition, there was an historical range contraction with most losses at the northern extent of the range (New York).
	Sufficient number of healthy populations	Adequate number of healthy populations to buffer against catastrophic losses of adaptive diversity.	Most bog turtle metapopulations are in poor to fair condition.

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Chapter 1 - Introduction

1.1 Background

The U.S. Fish and Wildlife Service (Service) is responsible for identifying species that may be in need of protection under the Endangered Species Act, as amended (ESA), for periodically assessing the status of those species, and for preparing a Recovery Plan with objective criteria, site-specific actions, and an estimate of time and costs. The Service listed the northern population of the bog turtle (*Glyptemys muhlenbergii*) as a threatened distinct population segment on November 4, 1997 (FR Vol. 63 No. 213 59605–59623). The Recovery Plan for the northern population of bog turtle was issued on May 15, 2001 (Service 2001, entire).

This report is intended to provide the biological support for the recommendation of whether or not to change or retain the current classification of the bog turtle as part of a 5-Year Review. The process and this interim SSA report do not represent a decision by the Service. Instead, this report provides a review of the best available information strictly related to the biological status of the bog turtle. Any proposals for changes in the species status would be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and announced in the ***Federal Register***. As part of the 5-Year Review, the Service will also assess how well the Recovery Plan currently describes conservation needs for the species.

The information used in developing this interim SSA report is the result of extensive literature searches, review of research and monitoring efforts, and expert information related to the bog turtle stemming from numerous correspondence over email and phone calls.

1.2 Analytical Framework

Using the SSA framework (figure 1.1), in stage 1, we described the species' ecology in terms of its resiliency, redundancy, and representation (collectively the "3Rs"); specifically, we identified the ecological requirements for survival and reproduction at the individual, population, and species levels. In stage 2, we assessed the species' historical and current condition in relation to the 3Rs and identified past and ongoing factors (beneficial and risk factors) that led to the species' current condition. We anticipate that in stage 3, assessment of the species' future condition and viability, will be completed in the near future to aid in possible Recovery Plan revisions.

For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in natural ecosystems within a biologically meaningful timeframe.

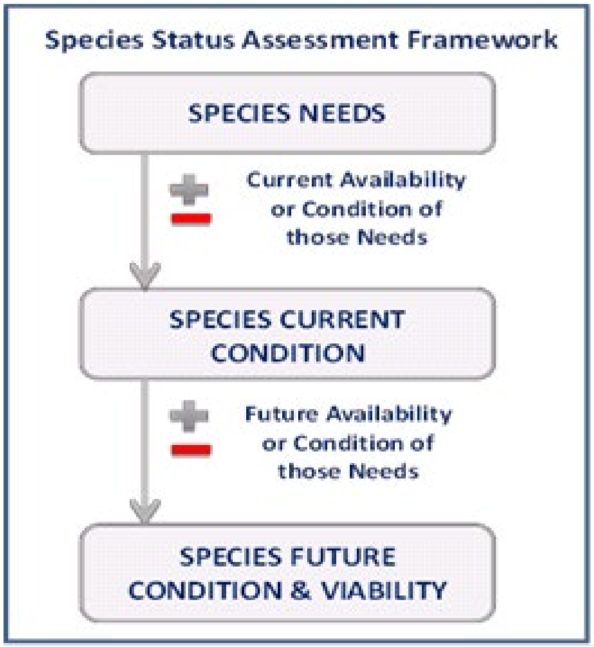

Figure 1.1. The species status assessment framework.

Resiliency, redundancy, and representation (together, the 3Rs), are defined as follows:

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

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

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

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

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

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

The decision whether to list a species is based *not* on a prediction of the most likely future for the species, but rather on an assessment of the species' risk of extinction. Therefore, to inform this assessment of extinction risk, we describe the species' current biological status in this report and we will complete stage 3 to more fully assess how this status may change in the future under a range of scenarios to account for the uncertainty of the species' future. We evaluate the current biological status of the species by assessing the primary factors negatively and positively affecting the species to describe its current condition in terms of resiliency, redundancy, and representation. We will evaluate the future biological status by describing a range of plausible future scenarios representing a range of conditions for the primary factors affecting the species.

Chapter 2 - Species Information

2.1 Introduction

In this chapter, we provide basic biological information about the bog turtle, including a review of taxonomic history to ensure it is a valid taxon, genetics, morphological description, and known life history traits. We then outline the resource needs of individuals, populations, and the species as a whole. This is not an exhaustive review of the species natural history; rather, it provides the ecological basis for the analysis of the current condition (chapter 4) of the northern population. For further information about the bog turtle, refer to Service (2001, entire) and Erb (2019, entire). Where appropriate, we make comparisons with the southern population or use information from the southern population as a surrogate for information for the northern population.

2.2 Taxonomy

The currently accepted classification is:
Kingdom: Animalia
Phylum: Chordata
Class: Reptilia
Order: Testudines
Family: Emydidae
Species: *Glyptemys muhlenbergii*

In 1801, Schoepff described this species as *Testudo muhlenbergii* based on a specimen collected by Gotthilf Heinrich Ernst Muhlenberg from Pennsylvania (Ernst and Bury 1977, p. 204.1). The genus *Clemmys* was first assigned to this species by Fitzinger in 1835 (Barton and Price 1955, p. 159). Bickham *et al*. (1996, pp. 89–97), Burke *et al*. (1996, pp. 572–584), Lenk *et al*. (1999, pp. 1911–1922), and Holman and Fritz (2001, entire) provided substantial evidence that the genus *Clemmys* as previously recognized was paraphyletic (meaning turtles in this genus descended from a common evolutionary ancestor) with respect to the sister genera *Emys and Emydoidea*. The sister species *insculpta* (wood turtle) and *muhlenbergii* were placed in the genus *Glyptemys,* leaving *guttata* (spotted turtle) in the monotypic genus *Clemmys*. While there are currently two competing taxonomic schemes regarding the other sister genera, the *Clemmys*/*Glyptemys* split has been adopted by professional herpetological organizations (*i.e*., Society for the Study of Amphibians and Reptiles [Crother 2017, p. 85] and Interagency Taxonomic Information System [ITIS][6]). No subspecies are recognized for *G. muhlenbergii,* although two geographically "distinct population segments" ("northern" and "southern") delineate the Federal listing status of threatened (northern) and threatened by similarity of appearance (southern) under the ESA. The Service finds that the bog turtle is a valid species that should be recognized as *G. muhlenbergii*, and has since adopted this change in the Code of Federal Regulations on October 15, 2021 (86 FR 57373).

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[6] ITIS Standard Report Page: *Glyptemys muhlenbergii*, accessed April 12, 2021.

2.3 Genetics

There is limited genetic variability in bog turtle populations. Amato *et al*. (1997, entire) evaluated mitochondrial DNA (mtDNA) variation in 20 individuals from northern and southern populations. While they found almost no mtDNA variability in a gene that was found to be phylogenetically informative for wood and spotted turtles, they acknowledged that these preliminary data using a small sample size should not be used in any conservation decisions for the species range-wide. Alternatively, Rosenbaum *et al*. (2007, entire) evaluated mtDNA base pairs in three genes from 41 individuals in 21 localities throughout the species range. While they found low levels of variation, they were able to detect differences between the northern and southern individual population of bog turtles. Individual populations in the northeast were fixed for haplotype A, the Prairie Peninsula-Lake Plain turtles had haplotypes A, B, and C, while the southern population turtles had D and E haplotypes (figure 2.1). The differences between haplotype A and haplotypes B, C, and D result from only a single nucleotide transitional mutation. Further, mismatch analysis supported the hypothesis of rapid range-wide expansion for the northern population.

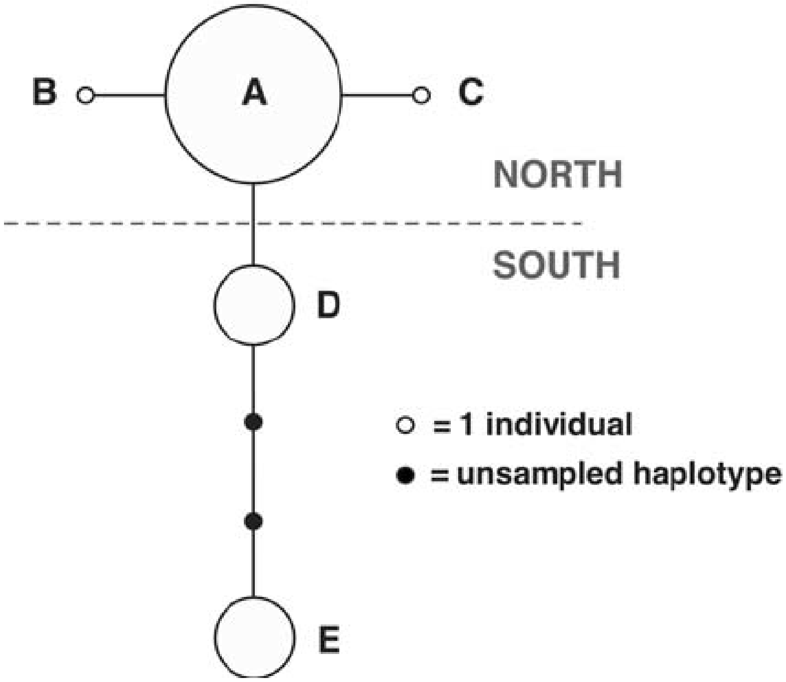


Figure 2.1. A TCS haplotype network for five haplotypes (using mitochondrial cytochrome *b* and displacement loop fragments combined) from 41 individual bog turtle samples. Samples were collected from individual populations in the northern (Massachusetts, New York, and Pennsylvania) and southern (North Carolina and Virginia) populations. Each line represents a single mutational change. Each haplotype is represented by a circle and the area of the circle is proportional to the number of individuals with that haplotype. Black circles indicate intermediate haplotypes not sampled by Rosenbaum *et al.* (2007, entire). This figure is from Rosenbaum *et al*. (2007, p. 336).

Shoemaker and Gibbs (2013, pp. 326–327) sampled blood from 234 bog turtles from eight New York and two Massachusetts individual populations and using 15 microsatellite loci and found no evidence of previous bottlenecks for any of the study individual populations.

2.4 General Distribution

The bog turtle has been reported from 12 states in the eastern U.S. (figure 2.2). A patchy distribution of individual populations is found in western Massachusetts and Connecticut, central New York, and southward through downstate New York, New Jersey, Pennsylvania, Delaware, and Maryland. These states comprise the "northern population." From Maryland, there is a 250-mile gap in the range, where populations appear again in southwestern Virginia, North Carolina, Tennessee, South Carolina, and northern Georgia. These states comprise the "southern population."

Bog turtles have been found at elevations ranging from near sea level in the northern population to 1,371 meters (m) (4,500 feet [ft]) in the southern population (Herman and George 1986, p. 127). Generally, individual populations are not found above 304 m (1,000 ft) in elevation in the northern population.

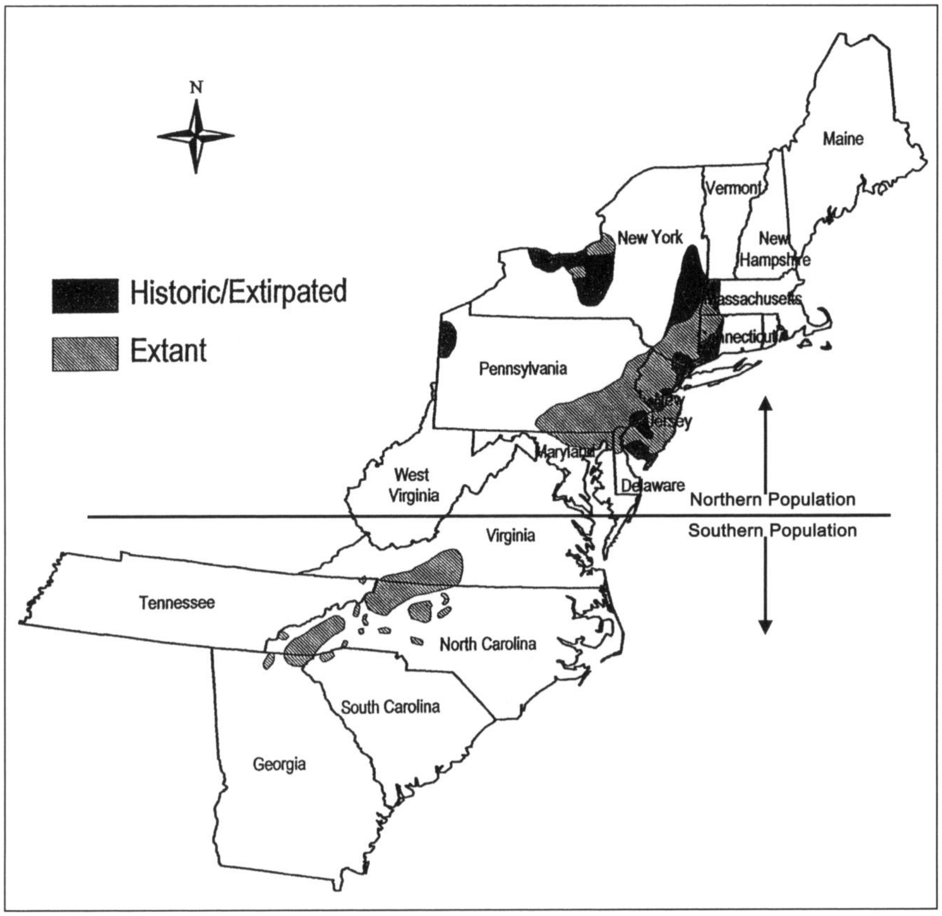


Figure 2.2. Rangewide distribution of the bog turtle (Service 2001, p. 3, modified in Rosenbaum and Nelson, 2010, p. 416).

2.5 Species Description

The bog turtle (figure 2.3) is one of the smallest turtles in North America, with adult males (from New York to Maryland) reaching a mean maximum carapace (the hard upper shell of a turtle) length of 85.5 millimeters (mm) (3.4 inches [in]) to 97.2 mm (3.8 in) and females within the same range reaching a mean maximum carapace length of 80.8 mm (3.2 in) to 93.3 mm (3.7 in) (Rosenbaum *et al.* 2018, unpublished poster). Bog turtle females are significantly smaller than males across the range (Lovich *et al*. 1998, p. 71) and overall carapace length increases from north to south (Lovich *et al*. 1998, pp. 71–72; Rosenbaum *et al*. 2018, unpublished poster).

The head, neck, and limbs tend to be black but sometimes may be brown with mottling. Some turtles have orange to red mottling on their legs and all bog turtles have a prominent ear patch that can range from light yellow to deep orange, and sometimes white or red. Bog turtles have large brown eyes and a deeply notched upper jaw. The carapace is a chestnut brown to black with visible concentric growth rings in all but the oldest worn individuals. The carapace is oblong, moderately domed, slightly keeled, and typically has 25 marginal scutes (bony plates along the edge of the shell) (figure 2.4). Some individuals have a yellowish-brown burst pattern on each scute. The plastron (ventral surface of the shell) is black with tan blotches growing out from the midline (figure 2.4). There are five claws with slightly webbed toes on the front feet and four on the hind. Adult males have a concave plastron compared to the flat female plastron and longer, thicker tails than females, with a vent posterior to the carapace edge.

Figure 2.3. A photo of a bog turtle. Photo credit: Service.

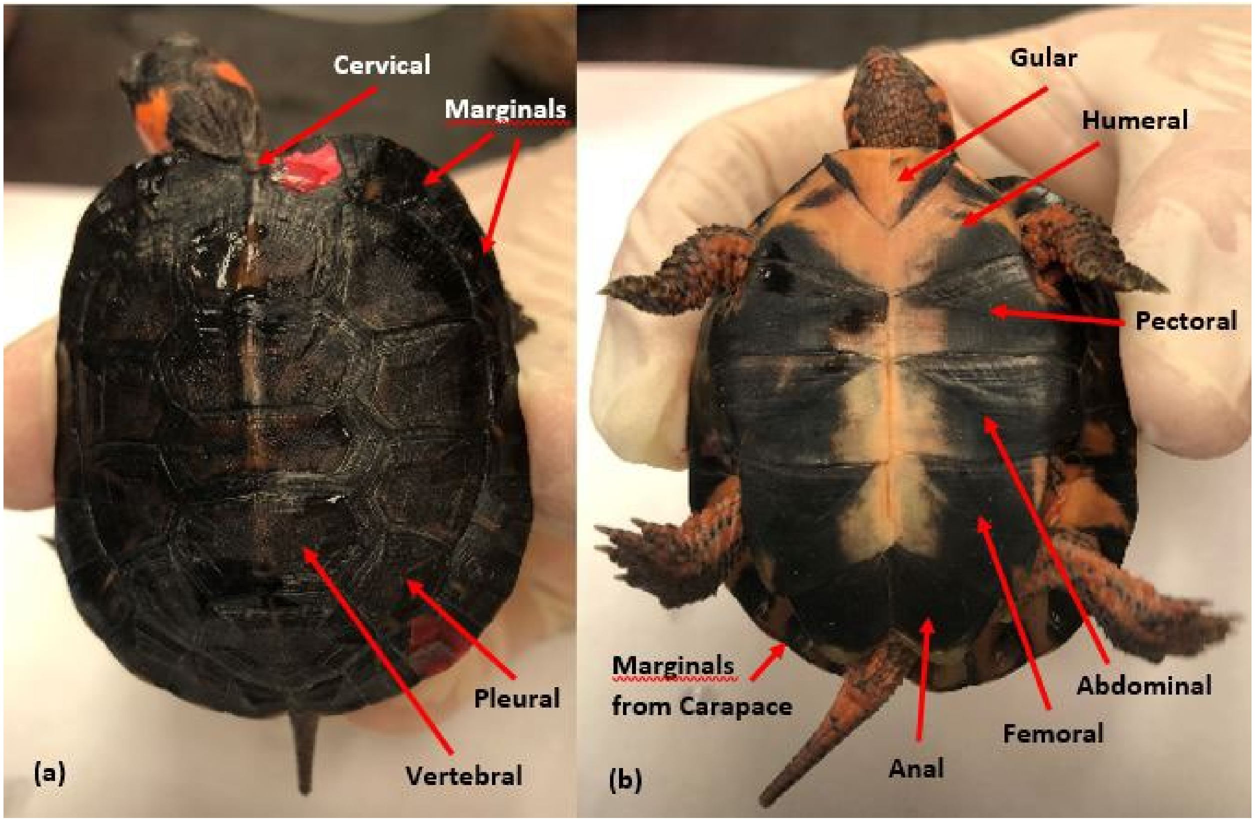


Figure 2.4. These photos depict the scutes of the (a) carapace, the hard upper shell, and (b) plastron, the ventral surface of the shell, of a bog turtle. Photo credit: Service.

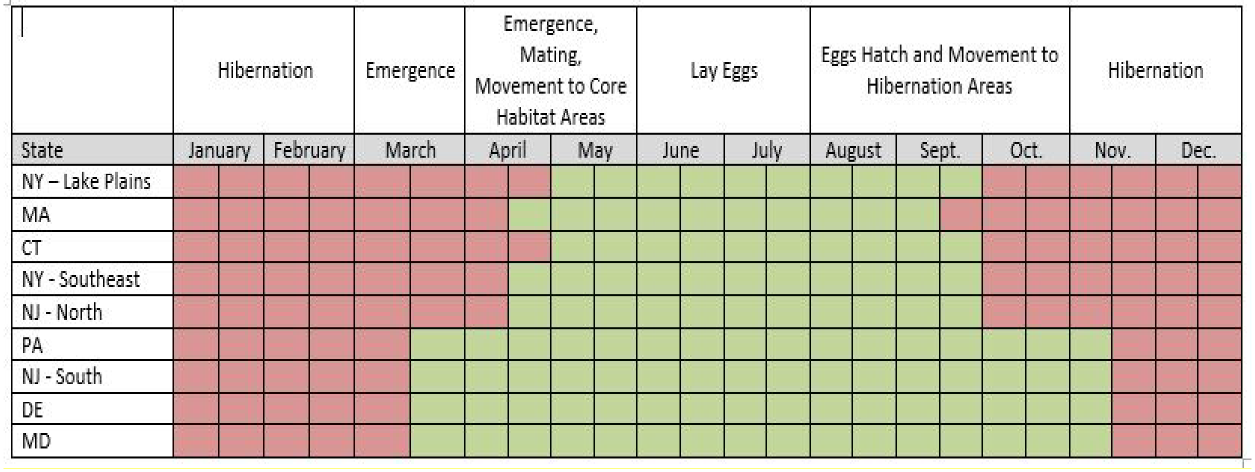
2.6 Life History

Life history includes the events that occur on an annual basis in a species' life and characteristics that affect the likelihood that individuals (as portions of populations) will survive and contribute to the population from one year to the next. All turtle life histories are thought to be characterized, to varying degrees, by delayed maturity (age at first reproduction), long lived, and repeated cycles of reproduction (Wilbur and Morin 1988, entire; Congdon and Gibbons 1990, entire), although life-history strategies vary depending on demography of each species (Riedle *et al*. 2012, p. 187). The bog turtle follows this general paradigm.

The annual cycle of the bog turtle is characterized by two seasons: the active season and the inactive or winter dormant season (table 2.1). The bog turtle active season in the northern population is dependent on latitude and weather conditions. In more northern states, such as Massachusetts, northern New Jersey, and southeastern New York, the active season typically begins by mid-April and ends by late September (Jones 2019, pers. comm.; Pipino 2019, pers. comm.; Tesauro 2019, pers. comm.; Zarate 2019, pers. comm.). In Connecticut, Ravesi (2019, pers. comm.) indicates bog turtles typically emerge the first to second week of May and are overwintering by the second or third week of October. In the counties bordering southeastern and eastern Lake Ontario in New York, the northernmost area of the bog turtle range, the active season begins in early May and ends late September. With periods of warmer weather in late winter and spring, turtles can emerge earlier from or enter later into hibernation. For example, bog turtles in southeastern New York have been observed as early as the first week of April and the last week of March for northern New Jersey (Tesauro 2019, pers. comm.). In Massachusetts, bog turtles are sometimes active in March (Jones 2021, pers. comm.). Occasionally, bog turtles begin to enter hibernation in the first week of October in northern New Jersey (Tesauro 2019, pers. comm.).

For the more southern states located within the northern population, such as Delaware, Maryland, southern New Jersey, and Pennsylvania, the active season can begin as early as late March to mid-April and continue through to early October to mid-November (Nazdrowicz 2019, pers. comm.; Smith 2019, pers. comm.). Bog turtles may occasionally move small distances within hibernation areas in the winter during warm spells (Nazdrowicz 2019, pers. comm.). Ernst (1977, p. 244) observed bog turtles active at an individual population in Pennsylvania as early as March 21. The timing in each of the states varies based on weather conditions.

Table 2.1. The annual life cycle of bog turtles by state in the northern population, from north to south. Red cells indicate roughly when bog turtles are in hibernation and green cells indicate when they are active on the landscape. Each month is split into "early" and "late" timeframes. Months may vary according to weather conditions.



	Hibernation				Emergence		Emergence, Mating, Movement to Core Habitat Areas				Lay Eggs				Eggs Hatch and Movement to Hibernation Areas						Hibernation			
State	January		February		March		April		May		June		July		August		Sept.		Oct.		Nov.		Dec.	
NY – Lake Plains	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥
MA	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥
CT	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥
NY - Southeast	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥
NJ - North	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥
PA	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥
NJ - South	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥
DE	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥
MD	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥

2.6.1 Reproduction and Recruitment

Females reach sexual maturity at about five to nine years of age and this may vary by latitude (Ernst 1977, p. 243; Holub and Bloomer 1977, p. 10; Whitlock 2002, p. 50; Shoemaker *et al.* 2013, p. 5; Tutterow *et al.* 2017, p. 294) (figure 2.5). At the northern edge of the range, it likely occurs at an older age (Whitlock 2002, p. 50) due to a shorter growing season that leads to slower growth (Rosenbaum *et al.* 2018, unpublished poster). Sexual maturity appears related to turtle size. Whitlock (2002, p. 58) found that female sexual maturity was reached at a minimum size of 80 mm (3.15 in) carapace length and 74 mm (2.91 in) plastron length in Massachusetts, based on measurements from gravid females. Size at maturity may vary by region, particularly in eastern Lake Ontario in New York where adults are smaller (Rosenbaum *et al.* 2018, unpublished poster). Once sexually mature, females do not mate each year (Holub and Bloomer 1977, p. 16).

Mating in bog turtles occurs in spring from March to June (Ernst and Lovich 2009, p. 268). Males locate females via visual and olfactory cues and may pursue females in a short chase. Courtship lasts about 35 minutes and may occur in or out of water (Ernst and Lovich 2009, p. 268). Nesting occurs from June to early July, with most eggs laid in June. In New England, eggs became calcified in early June and egg-laying was documented approximately 10 days later from the second to fourth week in June (Whitlock 2002, pp. 52, 72). In Maryland, Byer *et al*. (2018, p. 230) documented nesting occurred June 8 to 22. Similarly, Zappalorti *et al*. (2015, p. 575) found most nests occurred between June 8 to 29 in New Jersey and Pennsylvania.

Bog turtles rarely leave their wetland habitat to nest; females typically seek out elevated areas within the wetland such as sedge tussocks or root hummocks in open-canopy areas (Zappalorti *et al*. 2015, pp. 576–577), although nests have also been documented in rotting wood and stumps (Zappalorti *et al*. 2015, p. 576), and in adjacent pastures and railroad embankments (Ernst and Lovich 2009, p. 268). Eggs are typically concealed with vegetative material, such as blades of sedge or grass, sphagnum moss, or humus, but some eggs may be left partially or fully exposed (Zappalorti *et al*. 2015, pp. 576–77).

Adult females lay one to six (usually three to four) eggs per clutch, with no evidence to suggest multiple clutches are produced in a breeding season (Whitlock 2002, p. 51; Macey 2015, p. 96; Zappalorti 2017, p. 197; Byer *et al*. 2018, p. 230). Occasionally, females nest communally, with up to three clutches deposited within the same nest, possibly due to a lack of suitable nesting areas (Whitlock 2002, p. 60; Zappalorti *et al*. 2015, pp. 576, 578; Byer *et al*. 2018, p. 229).

Eggs hatch after an incubation period that varies across the range (67 to 89 days in southeastern New York [Macey 2015, p. 97]); 74 to 103 days in Connecticut and Massachusetts (Whitlock 2002, p. 57) and the young emerge in August, September, or October (Whitlock 2002, p. 57; Macey 2015, p. 102). Infertile eggs are common (Tryon 2009, p. 4; Zappalorti *et al*. 2017, p. 198), and not all females produce clutches annually (Whitlock 2002, p. 51; Byer *et al*. 2018, p. 230). There are few studies on bog turtle recruitment. Shoemaker *et al*. (2013, p. 6) estimated 0.97 yearling turtles produced per adult female per year. Of 42 nests found over a three-year study period, Whitlock (2002, p. 54) found that only a third of the nests produced greater than one hatchling.

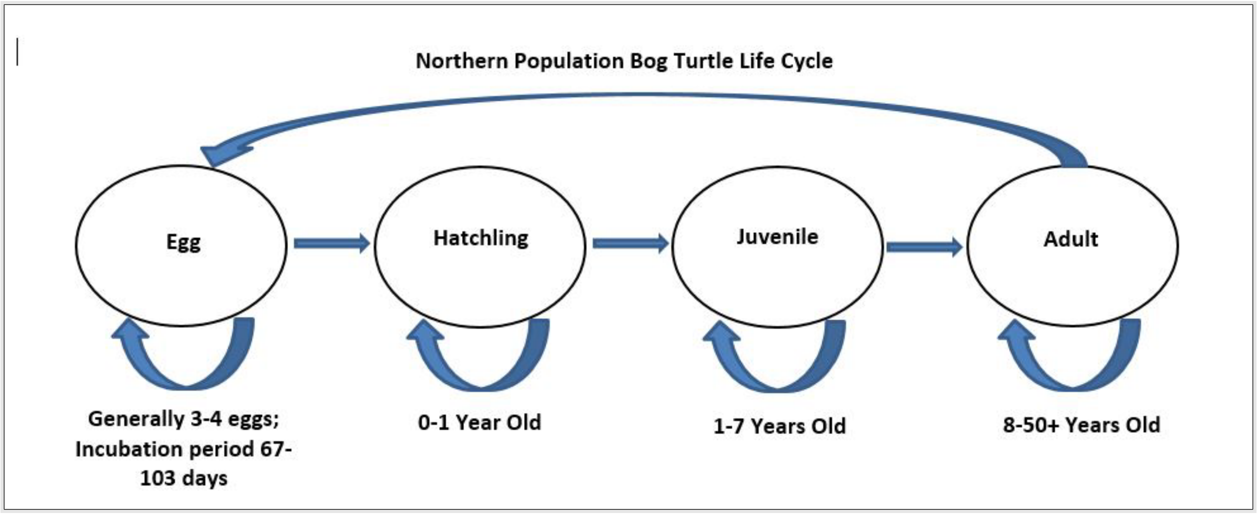


Figure 2.5. The bog turtle life cycle within the northern population. On average, adult females breed annually, laying one clutch of eggs, but some may skip years.

2.6.2 Longevity, Survival, and Growth

The life expectancy of a bog turtle remains unknown, but an ongoing long-term demographic study in Pennsylvania continues to extend the known maximum age, with the oldest marked bog turtle having been recaptured in 2020 at age 62 (Gress 2020, unpublished data), and multiple individuals known to be in the 40s and 50s (Gress 2009, p. 335 and unpublished data). They appear to have no reproductive senescence (Herman 1990, p. 58).

There are few individual populations where bog turtle demographic rates have been estimated. Adult survivorship estimates have been high, at 0.99 for a high-quality individual population in Massachusetts (Sirois *et al*. 2014, p. 457) and 0.96 for a complex of individual populations in New York and Massachusetts (Shoemaker *et al*. 2013, p. 5), but 0.72 to 0.96 was estimated at an individual population altered by a beaver impoundment in Massachusetts (Sirois *et al*. 2014, p. 457). In addition, a recent analysis in North Carolina reported lower adult survival (0.86 to 0.94; Tutterow *et al*. 2017, p. 297); however, it is unclear whether southern population survival rates accurately represent northern populations. Threats affecting both populations may vary. In addition, Knoerr (2018, pp. 17–18) stated that bog turtle wetlands in the southern population are found at a higher elevation (416 to 954 meters (m) [1,364 to 3,129 feet (ft)]; northern population bog turtle wetlands are found at lower elevations (less than 30.48 m [1,000 ft]) where the egg incubation period could be affected by cooler temperatures that negatively affect recruitment. Hatchling and juvenile survival rates are generally unstudied but ranged from 0.33 to 0.43 for egg/hatchling survival in Pennsylvania and New Jersey (Zappalorti *et al*. 2017, p. 198) to 0.48 for yearling turtles in New York (Shoemaker *et al*. 2013, p. 6).

Ernst (1977, p. 244) calculated hatchling growth rates at 34.6% for a Pennsylvania population, with gradual drops in growth per year measured thereafter through age 13. He noted that increases in temperature and humidity seem to stimulate growth. Bog turtle growth in both Massachusetts and Pennsylvania studies was rapid during the first five to eight years, typically approaching asymptotic size around 12 years of age (Lovich *et al*. 1998, p. 72; Whitlock 2002, p. 50). Bog turtles in eastern Lake Ontario in New York appear to grow more slowly, possibly due to shorter active season (Rosenbaum *et al*. 2018, unpublished poster).

2.6.3 Diet

Studies of bog turtle feeding behavior and diet include limited information from captive and wild turtles (primarily adults). The first report of, presumably wild, bog turtle stomach content includes both plants and insects (Surface 1908, p. 158). Later a wild turtle was observed to have the capacity to feed both terrestrially and aquatically (Barton and Price 1955, p. 162). Food items include a wide diversity of animals, primarily invertebrates, but also include dead animals (Campbell 1960, p. 16), root material and moss (Klemens 1993, p. 182). More comprehensive lists of animal prey items and consumed plants are detailed in Ernst and Lovich (2009, p. 270) and Melendez *et al*. (2017, entire).

Two of the broader studies of bog turtle feeding ecology and diet were conducted in New Jersey (Gemmell 1994 entire; Melendez *et al*. 2017, entire) and study populations are representative of habitats within the Atlantic Highlands and Coastal Plain physiographic provinces and Delaware and Hudson-Housatonic bog turtle recovery units[7]. While Gemmell employed stomach pumping, or flushing, in his study to analyze stomach content, Melendez *et al*. followed a less invasive approach of examining fecal samples, and this difference in methodology may have contributed to significant differences in their respective findings. In Gemmell's three-year study of 92 flushed stomachs, slugs (*Arion sp.*) made up nearly 70% of the turtle's diet. Similarly, Surface (1908, p. 158) found the stomach contents of one turtle to be 80% insects. In contrast, Melendez *et al*. (2017, p. 275) found 90% plant material in his 60 samples, primarily consisting of seeds. Melendez *et al*. (2017, p. 275) also found no significant differences between the diets of males and females or between his study areas. Bog turtles appear to be opportunistic foragers and feeding preference is likely based on food availability (Barton and Price 1955, p. 162).

2.7 Species Ecological Requirements/Resource Needs

2.7.1 Individual-level Ecology/Habitat Needs

General Habitat Association and Juvenile and Adult Needs

Bog turtles inhabit a variety of wetland types throughout their range that include shallow, spring-fed fens, sphagnum bogs, swamps, marshy meadows and pastures that have soft, muddy bottoms; clear, cool, slow-flowing water, often forming a network of rivulets; and open canopies. Wetland habitat is a mosaic of micro-habitats that include dry pockets, saturated areas, and areas that are periodically flooded, and bog turtles depend on these micro-habitats for foraging, nesting, basking, hibernation, shelter, and other needs (Service 2001, p. 12). Wetlands are often small, open-canopy, sedge meadows and fens bordered by more thickly vegetated and wooded areas.

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[7] See Service 2001, pp.32–37 for recovery units.

However, in the Prairie Peninsula-Lake Plain area of New York, wetlands are characterized as large complexes greater than 20 hectares (ha) (49 acres [ac]) with less than 1 to 46 ha (2 to 113 ac) of open water (Rosenbaum and Nelson 2010, p. 419). Bog turtles primarily use seepage-fed or spring-fed emergent wetlands associated with streams for nesting, basking, and foraging. Optimal wetlands are characterized by native sedges, grasses, forbs, scattered shrubs, and by perennially saturated mucky soils.

Bog turtle habitats often feature subsurface water flow and typically contain rivulets or watery trails created by naturally flowing water or by wildlife (Holub and Bloomer 1977, p. 11; Service 2001, pp. 13–14). Relatively stable, year-round supplies of clean groundwater support the bog turtle's food base, brumation (hibernation), estivation areas, and their nesting habitat. The soft substrate and slow-moving water both above and below the surface protect the bog turtles against freezing and overheating. Groundwater flowing into these wetland areas assists in the maintenance of more constant temperatures which are cooler in summer and warmer in winter months than the surrounding air and surface water temperatures.

Bog turtle wetland hydrology and soils are strongly related. The groundwater-supplied hydrology results in wet and dry pockets to total saturation with varying degrees of surface water (Chase *et al*. 1989, p. 359). Saturated soils that have low soil strength allow bog turtles to more easily burrow into the mud to avoid thermal stress or predators (Carter *et al*. 1999, p. 858). In Virginia, bog turtles were found in locations with significantly lower strength soils than nearby random wetland areas (Feaga *et al*. 2013, p. 410). Low soil strength areas used by turtles may coincide with topographic low spots where fine sediments have accumulated over large alluvium, such as in a former stream bed (Feaga *et al*. 2013, p. 410). Soil organic carbon accumulation at the surface, a secondary outcome of nearly continuous saturated conditions, may be important for the maintenance of low strength soils.

Bog turtles have also been documented in atypical habitat. For example, they have occasionally been found for long periods of time in water bodies such as ponds (Miller 2019, p. 31), some as a result of disturbance to core habitat (Holub and Bloomer 1977, p. 14). At an individual population in Pennsylvania, a female turtle traveled 183 m (200 yards) downstream of her wetland and spent two weeks in a round corrugated pipe; she was later seen swimming in the creek. She returned to the wetland after three weeks (Brookens 2020a, pers. comm.). At another individual population in Pennsylvania, a female bog turtle was tracked to a large man-made lake and remained in a stand of *Phragmites* at the lake edge for 10 days. It made short movements along the shore of the lake within the *Phragmites* stand (Torocco 2020a, pers. comm.).

Upland habitat surrounding occupied wetlands may also be important. Bog turtle activity has been observed a short distance from wetland boundaries during the active season (Roos and Maret 2018, p. 36; Zarate 2019, pers. comm.). For example, fifteen bog turtles used upland areas within 5 m (16 ft) of a wetland edge and two turtles were found beyond that distance, but not beyond 10 m (33 ft) (Roos and Maret 2018, p. 36). This may indicate upland use by bog turtles is more frequent than previously known. Bog turtles may be using these areas to search for hibernation sites, as travel corridors to adjacent wetlands, or as refugia when air temperatures are high.

The bog turtle is active in the spring, summer, and fall and inactive in the winter when it hibernates. Therefore, depending on whether the turtle is active or inactive determines what type of habitat is required. The bog turtle also requires different habitat types during its various life stages (*i.e.*, eggs and hatchlings vs. juveniles and adults) (table 2.2).

Nest and Hatchling Needs

Bog turtle nest site selection has important consequences for eggs and hatchlings. Because most turtle species do not exhibit parental care (Agha *et al*. 2013, p. 254), offspring are left to fend for themselves in post-ovipositional nest environments where nest predation can be high and variable (Congdon *et al*. 1994, entire) and up to 100% in some years and some species (Ernst and Lovich 2009, p. 269). Post-ovipositional environment can affect development rate and duration; hatchling turtle sex ratios, phenotype, and growth rate (Zappalorti *et al*. 2015, p. 573). Geography, elevation, and weather influence the incubation period and affect hatching success of bog turtle eggs (Tryon 2009, p. 4).

Unlike most other semi-aquatic turtles, the bog turtle does not leave its wetland habitat and travel to dry, upland areas to lay eggs. Instead, females select a slightly elevated area, generally on raised clumps of tussock sedges (Barton and Price 1955, p. 163; Zappalorti 1976, p. 129 as cited in Zappalorti *et al*. 2015, p. 574). The practice of nesting within their wetland habitat may reduce predation and competition with other turtle species for nesting habitat. Nesting areas typically have limited canopy closure, support an array of moisture-tolerant plants and provide ample solar exposure (Ernst and Lovich 2009, p. 268). Typically, bog turtle nests are found on top of pedestal-forming vegetation such as tussocks of grasses or sedges, moss-covered stumps, or in *Sphagnum* moss but have also been found in jewelweed (*Impatiens sp*.), sensitive fern (*Onoclea sesibilis*) and narrow-leaved cattail (*Typha angustifolia L*.) (Zappalorti *et al*. 2015, p. 576). Macey (2015, p. 48) found that females in New York nested in small (10 m [33 ft] diameter) areas and selected microhabitats with low densities of woody stems, low percent cover of woody vegetation, forbs and ferns and in close proximity to water/saturated soil. The nesting areas also coincided with low vegetation height and high percent availability of moss, sedges and other graminoids. Zappalorti *et al*. (2015, entire) evaluated nests at sites in New Jersey and Pennsylvania from 1974–2012 and found mean nest elevation above substrate to be approximately 8.2 centimeter (cm) (3.2 in) (with a range of 1.4 to 27.1 cm [0.6 to 10.7 in]). Most nests concealed under vegetation were covered with a layer of humus, grass blades or sphagnum moss at a depth ranging from 0.1 to 3.5 cm (0.04 to 1.4 in) (mean of 1.8 cm [0.7 in]).

While nests are often elevated above the surface of the ground, they have also been observed extremely close to the water's surface where the nest may become saturated with water. In New England, nests were generally greater than 10 cm (3.9 in) above the surrounding water level, but seven nests appeared highly vulnerable to flooding (distance to water less than 10 cm [3.9 in]), trampling (hummock height less than 10 cm [3.9 in]), or exposure (egg depth=0 cm) (Whitlock 2002, p. 54).

Bog turtles in southeastern New York and western Massachusetts displayed fidelity to nest-site areas (coarse-scale nest-site fidelity) as 100% of females returned to the same nest-site area the second year they were observed nesting (Macey 2015, p. 30). Zappalorti *et al*. (2015, p. 578) also observed nest fidelity in females at wetlands in Pennsylvania and New Jersey and Byer *et al.* (2018, p. 231) observed this at two individual populations in Maryland. They also found evidence of communal nesting area at two individual populations in Pennsylvania. Byer *et al*. (2018, p. 229) observed nests laid upon another nest. Limited nesting habitat conditions may explain why multiple females nest in the same tussock (Holub and Bloomer 1977, p. 17), some display nest fidelity (Macey 2015, p. 33), and nests may be laid upon another nest.

Hibernation Needs

Hibernation site selection is very important to bog turtles as Smith and Cherry (2016, p. 477) noted they will spend up to six months a year (or about half of their lives) underground. Although bog turtles are dependent on suitable open-canopy wetlands for many of their life history functions during the active season, they also utilize more densely vegetated areas for hibernation. Hibernation sites are often associated with woody roots, and can include shrubby hummocks, spring-fed rivulets, wildlife (*e.g*., muskrat, vole) burrows, and sedge clumps (Ernst *et al*. 1989, pp. 761; Smith and Cherry 2016, p. 477). A rock wall has been used for hibernation at a wetland in New York (Rayman-Metcalf 2020a, pers. comm.). Small clumps of woody vegetation within an open emergent wetland may be preferred as hibernating spots, potentially because these locations have several desirable features, including root structures, spring flow, and solar exposure. Eichelberger (2005, p. 24) found that all of 10 tracked turtles hibernated in a swamp forest in the root balls of large white pines. Ernst *et al*. (1989, p. 762) found five juvenile bog turtles hibernating at the base of a cedar stump while the adults hibernated in a different location approximately 40 m (131 ft) away. Bog turtles have also been found hibernating in the root networks of reed canary grass (Gress 2008, unpublished data; Brookens 2020b, pers. comm.). Bog turtles are often found partially to completely buried in mud and water (Ernst *et al*. 1989, p. 761).

All hibernation sites require persistent spring seeps or flowing water to avoid freezing. This may explain why bog turtles have been found hibernating in roadside and agricultural ditches where no root structures were present (Torocco 2020b, pers. comm.). If the ditches have diverted water away from the core wetlands, the best hibernating areas may be in the ditches where spring runoff has been concentrated. In some cases, bog turtles have been documented to exhibit fidelity to one or more hibernation spots in a wetland (Ernst *et al*. 1989, p. 762; Brookens 2020c, pers. comm.; Smith 2020a, pers. comm.).

However, other studies have shown that turtles don't use the same areas every year, suggesting there may be competition among the turtles for the best sites. Radio-telemetry work conducted by Smith (2020b, pers. comm.) indicated high communal activity at hibernacula while other hibernacula were being utilized by one or two individuals. Hibernacula with high communal activity may be better suited to avoid predation, have highly oxygenated water, and/or are void of winter icing (Smith 2020b, pers. comm.). In New Jersey, Ernst *et al*. (1989, p. 762) found that most bog turtles hibernated alone, with a few observations of groups of two to five bog turtles hibernating together. Bloomer (1978, p. 40) observed between 3 and 141 individuals hibernating together at two different locations, respectively. Spotted turtles (*Clemmys guttata*) are occasionally found hibernating with bog turtles (Drasher 2020, pers. comm.). One study found a young snapping turtle hibernating among bog turtles (Brookens 2020d, pers. comm.).

In some cases, bog turtles do not remain stationary at a single location throughout the hibernation period. Gress (2008, unpublished data) noted a correlation with temperature and bog turtle movement during hibernation. One turtle moved 30 m (98 ft) in a two-week period in 2005. Turtle movements declined when substrate and water temperatures were consistently below 5°C (41°F). Smith (2020b, pers. comm.) noted that even with high site fidelity at communal hibernacula, shifting of individuals was observed.

Dispersal Needs

Bog turtles require dispersal habitat (*i.e*., connections between core wetlands) to respond to changing wetland conditions (*e.g*., vegetative succession, habitat degradation, drought). However, the routes most commonly used by bog turtles during apparent dispersals or migrations are unknown. Because clusters of core bog turtle wetlands are often found within a single watershed, stream corridors are thought to be important for dispersal, and there is some evidence from the southern population that bog turtles use stream corridors for dispersal (Somers *et al*. 2007, entire; Feaga 2010, pp. 135, 141–142, 154). However, there are also documented instances of bog turtles moving long distances across upland habitats, including deciduous and coniferous forests (Carter *et al*. 2000, p. 77; Feaga 2010, pp. 135, 142, 154), agricultural lands (Feaga 2010, pp. 135, 142, 154), and developed areas (Pittman and Dorcas 2009, pp. 784, 787, Rayman-Metcalf 2020b, pers. comm.). There are records of bog turtles found on roads far from wetlands or streams. One road observation of a live individual (unknown sex) in Orange County, New York is over four miles (6.4 kilometer [km]) from an occupied wetland (Rayman-Metcalf 2020c, pers. comm.).

Table 2.2 provides a summary of the resource needs related to habitat of bog turtles in the northern population.

Table 2.2. Bog turtle resource (habitat) needs for life history functions

Life Stage	**Resource Needs (Habitat)**
All	Need a sufficiently dynamic wetland (*i.e.*, bog, fen) system to allow natural or managed creation of open habitat needed for this species: grazers, beaver, fire, periodic wet years important for maintaining microhabitats; groundwater recharge area to maintain surface and subsurface water levels
Eggs	Laid on tussocks and hummocks in open areas with short vegetation
Hatchlings	Tussocks and hummocks in open herbaceous meadows and fens with short vegetation nearby
	Food resources - invertebrates, seeds
Juveniles and Adults	Basking - tussocks, hummocks, and mucky soils for thermoregulation and growth; wet, saturated conditions, shallow water, but not deep, standing water; very young individuals are often concentrated together
	Retreat - escape predators and thermoregulation, seek cover under woody brush piles, muck or thick peat soils and may leave preferred habitat and seek shelter in woods or other areas during periods of excessive heat
	Nesting (adults) - open-sunny, low and sparse herbaceous mosaic of wet tussock/hummock areas interspersed with dry pockets; nest on top/within hummocks; stable water levels; young often concentrated together (nursery areas)
	Hibernation - more densely vegetated areas at the interface zone between open fen habitats, shrub, and forested swamps with spring heads or seeps percolating up from the ground around them Individuals hibernate in hummocks in tunnel-like cavities leading underground, approximately >1 m in root systems within matrix of rocks, muck-like soils, air pockets, oxygenated water, and areas where water flows all year round; soft mud within muskrat and meadow vole burrows, under sedge clumps, and among under other natural substrates
	Food resources - invertebrates, seeds
	Hydrology - continuous water flow, shallow surface water or saturated soils year round; stable (no fluctuation) water levels in nesting areas; flowing subsurface water for hibernation and flowing, shallow rivulets for movement and feeding
	Connectivity for within-season movements between core habitat areas (*e.g.*, feeding, nesting, basking, hiding areas, hibernating areas)
	Safe corridors that provide suitable dispersal habitat - can be upland, stream, or wetland (*i.e.*, few roads with low traffic volumes, developed landscapes/uplands or unsuitable habitat between bog turtle wetlands)

2.7.2 Population-level Ecology

In this section, we provide our working definition of a bog turtle population and then we describe the needs of a healthy population (*i.e.*, what a population requires to sustain itself over time). Biologists from states within the northern range of the bog turtle worked together on a Conservation Plan for the species and developed consistent terminology for describing bog turtle populations (Erb 2019, pp. xi–xiii) as follows:

> A **population** is defined as a functionally reproductive group of individuals (*e.g.*, at least one individual from each sex or evidence of reproduction such as presence of a hatchling

> or juvenile) using one or more core habitat areas[8], which are within 300 m[9] (984 ft) of each other, with no major barriers between them. Movement between core habitat patches likely occurs every 1 to 10 years.
>
> A **metapopulation** is defined as a group of [individual] populations with genetic exchange feasible through occasional dispersal events. Populations are close enough to each other to allow occasional movements within one generation time (10 to 40 years) of an individual: less than 3 km (1.8 mi) of contiguous wetland, less than 2 km (1.2 mi) of intermediate or mosaic upland-wetland habitat, or less than 1.5 km (0.9 mi) undeveloped upland habitat.

Healthy or resilient populations are those that are able to respond to and recover from stochastic events (*e.g*., heavy rains, drought, flooding) and normal year-to-year environmental variation (*e.g*., temperature, rainfall). Simply said, healthy populations are those able to sustain themselves through good and bad years. To be resilient, populations must: (1) have healthy demography and (2) occupy areas with suitable habitat conditions for all life stages and seasons.

These population-level requisites are discussed below and summarized in table 2.4. Another consideration when describing the needs of resilient populations is the concept of ensuring that any threats acting upon the populations are not causing (or anticipated to cause) reductions in species level demography or habitat needs. This is not a separate item in table 2.4 as a threat is not a conservation need. However, bog turtles rely on early successional, open habitats that require periodic management and reduction of threats associated with habitat modification; therefore, as with other conservation-reliant species, bog turtles require long-term habitat management to achieve these population needs. This is similar to other conservation-reliant species that often need continued habitat management or continued responses to ongoing threats. In addition, multiple threats can be acting upon all of the factors. Threats and conservation actions are discussed further in chapter 3.

Population Size

Small numbers of adults may have implications for individual population fitness. Shoemaker and Gibbs (2013, p. 327) found allelic richness was substantially lower and kinship analysis suggested a significantly higher proportion of close-kin pairs at wetlands in southeastern New York with the lowest estimated bog turtle abundance compared to other wetlands. With data from the same wetlands, Shoemaker *et al*. (2013, pp. 6–7) found that modeled extirpation risk over 100 years decreased from 51 to 20% for an initial individual population of six adult females, 5 and 1% for an initial population of 10, 20, and 30 adult females, respectively. They concluded that bog turtles in this metapopulation can persist as stable individual populations with

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[8] Core habitat is defined as an area that meets bog turtle suitable habitat requirements where turtles are most frequently found. Multiple core habitat areas may be found within a single delineated wetland but may cross multiple landowner parcels. Additional details on suitable habitat requirements can be found at: *https://www.fws.gov/media/guidelines-bog-turtle-surveys-phase-1-and-2-surveys*

[9] The 300 m distance in the definition of "population" is the potential travel distance that bog turtles may take to seek other wetlands with core habitat. This should not be confused with the 300-foot buffer described in the Service's 2001 (pp. A1–A3) Conservation Zones guidance that is a protective upland vegetative area surrounding an individual wetland containing core bog turtle habitat.

as few as 15 to 20 adult females (Shoemaker *et al*. 2013, p. 8). This may differ for isolated, individual populations that are not part of a metapopulation.

While survey data is lacking for 24% (118) of our known individual populations due to wetland access restrictions, the majority of individual bog turtle populations appear to be small, with fewer than 30 individuals (including both sexes) actually observed (figure 2.6; Erb 2019, pp. I1–I2) or estimated using standardized monitoring data (figure 2.7, table 2.3). Table 2.3 provides individual population size estimates that have been reported in literature or by species experts.

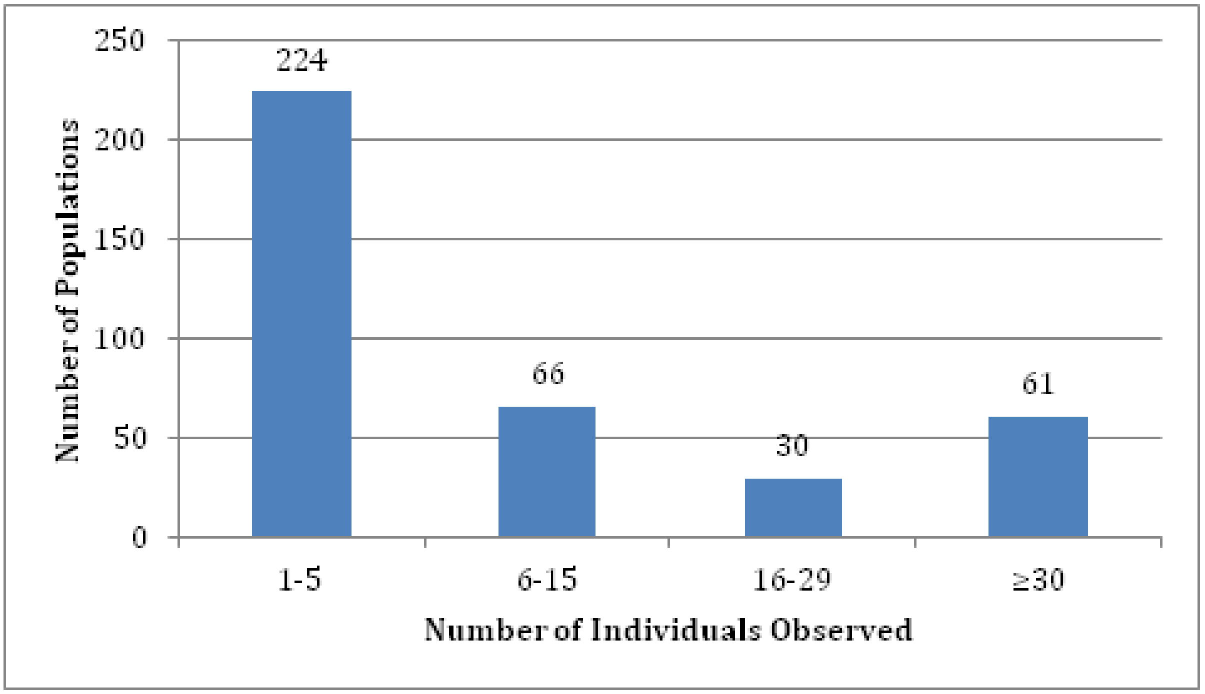

Figure 2.6. The number of individual populations known to have at least 1–5, 6–15, 16–29, or ≥30 individuals for 508 extant populations in the northern range based on expert input (Erb 2019, unpublished data).

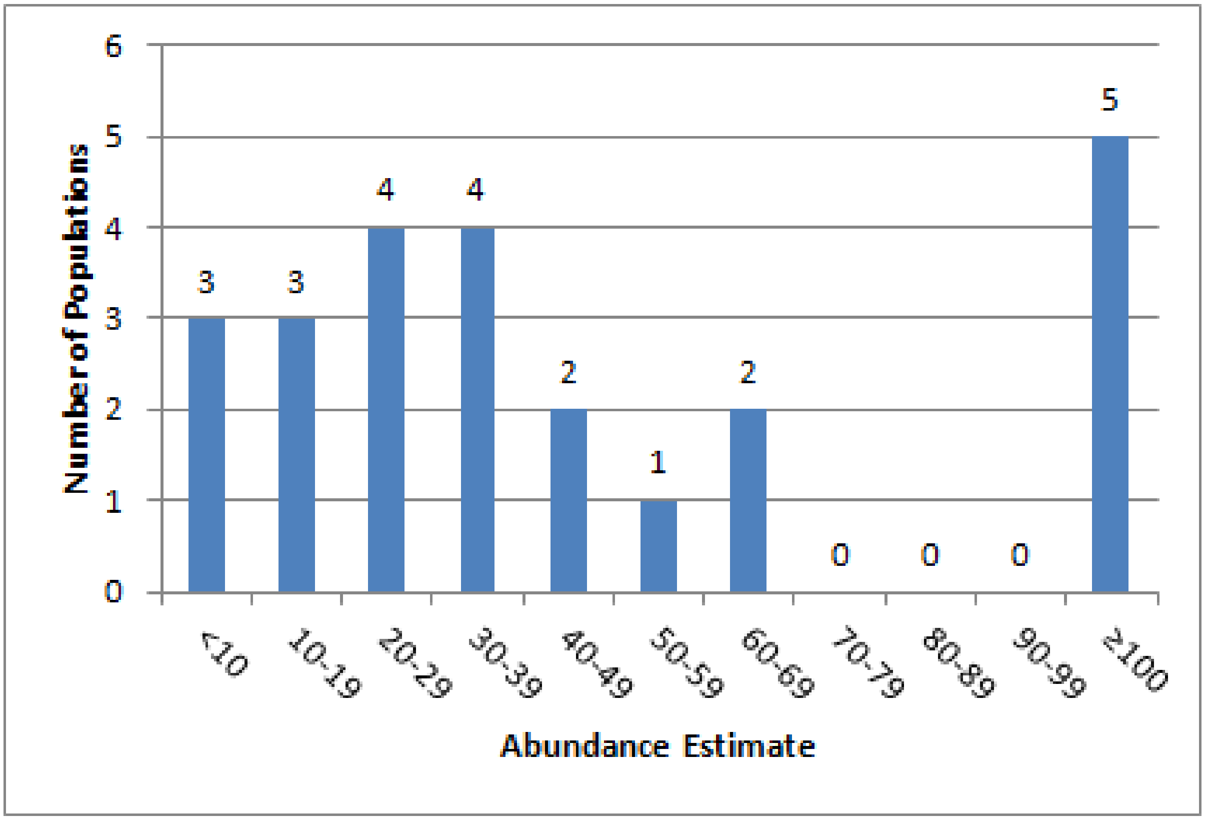

Figure 2.7. Population size estimates for 24 of 508 extant individual bog turtle populations in the northern range based on expert input (Erb 2019, unpublished data).

Table 2.3. Population size estimates reported in the literature, report or by personal communication for 24 of 508 individual bog turtle populations within the northern range including the sampling wetland ID, year of estimate, estimator type, and source. Population size estimates for wetlands surveyed decades ago may not be reflective of the current population size for that sampling wetland.

Sampling Wetland ID	Year	Estimator type	Population Size Estimate	Source
Site 1	1994-1998	Lincoln-Peterson	38	Whitlock 2002
Site 2	1994-1998	Lincoln-Peterson	41	Whitlock 2002
MA-03	2009	Cormack-Jolly-Seber	35	Sirois, *et al*. 2014
MA-04	2009	Cormack-Jolly-Seber	20	Sirois, *et al*. 2014
MD-BA-11	1979	Schnabel	41	Chase *et al*. 1989
MD-BA-212	1979	Schnabel	21	Chase *et al*. 1989
MD-BA-71	2015	Schnabel	25	Smith 2018, unpublished data
MD-CA-114	2015	Schnabel	30	Smith 2018, unpublished data
MD-CA-140	2015	Schnabel	268	Smith 2018, unpublished data
MD-CA-147	1979	Schnabel	10	Chase *et al*. 1989
MD-CA-28	1979	Schnabel	35	Chase *et al*. 1989
MD-CA-36	1979	Schnabel	3	Chase *et al*. 1989
MD-CA-94	1979	Schnabel	26	Chase *et al*. 1989
MD-HA-406	1979	Schnabel	230	Chase *et al*. 1989
MD-HA-411	2015	Schnabel	46	Smith 2018, unpublished data
MD-HA-78	2015	Schnabel	69	Smith 2018, unpublished data
MD-HA-86	1979	Schnabel	1	Chase *et al*. 1989
NJ-083.1	1991	Schnabel	50	Gemmell 1994, p. 69
NY-CFP	2009	Royle and Dorazio	5	Shoemaker *et al*. 2013
NY-SHR	2009	Royle and Dorazio	38	Shoemaker *et al*. 2013
NY-50-01	2015	2Capture[10]	18	Erb 2021, pers. comm.
NY-38-03	2017	2Capture	160	Erb 2021, pers. comm.
PA-LANC-01-A	2012	R packages tree[11]	63	Gress 2018, unpublished data
PA-MONR-13-A	2013	R packages tree	17	Gress 2018, unpublished data
PA-MONR-15-A	2011	R packages tree	283	Gress 2018, unpublished data
PA-MONR-16-B,C	2011	R packages tree	172	Gress 2018, unpublished data

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[10] "Capture" estimates density using spatial data of trap locations a nested-grid approach from data derived from a lattice of equally spaced trap locations (Otis *et al*. 1978).

[11] The "tree" program is Classification and Regression Trees, a cross-validation assessment to identify deviance of number of misclassifications as a function of the cost-complexity parameter (Ripley 1996).

Sex Ratios

Sex-determining mechanisms in reptiles are identified as genotypic[12] or environmental[13], with the vast majority of turtles having environmental sex determination (Janzen and Paukstis 1991, p. 152). However, Literman *et al*. (2017, p. 655) recently concluded that bog turtles likely use genotypic sex determination, based on results of research and comparisons with the related wood turtle (*Glyptemys insculpta*).

Comprehensive study of bog turtle population demographics is limited, as is reporting of sex ratios of wild populations, but there are several reports available based on large datasets and studies. For example, Chase *et al*. (1989, p. 359) reported from Maryland a sex ratio of 1:1 for 174 adults captured. However, several studies have reported female bias. For example, in Massachusetts, Whitlock (2002, p. 92) found 97 adults with 39 males and 58 females. Tutterow *et al*. (2017, p. 295) also identified more females were captured than males at 10 of 11 wetlands in North Carolina. Shoemaker (2011, p. 14) found sex ratios were female-biased in New York, with a total of 408 females captured (149 unique individuals) and 256 males captured (84 unique individuals), although sex ratios of captures varied from wetland to wetland. In a New Jersey dataset of unique bog turtle captures between 1990 and 2015, there were 507 documented males to 714 females (Zarate 2020, pers. comm.). While the majority of these reports identify female-dominant populations, Gibbons (1970, pp. 252–253) and Georges *et al*. (2006, p. 477) caution that unequal sex ratios may be the result of sampling bias, selective sampling, improper methodology, or other factors. Given that many bog turtle wetlands have limited sampling, sex ratios are not likely accurately estimated; therefore, this metric will not factor into population ranking for the SSA (see chapter 4).

Adult Survival

As described in section 2.6.2, estimated adult bog turtle survival rates are much higher than those for juveniles. Growth and sustainability of long-lived turtle populations requires high adult survival rates (Congdon *et al*. 1993, pp. 830–832; Heppell 1998, p. 369). Ultimately, high adult female survival rates are essential to allow for the necessary adult female populations discussed above. In most cases, we lack information on this parameter and rely on adult female numbers for determining population condition. This is supported by Tutterow *et al*. (2017, p. 298) who observed that bog turtle wetlands in North Carolina with a greater number of turtles generally had higher adult survival than smaller populations. Longevity in vertebrates and associated delayed sexual maturity results in populations less resilient to factors increasing mortality of juveniles and adults (Congdon *et al*. 1994, p. 406).

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[12] Genetic sex determination is when male and female individuals of most species are determined by sex chromosomes.

[13] Environmental sex determination is when male and female individuals are determined by non-genetic cues such as temperature, nutrient availability or photoperiod.

Recruitment and Age Structure

While adult survival is the most important demographic factor for the bog turtle, fairly high juvenile survival rates and recruitment is essential at some scale. Shoemaker (2011, p. 16) estimated 0.23 yearling turtles produced per adult turtle per year and new adults (9-year old) represented 4.5–5% of the adult population of their study wetlands. Shoemaker *et al*. (2013, p. 8) found that varying recruitment rates did not influence probability of persistence, and their modeled bog turtle populations persisted across the entire range of plausible parameter values given sufficient adult population size. However, they cautioned that the presence of long-lived species like the bog turtle can mask below-replacement recruitment levels for years, in part due to the difficulty in detecting juveniles, and recommended development of a rapid assessment metric for bog turtle recruitment (Shoemaker *et al*. 2013, p. 8).

We generally do not have detailed information to assess recruitment for individual bog turtle populations (*e.g*., number of nests or eggs laid/season, nest success, hatchling success, and annual survival rates). However, we can qualitatively assess recruitment based on observations of age classes present. In some cases, no signs of reproduction are observed. In others, gravid female, eggs or nests are observed but there is no indication of the fates of those eggs. In some cases, hatchlings, yearlings, or juveniles are observed and finally, in some cases, subadults and/or multiple age classes are documented.

Interconnectedness

The Service (2001, p. 7) has long recognized that many individual bog turtle populations function as a metapopulation and connections among populations are important for their overall demographic health and this was recently reaffirmed by state partners (Erb 2019, pp. xi–xiii). Some individual populations may be isolated while others are connected to multiple other populations in a complex of suitable and unsuitable habitat.

There are numerous observations of long distance and inter-wetland movements by bog turtles, with multi-day movements as large as 750 m (0.5 mi) and year-long movements as large as 2.7 km (1.7 mi) (Eckler *et al*. 1990, p. 70; Carter *et al.* 2000, p. 77). In Virginia, Carter *et al*. (2000, p. 77) observed 75% of net movements were less than 20 m (65.6 ft); however, they documented some inter-wetland movement in one year with 3 of 31 adult turtles moving between neighboring wetlands greater than 200 m (656 ft) from each other (Carter *et al*. 2000, pp. 77–78).

The level of connectivity may influence genetic exchange. At a fen complex in New York, Shoemaker and Gibbs (2013, p. 329) observed high levels of connectivity via microsatellite analysis among complexes of occupied fens with nearest-neighbor distances of 1–2 km or less. Using simulation modeling, Shoemaker and Gibbs (2013, p. 328) inferred that dispersal has occurred at a mean rate of approximately 0.33 individuals per year (approximately 1% of each individual population per year). However, capture-recapture results did not support evidence of high connectivity from these wetlands (Shoemaker 2011, p. 18) and they suggest this could be due to undetected dispersing juveniles or rare and episodic periods of high dispersal (Shoemaker and Gibbs 2013, p. 329).

Pittman *et al*. (2011, entire) examined one isolated and declining individual bog turtle population in North Carolina for population stability and genetic diversity by comparing its genetic status with five other individual bog turtle populations in North Carolina. The isolated population was found to have an allelic richness and observed heterozygosity that fell within the range of the other individual populations (3.8–6.3 and 0.588–0.703, respectively), as well as high molecular variation that was similar to the connected individual populations indicating the presence of multiple generations of old turtles.

Core Habitat Size for a Population

The suitable "core" habitat patches that bog turtles are found most often associated with represents only a portion of the habitat types found in a wetland. In general, these core habitat patches for the northern population are small in size ranging from less than 0.81 ha (2 ac) to over 3.24 ha (8 ac) (Erb 2019, unpublished data). Approximately 42% of individual populations in the northern range occur within core habitat areas of 3.24 ha (8 ac) or less. Some of the largest core habitat patches are found in the Prairie Peninsula-Lake Plains area in New York, ranging between 6.0 ha (14.83 ac) and 28 ha (69.19 ac) (Rosenbaum and Nelson 2010, p. 428).

We lack information that suggests a strong relationship between core habitat size and bog turtle population size or health across the range. However, at four long-term study wetlands in New York, Shoemaker *et al*. (2013, p. 5) found bog turtle abundance estimates correlated strongly with estimated core fen area with expected abundance of 20 adult turtles for a 1-ha (2.47-ac) fen and 60 adult turtles for a 5-ha (12.4-ac) fen (Shoemaker *et al*. 2013, p. 5). Given the current uncertainty about the importance of this metric and the fact that almost half of the individual populations have small core habitat size, this metric will not factor into population ranking for the SSA.

Habitat Condition (suitable soils, vegetation, and hydrology) and Ecological Processes to Maintain Suitability

Suitable habitat conditions are described above (Individual Needs section) and include wetlands that provide micro-habitats for foraging, nesting, basking, hibernation, and shelter. Wetlands are often small, open-canopy, sedge meadows and fens bordered by more thickly vegetated and wooded areas.

Bog turtles depend on a mosaic of early successional wetland habitat created by regular disturbance (*e.g*., beaver, deer, cattle) (Service 2001, p. 12). In some areas, fire may have played an important role in maintaining the open nature of bog turtle wetlands (Service 2001, p. 13). Without disturbances, similar to other early successional habitats, vegetation succession will occur; however, in fens with intact hydrology, this succession occurs very slowly. Succession may be sped up with nutrient inputs or changes to hydrology (see chapter 3).

Upland Buffers

Vegetated upland buffers may help alleviate stressors that are discussed in chapter 3 and are important to maintain the natural function of wetland systems. The Service (2001, pp. A1–A3) developed three Conservation Zones for the bog turtle which includes the concept of upland buffers. Zone 1 is the entire wetland and not just the core bog turtle habitat. Zone 2 extends 300 feet from the entire wetland edge and Zone 3 includes the area up to a wetland drainage basin boundary or at least a half mile beyond Zone 2. Zones 2 and 3, when they contain intact native vegetation, help preserve groundwater hydrology, and filter out road salt, sediment, pesticides and nutrients before they enter the wetland, which can exacerbate the establishment of invasive plant species (Ehrenfeld and Schneider 1991, p. 482), may affect the food resource, and provide a continuous, connected landscape that allows for bog turtles to disperse to adjacent wetlands.

Key Uncertainties/Assumptions

Below are key assumptions and uncertainties that we made related to the bog turtles ecological requirements/resource needs:

- we lack robust demographic studies across the range; however, we used the best available information (including feedback from bog turtle experts) to determine appropriate condition categories.

    - for example, Shoemaker *et al.* (2013, p. 8) suggested a minimum of 15 females is needed for a viable individual population which equates to a minimum of 30 adults if there is a 1:1 sex ratio. Some survey efforts in the northern range have found a female bias (Shoemaker 2011, p. 14; Tutterow *et al*. 2017, p. 295; Whitlock 2002, p. 92). However, we lack sufficient information to suggest this is the case across individual populations and for the purposes of estimating population size we assumed a 1:1 sex ratio rangewide. We may be overestimating population size by making this assumption. There are no other models to suggest any other population size that influences population resilience; therefore, we made the assumption that individual populations of at least 15 females are resilient.

    - we have limited recruitment data for a variety of reasons including: wetland access (or inaccessibility), highly variable level of survey effort, and difficulty of locating nests and hatchlings. We assume that some level of recruitment is occurring with the presence of gravid females, nests, and/or younger age classes.

    - we have limited data regarding the survival rate of adults, but we assume that it is high across the northern range because adults are long-lived despite being in individual populations of small size. Shoemaker (2011, p. 17) stated that over a 100-year period, bog turtles can persist in an individual population of 10–20 breeding adults. Shoemaker (2011, p. 21) also estimated adult survivorship for bog turtles in eastern New York at 0.96.

    - limited data exists regarding the level of immigration/emigration to other individual populations. We assume, based on Shoemaker *et al*. (2013, p. 328), that dispersal estimates are approximately one bog turtle per year.

- we do not fully understand how important metapopulation structure or larger scale connectiwity is for bog turtles. Larger wetlands may not need frequent connectivity to another wetland, but some connectivity for dispersal is likely important over the long-term for genetic variation.

- we have high confidence that appropriate soils, hydrology, and vegetation are essential for bog turtles. While we could not find literature to support specific thresholds for impacts to these factors (*e.g.*, what level of hydrologic disturbance or amount of invasive plant species cover results in what population metric decline), we developed thresholds using expert knowledge of bog turtle wetlands. In the future, we are planning to conduct additional analyses correlated to population size with various landscape metrics.

Summary of Population Needs

In general, individual bog turtle populations would be considered healthy if they have multiple connected patches of high-quality habitat with intact buffers, high adult survival with a minimum of 15 females present and a recruiting population. Individual bog turtle population needs are summarized in table 2.4.

Table 2.4. The requisites for healthy bog turtle populations.

Population Health	**Element/Factor**	**Summary**
Healthy demography	Sufficient number of adults	A larger individual population is assumed to be more robust. Minimum population size of 15 females appears resilient.
	Presence of males and females	Need both males and females for sexual reproduction.
	High adult survival	Bog turtles are a long-lived species.
	Sufficient recruitment and age structure	Presence of all age classes demonstrates recruitment is occurring.
	Interconnectedness (part of metapopulation)	Two levels - periodic dispersal events and metapopulation dynamics. Increased resiliency with ability for repopulation of wetlands. Allows for gene flow.
Habitat to support healthy demography	Suitable soils and associated vegetation for all life stages	Soft soils for hibernation and burrowing. Soils associated with wetland vegetation for safe nesting, basking, and foraging.
	Intact hydrology and ecological processes	Continuous flow, shallow surface water or saturated soils year-round; stable water levels in nesting areas; flowing subsurface water for hibernation and flowing, shallow rivulets for movement and feeding. Bog turtles depend on a mosaic of early successional wetland habitat created by regular disturbance.
	Intact upland buffer	Important for reducing exposure to threats. Protects core habitat from degradation.

2.7.3 Species-level Ecology

For the purpose of this assessment, we define viability as the ability of the species to sustain metapopulations in the wild over time. The bog turtle needs multiple healthy (resilient) metapopulations (table 2.4). Resiliency is the ability of a population to recover from harsh years and stochastic events. To be resilient, the bog turtle must have healthy metapopulations; that is, metapopulations that are able to sustain themselves through good and bad years. The more metapopulations, and the wider the distribution of those populations (redundancy), the less likely that a species as a whole will be negatively impacted if an area of the species' range is negatively affected by a catastrophic event and increases the probability of maintaining natural gene flow and ecological processes (Wolf *et al.* 2015, pp. 205–206). Species that are well distributed across their historical range are less susceptible to the risk of extinction as a result of a catastrophic event than species confined to smaller areas of their range. We consider novel disease, drought, and floods as possible catastrophic events that may impact multiple metapopulations. There may be events that may drastically reduce the viability of individual populations as well, such as poaching or dramatic wetland alteration—fill or draining of a wetland.

Furthermore, diverse and widespread metapopulations of bog turtle may contribute to the adaptive diversity (representation) of the species if redundant metapopulations are adapting to different conditions. The bog turtle has a fairly wide distribution. Maintaining metapopulations across historical latitudinal and climatic gradients increases the likelihood that the species will retain the potential for adaptation over time. In considering what may be important to capture in terms of representation for the bog turtle, we identified several means of describing bog turtle diversity: genetic diversity, behavior differences and potential adaptation to variation in climatic conditions across latitudinal gradients, and habitat differences.

Gene flow is influenced by the degree of connectivity and landscape permeability (Lankau *et al.* 2011, p. 320). Gene flow may be somewhat limited among bog turtle metapopulations due to their patchy distributions and the infrequency in dispersal events. As discussed in section 2.3, Rosenbaum *et al*. (2007, p. 336) found differences between northern and southern bog turtle populations. Shoemaker and Gibbs (2013, p. 329) found high levels of gene flow between individual bog turtle populations in southeastern New York and southwestern Massachusetts, despite failing to detect movement of individuals between wetlands using typical survey techniques. Maintaining metapopulations across the latitudinal gradient is important to conserve this genetic diversity.

As discussed in section 2.6, the bog turtle active season varies depending on latitude and weather conditions across the range. The active season is shorter for more northern populations with later emergence and earlier entry into hibernation. Southern turtles have greater carapace length than northern turtles, and this may be related to the longer growing season (Lovich *et al.* 1998, pp. 71–72). Bog turtles in eastern Lake Ontario in New York appear to grow more slowly, possibly due to shorter active season (Rosenbaum *et al*. 2018, unpublished poster). Larger hatchlings have also been observed in the south (Lovich *et al.* 1998, p. 72).

Habitat availability by elevation changes across the latitudinal gradient as well, as turtles can be found at higher elevations in the southern population than the northern population. Finally, while bog turtles use similar wetland habitats, there is some variation across the range in the ecological community including swamps, fens, sedge meadows, and wet pastures. Tussock sedge is a common component of most bog turtle wetlands outside of the Prairie Peninsula-Lake Plain RU and only medium, rich, or marl fens, at the margins of ponds and are surrounded by extensive red maple-tamarack or red maple swamps are used in the Prairie Peninsula-Lake Plain RU (Rosenbaum and Nelson 2010, p. 425).

Beever *et al*. (2016, p. 133) describes these observed differences, in our case throughout the range of the bog turtle, as the species' "fundamental" adaptive capacity where the evolutionary, dispersal, and behavioral abilities explain how a species has adapted to its current ecological niche. Human-caused influences (*e.g*., land-use changes, pollution) on a species may negatively impact the fundamental adaptive capacity by limiting dispersal capabilities that can lead to reduced gene flow between populations (Beever *et al*. 2016, p. 135). For bog turtle, land-use changes have led to the fragmentation of connecting corridors to other individual populations due to the construction of roads and residential/commercial developments, among other types of development. These types of influences reflect the "realized" adaptive capacity that can impact a species' continuing ability to adapt to changes in the environment, such as to disease or climate change. Management actions (*e.g.*, protection of connecting corridors, habitat restoration) may help overcome the impacts of negative influences that would otherwise compromise a species' fundamental adaptive capacity.

While the concepts of the 3 Rs were not explicitly discussed in the Recovery Plan, the bog turtle recovery units (Service 2001, pp. 31–37) (figure 2.7) were based upon, "habitat distinctiveness, biogeographical and ecological affinities, and variation in the intensity and severity of the multiple threats to the species' survival." We find that for the purposes of this interim SSA, these recovery units reflect geographic units that are intended to help maintain adaptive capacity for the bog turtle. We discuss adaptive capacity further in chapter 3 in terms of how it is related to the anticipated ability of the bog turtle to respond to change.

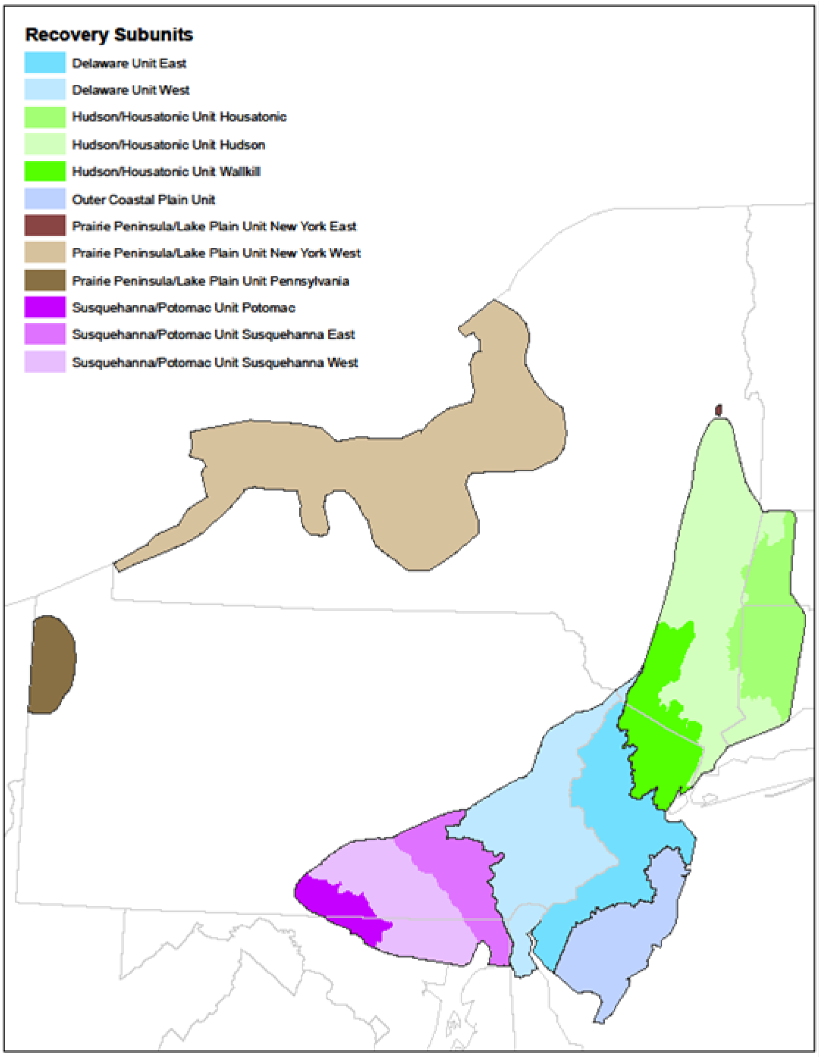

Figure 2.7. Recovery units from the bog turtle Recovery Plan.

Summary of Species Needs

In summary, the bog turtle requires multiple resilient metapopulations spread across its geographical extent to maintain its ecological and genetic diversity (table 2.5). Information to date suggests that bog turtles have some genetic structure between northern and southern populations and there are some differences in habitat, morphology and life history across the range. Based on the information we have to date and outlined in chapters 1 and 2 above, we believe the breadth of adaptive diversity can be captured by five representative units, also currently defined as recovery units as described by the Service (2001, pp. 31–39).

Table 2.5. The ecological requirements for species-level viability.

3 Rs	**Requisites**	**Description**
Resiliency (*able to withstand stochastic events*)	Healthy populations	Populations with: • sufficient number of adults • presence of males and females • high adult survival • sufficient recruitment and age structure • interconnectedness (part of metapopulation) • suitable soils and associated vegetation • intact hydrology and ecological processes • intact upland buffer
Representation (*to maintain evolutionary capacity*)	Maintain adaptive diversity	Healthy populations distributed across areas of unique adaptive diversity (*e.g.*, across latitudinal gradients) with sufficient connectivity for periodic genetic exchange.
Redundancy (*to withstand catastrophic events*)	Sufficient distribution of healthy populations	Sufficient distribution to guard against catastrophic events (*e.g.*, novel disease, drought, and floods) significantly compromising species adaptive diversity.
	Sufficient number of healthy populations	Adequate number of healthy populations to buffer against catastrophic losses of adaptive diversity.

Chapter 3 - Factors Influencing Viability

In this chapter, we describe multiple factors (positive and negative) that affect or are reasonably likely to affect bog turtles in the northern population at the individual and metapopulation levels. We considered a wide range of factors (table 3.1) and focus our discussion on those that are known or are likely to have population-level impacts. The number and location of individual or metapopulations affected and degree of influence of these factors determine their impact on the species as a whole, across the species' range, and within any unique environmental settings or genetic lineages.

Table 3.1. The factors currently influencing bog turtle viability at the individual- and metapopulation-levels.

Factor	**Factors affecting individual animals**	**Factors affecting multiple individuals – metapopulation-level impacts**
Inherent factors	X	X
Habitat loss or alteration from development or natural processes: -altered hydrology (filling, draining, conversion of wetlands by humans or beaver, effects from development, roads, agriculture, precipitation changes) -vegetation changes (invasive species encroachment and vegetation succession)	X	X
Inappropriate habitat management (direct impacts to individuals)	X	X
Roads (mortality and reduced dispersal)	X	?
Collection/Poaching	X	X
Predation	X	X
Flooding (direct impacts to individuals)	X	X
Disease	?	?
Pollution/Contaminants	X	X
Effects from climate change: -temperature extremes -changes in snowpack -changes in precipitation, -saltwater intrusion	?	?
Conservation actions	X	X

We first considered the factors that led to the species listing. When the bog turtle was listed as a threatened species in 1997, the primary factors that led to the listing were habitat loss and degradation from agriculture and development, which results in: hydrologic alterations; plant succession and introduction of invasive plants; road mortality; water quality degradation from sediment and pesticides and overgrazing and mowing from agriculture. We then considered information provided by the 2011 threats ranking exercise and the Conservation Plan (Erb 2019, pp. 2–3, A7–A8, B7–B8, C7, D7–D8, E7–E9). Bog turtle experts ranked development, succession, invasive species, and hydrology as the most significant threats in the Conservation Plan (figure 3.1).

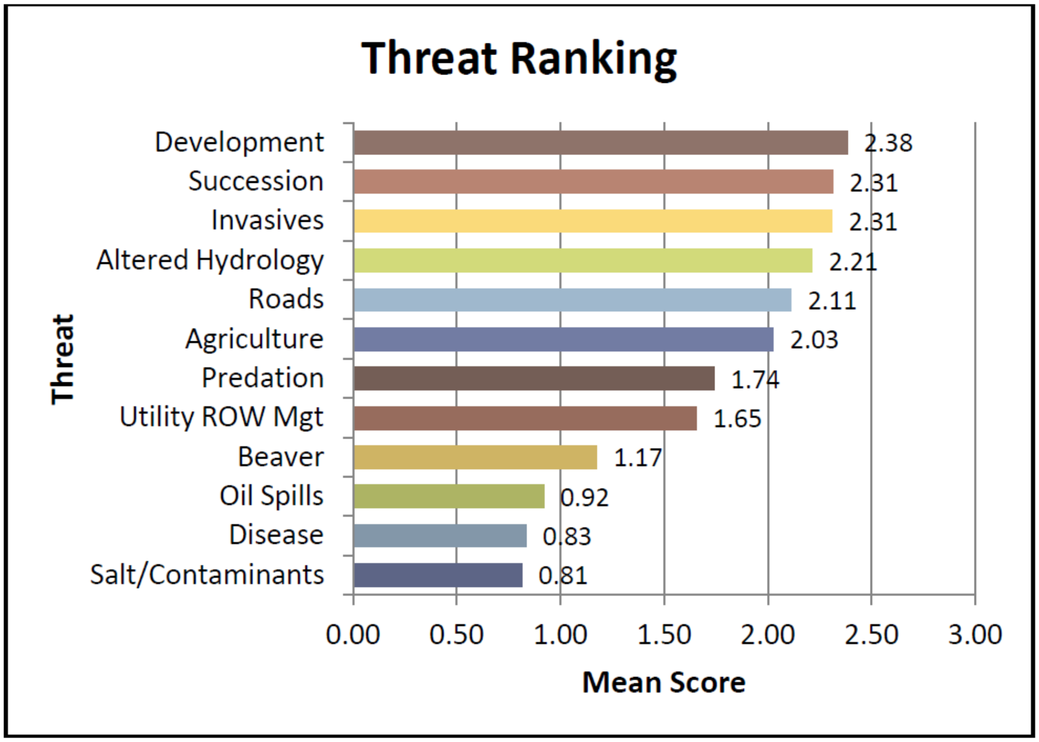

Figure 3.1. The combined threat ranking for the Delaware, Hudson-Housatonic, and Susquehanna-Potomac Recovery Units, based on expert surveys (Erb 2019, pp. 2–3).

Finally, we considered the factors discussed in the listing rule and Conservation Plan, as well any other plausible factors and focus our discussion on those that are currently known or are likely to have metapopulation-level impacts.

The primary negative factors (stressors or threats) currently influencing the status of the species are inherent factors (*e.g*., narrow habitat niche) and several external factors resulting in loss or alteration of habitat or directly influencing demographic rates (figure 3.2) for the northern population as a whole and by recovery unit (table 3.2). The primary positive factors are efforts to protect and manage bog turtle wetlands or areas with core habitat patches. The number and location of individual and metapopulations affected and the degree of influence of these factors determine their impact on the species as a whole, across the species' range, and within any unique environmental settings or genetic lineages. In chapter 4, we describe how these factors influence the current condition of the species.

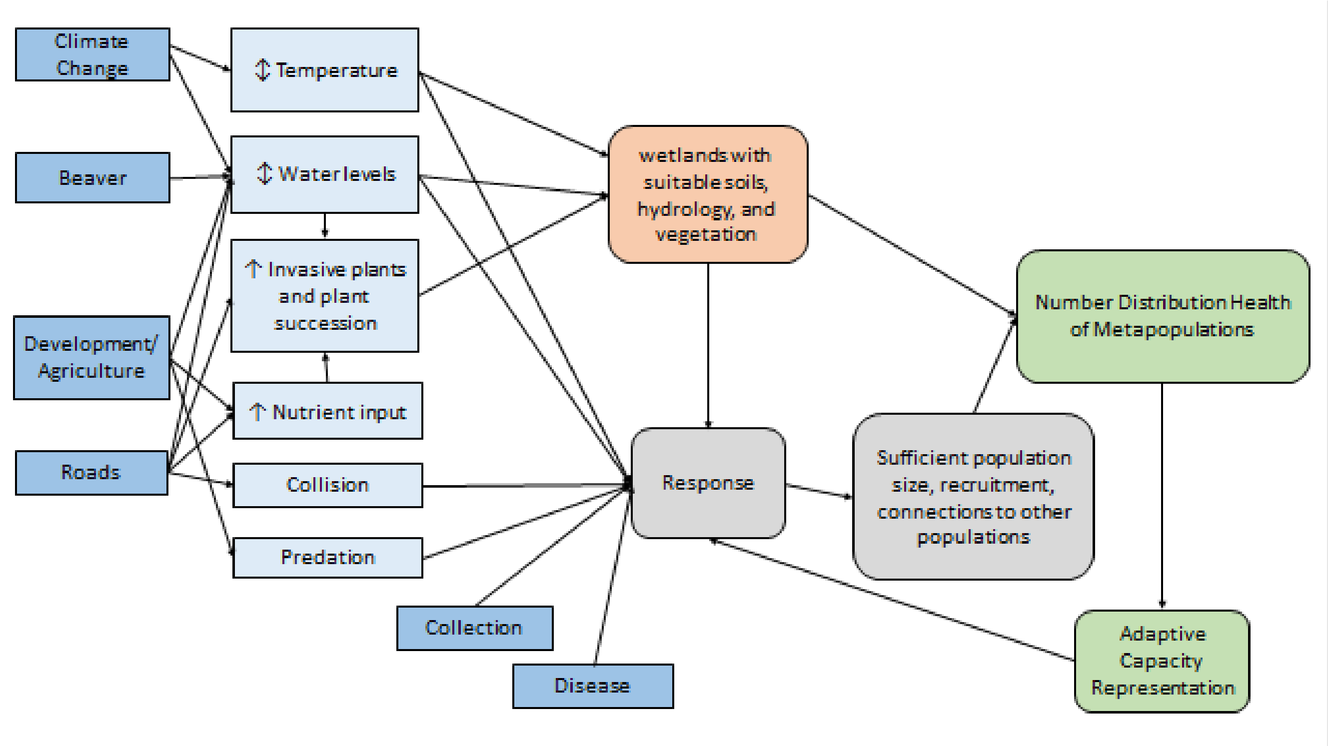

Figure 3.2. The primary extrinsic factors influencing bog turtle population health (resiliency).

Table 3.2. The primary factors influencing bog turtle population health (resiliency) per recovery unit as described in the Conservation Plan by Erb (2019, pp. A7–A8, B7–B8, C7, D7–D8, E7–E9). Experts ranked many threats on a scale of 0–3. Primary threats that received a score of 2 or higher and are presented in this table.

Recovery Unit	**Threats**						
	Agriculture	Altered Hydrology	Beaver	Development	Invasive Plants	Roads	Succession
Delaware	X	X		X	X	X	X
Hudson-Housatonic		X	X	X		X	X
Outer Coastal Plain*		X		X		X	X
Prairie-Peninsula-Lake Plain*	X	X	X			X	
Susquehanna-Potomac	X	X		X	X	X	X

*Scores were not applied for threats ranking for the Outer Coastal Plain or the Prairie-Peninsula-Lake Plain Recovery Units as was done for the other recovery units. Experts simply listed the primary threats recovery unit-wide.

3.1 Inherent Factors

One reason for the unequal extinction risk among species is likely to be that the intrinsic ecological traits of a species determine how well it is able to withstand the threats to which it is exposed (Cardillo *et al.* 2004, p. 0910; Mattila *et al.* 2008, p. 2322). Foden *et al.* (2018, entire) describe methods for assessing species vulnerability and response to the effects of climate change; however, these methods may be considered in overall risk assessments for a species ability to respond to all threats, including novel threats like climate change. They suggest that the ability for a species to adjust to changes in its environment is related to the features associated with sensitivity and is facilitated by high levels of phenotypic plasticity, dispersal ability, or genetic diversity (Foden *et al.* 2018, p. 10). These can enable a species to adjust to new conditions by (1) shifting locations, (2) modifying behaviors, physiology or life history, or (3) evolving new traits (Foden *et al.* 2018, p. 10). Thurman *et al.* (2020, entire) condensed this into the two concepts of "persist in place" or "shift in space" and also developed an attribute-based framework for evaluating species' adaptive capacity.

Bog turtles exhibit several inherent traits that influence population viability, including its specialized habitat requirements, limited dispersal ability, small individual population sizes in many instances, and delayed sexual maturity. As discussed in chapter 2, bog turtles are limited to highly specific habitat of open, calcareous, low shrub fens and expected dispersal distances for bog turtles are generally less than 20 m (65.7 ft) (Carter *et al*. 2000, p. 77). Due to its specific habitat requirements and limited dispersal capacity and behavior, it is unlikely that bog turtles will frequently be able to move from current fen locations to other wetlands. A general consequence of habitat specialization and limited dispersal capacity, either in isolation or combined with these threats, is the potential loss of genetic diversity within metapopulations of the species. In addition, smaller populations of any wildlife species may have reduced genetic diversity and relatively low genetic diversity is documented within the bog turtle (Rosenbaum *et al*. 2007, p. 335). Genetic drift[14] occurs in all species but is more likely to negatively affect populations that have a smaller effective population size[15] and populations that are geographically spread and isolated from one another, such as for bog turtle.

3.2 Habitat Loss or Alteration

In addition to the inherent factors discussed above, the primary factor influencing bog turtle population health is availability of quality habitat for all life stages. As discussed above and in chapter 2, bog turtles are found in open, canopy wetlands, including fens. Fens are especially sensitive to relatively small changes in hydrology (van Diggelen *et al.* 2006, p. 159). For the purposes of this report, we organized stressors into those that alter hydrology, those that alter vegetation, and those that directly impact turtles. We identify several sources of each stressor within the following sections.

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[14] The variation in the relative frequency of different genotypes in a small individual population, owing to the chance disappearance of particular genes as individuals die or do not reproduce.

[15] The number of individuals in an individual population who contribute offspring to the next generation.

3.2.1 Altered Hydrology

As discussed in chapter 2, intact hydrology is essential for the maintenance of appropriate soil (soft for burrowing and cover) and vegetation characteristics. Groundwater seeps, springs, and rivulets provide a continuous flow of water through the wetlands, maintaining the saturated, soft soils present. There are a variety of ways that bog turtle wetland hydrology may be altered and the effects of alteration may be short term (reversible) or long-term. Below we discuss changes to hydrology from directly filling or converting wetlands, impacts from adjacent upland activities, and impacts from weather events and climate change.

Filling, Draining or Conversion

Irreversible damage may be done by filling or draining bog turtle wetlands. Draining or converting fens to open water marshes (*e.g.*, with water control structures) may also result in long-term damage.

Residential, commercial, and energy developments are primary sources of fill or conversion of bog turtle wetlands. Direct and indirect impacts to wetland habitats from human developments have long been cited as a major cause of individual bog turtle population loss and decline (Service 2001, p. 19). In addition to temporary or permanent filling of wetlands, development projects may include building obstructions in wetlands and waterways, and direct discharges into wetlands and waterways (*e.g.*, permitted discharges of fill for development or for stormwater collection). While these activities are largely regulated by Federal, state and local statutes, such as the ESA and Clean Water Act of 1972, they do still occur at bog turtle wetlands (*e.g.*, partial fill associated with wetland crossings of pipelines, power lines or access roads). Without ESA protections, far more impacts are anticipated. Impacts from filling or discharging materials into bog turtle wetlands include death or injury of turtles of all life stages and loss of habitat for feeding, nesting, cover, or hibernating. Draining and tiling wetlands to increase tillable acreage is another source of wetland conversion.

The loss of wetlands in a landscape can have significant impacts to the metapopulation dynamics of wildlife species, especially those with low population growth rates and low densities, such as turtles (Gibbs 1993, p. 30). It is assumed that with the loss of wetland habitat, individual populations become more isolated and fragmented from other wetlands reducing the availability of connected core habitats for dispersal, as well as reducing the available source populations for dispersal, (Gibbs 1993, p. 30; Semlitsch and Bodie 1998, p. 1132). Feaga *et al*. (2012, p. 1019) stated that bog turtle survival and fitness is dependent on nearly continuous saturation of wetland soil so individuals can bury themselves in the mud to evade predation, regulate body temperature and stay hydrated. Alteration of these wetlands, especially from ditching, tiling, and pond creation, make it difficult for bog turtles to carry out these functions as habitat becomes unsuitable.

A natural source of wetland conversion is the beaver (*Castor canadensis*). Beaver activity can support or create bog turtle habitat in the long term as beaver ponds gradually convert to wet meadows. For instance, historical beaver trapping likely resulted in the loss of suitable bog turtle habitat via forest succession (Klemens 1993, p. 178). In urbanized areas, beavers are often considered “nuisance” wildlife due to undesirable impacts to human property. Increasing development will likely result in greater beaver control efforts and loss of beaver habitat. Subsequently, the long-term benefits provided by beavers to bog turtle habitat will likely be suppressed. Alternatively, flooding caused by beaver dams can adversely impact turtles and render habitat unsuitable as occurred at a bog turtle wetland in southeastern New York (Rayman-Metcalf 2021, pers. comm.). Beaver flooding is not usually a problem unless a wetland is surrounded by roads and/or development that prevent historical shifting of the wetland due to these natural perturbations. In coordination with state wildlife agencies, beaver control measures have successfully been used to reduce turtle mortalities and improve habitat quality at some bog turtle wetlands.

Altered Hydrology from Adjacent Activities

Residential, commercial, and energy development may alter bog turtle wetland hydrology in a variety of ways. Wright *et al*. (2006, entire) provide an extensive review of indirect impacts to wetlands from development, including hydrologic changes and stressors and water quality stressors, most of which would lead to adverse impacts to bog turtle habitats and individual populations. Impacts also may originate in the adjacent uplands and surrounding landscape and can include increased stormwater and contaminated surface runoff (including lawn treatments and parking lot contaminants), increased sedimentation from construction, and alteration of underlying hydrologic regimes. However, most states and local governments have sediment and erosion control measures that are required for construction. Also, roads may act as dams flooding or drying out adjacent wetlands.

Bog turtle habitats are sustained by groundwater regimes that are sensitive to changes in subsurface water supplies. Development occurring in groundwater recharge areas results in increases in impervious surfaces, compaction of soils, and stormwater conveyance that all contribute to reductions in groundwater recharge (Wright *et al*. 2006, p. 22). Impervious surfaces also can increase the flow of surface water runoff into wetlands and temporarily increase water levels (Feaga *et al*. 2012, p. 1019) and increase erosion and sedimentation, especially if adjacent to a bog turtle wetland. Also, demands on water supply and associated additions of wells can, in turn, lower water tables, drying out bog turtle wetlands. Alteration of hydrology can lead to an increase in woody vegetation, a change in herbaceous vegetation and succession into a bog turtle wetland, reducing the quality of the core habitat.

3.2.2 Changes to Vegetation

Tesauro and Ehrenfeld (2007, p. 293) state the advancement and succession of invasive plants contributes to the loss of bog turtle habitat. Both herbaceous and woody species (native and/or invasive) associated with succession can reduce the amount of available suitable bog turtle core habitat and negatively impact individual populations in many wetlands across the range to varying degrees. If the hydrology of a wetland is altered resulting in a sustained lowered water table, enhanced vegetative succession occurs. The addition of nutrients helps invasive (and some native) species outcompete native wetland vegetation used by bog turtles; they grow tall and shade out the native plants. Repeated vegetation management is likely needed to continue to set back the seral stage and reduce succession into core habitat.

Invasive Species

We evaluated the relative threats posed by invasive understory species and determined that cattails (*Typha* spp), reed canary grass (*Phalaris arundinacea*), multiflora rose (*Rosa multiflora*), purple loosestrife (*Lythrum salicaria*), glossy buckthorn (*Frangula alnus*), and common reed (*Phragmites australis*) are currently the primary species that could affect population-level dynamics of the bog turtle. Werner and Zedler (2002, pp. 457–465) attribute reductions in tussock sedge, tussock microtopography, and native plant abundance and diversity at a non-bog turtle wetland due to the presence of lower organic matter content with increased densities of species such as cattail and reed canary grass. Similar effects from these species are likely occurring at individual bog turtle populations in the northern range.

For example, cattails can form a monoculture and plants grow tall reducing sunlight needed for basking and nesting turtles. Also, bog turtles are known to avoid dense cattail patches likely due to the presence of firmer and siltier soils (Roos and Maret 2018, p. 23; Travis *et al*. 2018, p. 728, 737). However, at smaller densities, cattails can provide shade and food for bog turtles (Roos and Maret 2018, p. 32).

Reed canary grass has been known to establish in bog turtle wetlands as a result of flooding events and from storm water management associated with housing developments (Tesauro, 2001, p. 29; Sirois *et al*. 2014, p. 456). The rhizomes form dense mats that makes burrowing in mucky soil impossible and covers over rivulets (Tesauro 2001, p. 29), used by bog turtles. Reed canary grass also reduces light penetration and outcompetes other native plants (Byer *et al*. 2017, p. 70).

Multiflora rose is another invasive plant species that is known to degrade bog turtle habitat. Over a 17-year period, the presence of multiflora rose at a bog turtle wetland in Maryland attributed to decreased sedge tussocks used for nesting which coincided with an increased home range of bog turtles (Morrow *et al*. 2001, p. 72). However, at low density, multiflora rose could be beneficial to bog turtles. Roos and Maret (2018, p. 38) found individuals under multiflora rose bushes possibly seeking out shade and/or shelter.

Purple loosestrife is well-established in many bog turtle wetlands. Plants grow tall and form a wide crown that reduces sunlight needed for native plant survival (Kiviat 1978, p. 35; Malecki *et al*. 1993, p. 681; Tesauro and Ehrenfeld 2007, p. 298). Monotypic stands reduce wetland plant biodiversity and reduces food and habitat for species such as the bog turtle (Nelson et al. 1996., p. 72).

Glossy buckthorn is a shrub of Eurasian origin that is aggressive in bogs and fens. Wetlands with glossy buckthorn have fewer characteristic fen plant species, lower soil pH, fewer vegetative hummocks, and lower light availability (Fiedler and Landis 2012, p. 44).

Lastly, common reed is abundant in wetlands across the U.S. The growth of native wetland plants is suppressed with the presence of common reed (Richburg *et al.* 2001, p. 253), creating a monoculture and closed canopy that reduces productivity of native plants and reduces burrowing capability of bog turtles (Tesauro 2001, p. 27). Bog turtles can seek refuge in common reed patches to escape high daytime temperatures; nesting habitat is not available in these patches

(Utter 2020, unpublished data). Common reed presence is also associated with road salt entering wetlands that border roads, resulting in high tolerance to road salt and outcompeting native plant species. Richburg *et al*. (2001, p. 252) found that elevated salt concentrations penetrated a wetland in Massachusetts more than 600 m (> 1968 ft) from a highway. As a result, common reed dominance has changed the composition and structure of the wetland vegetation present (Richburg *et al*. 2001, p. 253).

Succession

As mentioned in chapter 2, bog turtles depend on a mosaic of early successional wetland habitat created by regular disturbance (*e.g*., beaver, deer, grazing animals, fire) (Service 2001, pp. 12–13). Without disturbances, as with other early successional habitats, vegetation succession will occur.

There may be multiple sources of vegetation succession, including natural succession from early successional to late successional plant growth over time, as well as human-induced or accelerated succession from sources such as increased nutrient input (enrichment) and altered wetland hydrology. In fens with intact hydrology, this succession occurs very slowly but succession may be sped up with nutrient inputs or changes to hydrology. Water levels may be influenced by impoundments (human or beaver) or roads that restrict flow into or out of the fens. Restriction of flow into wetlands results in drying out of saturated soil and increasing shrub growth. Taller shrubs shade out nesting and basking habitat. Here we provide some additional details about nutrient input. Sources of changes to hydrology were discussed above.

Bog turtles use a variety of wetland types including fens. Fens are characterized by a very low supply of nitrogen and phosphorous (Bedford and Godwin 2003, p. 614) and many fens are degraded by altered hydrology or by nitrates moving in groundwater, by phosphates absorbed to sediment in run-off, or by altered water chemistry caused by development within fen watersheds (Drexler and Bedford 2002, p. 278; Bedford and Godwin 2003, p. 617). Drexler and Bedford (2002, pp. 276–278) observed that nutrient loading of a fen in New York (not a bog turtle wetland) resulted in reductions in species richness of both vascular plants and bryophytes and increases in monotypic stands of Canadian reedgrass (*Calamagrostis canadensis*), lake sedge (*Carex lacustris*), hairy willowerb (*Epilobium hirsutum*), and broadleaf cattail (*Typha latifolia*), especially in an area adjacent to a farm field. Dense cover reduces fen biodiversity through direct space competition, or by reducing seedling growth from decreased available light and increased litter layer (Jensen and Meyer 2001, pp. 173–179).

Residential, commercial, and energy development adjacent to bog turtle wetlands can increase the rate of vegetation succession (Klemens 1991, p. 8). Even if the patches of open wetlands occupied by bog turtles are protected, adjacent activities that cause nutrient enrichment, and contaminant inputs from septic, road, and fertilizer runoff can cause increased vegetation succession. The latter causes rapid growth of vegetation with subsequent canopy closure (Klemens 1989, pp. 3–4).

In summary, altered hydrology, which leads to mostly negative changes in vegetation (type and abundance) and increased succession, is impacting a high number of bog turtle metapopulations currently across the northern range. Erb (2019, pp. A8, B8, C7, D8, E8) stated that altered hydrology is a top threat within all of the northern range states in all five recovery units. A subsample of 50 individual bog turtle populations where rapid population and habitat assessments were done indicated that 57% of these individual populations are impacted by a change in hydrology (Erb 2019, p. 34).

3.3 Inappropriate Site Management (Death or Injury to Turtles)

Given that invasive species and succession result in reduced habitat quality for bog turtles, some form of management is frequently necessary. The Recovery Plan (Service 2001, p. 59) identifies controlling succession and invasive native and exotic plant species (task 6.3.1) as a Priority 1 recovery action. Methods of vegetation control vary depending upon the target plant species and may include chemical control (herbicides), biological control (*e.g.*, introduction of insects, grazers), burning, and mechanical and/or manual removal.

Because bog turtles are present year-round in their wetlands, management activities can result in impacts to individual turtles and the Service has developed best management practices and a programmatic consultation (Service 2019, entire) for actions that the Service funds, conducts, or authorizes to reduce adverse impacts while restoring and managing bog turtle habitat for the overall benefit of the species. The biological opinion details the types of impacts (positive and negative) anticipated from various management actions. Conducting vegetation management activities in bog turtle wetlands without employing the best management practices is likely to result in increased risk of death or injury to bog turtles or their nests and may result in damage to the habitat.

It is estimated that 57 Service-involved habitat restoration projects between 2012–2018 have avoided or minimized negative impacts to bog turtles by following conservation measures outlined in the biological opinion (Service 2019, p. 2). Similarly, a programmatic biological opinion was also used for habitat restoration projects funded by the Natural Resources Conservation Service (NRCS) in the northern range.

3.4 Roads (Mortality and Reduced Dispersal)

As mentioned above, increased urbanization from development can lead to expanded transportation networks or increased traffic on existing roadways. Roads impact individual bog turtle populations in a variety of ways. For example, they are a source of pollution through vehicle accidents or spills or surface water runoff and increased invasive species through movement of plant seeds or introduction of road salt (see Invasive Species section). They may also alter the hydrology of a wetland by fragmenting a wetland or changing surface water runoff patterns (see Alteration of Hydrology section).

Roads can also result in direct mortality of vehicle-struck individuals and created barrier effects on movement. These effects may lead to significant population declines for many wildlife species (Langen *et al*. 2009, p. 104), including those already facing extinction risks. While Myers and Gibbs (2013, p. 260) did not find that proximity to roads influenced bog turtle occurrence within a wetland, most roads were likely constructed after wetlands had long been occupied by the species.

Myers and Gibbs (2013, p. 262) also noted that road density in New York did not influence bog turtle persistence or distribution, and that they may experience less mortality than other turtle species. Bog turtles nest directly in wetlands; and thus, are less likely to cross roads than those species that use upland habitats to nest (Myers and Gibbs 2013, p. 262). New York Natural Heritage Program (NYNHP) element occurrence data includes bog turtles found on roads, including mortality records (DOR; dead on road records). Since 1978, 19 bog turtles have been found either DOR (N=5; assumed vehicle strike), alive crossing roads (N=12), or alive/dead on railroad tracks (N=1). Of the 19, five were male, five were female, and nine were unknown sex. Most of the road or railroad track records were in close proximity to known core habitat, but there were two instances of males that traveled over 1000 m (3280 ft), two other individuals (one male/one unknown) over 500 m (1640 ft), one male approximately 1.9 miles (3.06 km), and another individual (unknown sex) four miles (6.4 km) away from core habitat, indicating potential dispersal events. In any case, this NYNHP data is likely an underestimate as it is assumed that bog turtles successfully cross roads and go undetected, especially in areas with reduced traffic. It is currently unknown if the same patterns of road records are found in the other northern range states. At least for New York, we agree with the assumptions made by Myers and Gibbs (2013, p. 262) that bog turtles are less likely to be crossing roads than perhaps their other congeners.

In addition to direct mortality, roads may deter bog turtles from crossing to travel to other wetlands. Bog turtles do require regular or intermittent opportunities to disperse to new wetland areas or within a home wetland complex, and the proximity, density, and traffic volume of roads within the dispersal corridor each can be a factor in the success or failure in successful migrations. In some cases, the inability to disperse is due to the road infrastructure itself or traffic volume over certain thresholds. Road design and infrastructure may result in significant barriers to movement in cases of roadway fencing or sound walls, high vertical curbing, or Jersey barriers. Traffic volume can also influence a species ability to disperse across a roadway. Animals, in general, can be fully repelled from entering highways due to vehicle movement and/or traffic noise at 10,000 vehicles per day, which can act as an effective barrier for dispersal (Seiler 2003, pp. 28–30). Gibbs and Shriver (2002, p. 1649) state that most turtle populations cannot withstand even a 2–3% annual loss in numbers from road mortality to be sustainable over time. Given the density and high-volume road network within the northeast U.S., it is likely that some bog turtle wetland habitats may be isolated from others if by nothing else than roadways.

In summary, roads are not expected to result in species-level impacts. However, many individual populations throughout the range are in close proximity to roads and may potentially experience higher mortality or reduced dispersal ability at the local-level if roads have higher traffic volumes.

3.5 Illegal Collection

In 1975, the bog turtle was added to Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in order to monitor trade in the species. In 1992, the bog turtle was transferred from Appendix II to Appendix I due to the increased number of bog turtles being advertised for sale, the increased price being paid for individuals and pairs, and illegal trade not being reported under CITES (57 FR 7722, March 4, 1992). Both import and export permits are required from the importing and exporting countries before an Appendix I species can be transported, and an Appendix I species cannot be exported for primarily commercial purposes. From what we know, between 1999–2010, Service law enforcement found no import or export records of bog turtles, although there are records of transfers for scientific purposes (non-commercial) from Japan to the U.S. and the U.S. to Germany (Momentum 2011, p. 12). It is unknown whether these transfers involved northern or southern population range bog turtles. No import, export or scientific permits have been issued since 2010 (Tapia 2021, pers. comm.).

Because of the increased demand for bog turtles, the Service (2001, p. 22) described their exploitation for commercial or private use the second most important threat to this species, after habitat loss, due to their small size, attractive shells and body coloration, and their rarity. However, illegal collection of bog turtles is not as obvious to detect as habitat loss, as no evidence is left behind that alerts biologists or law enforcement that the activity has occurred other than an observed reduction in population numbers. With habitat loss, there is an obvious physical alteration of habitat whether fill of a wetland has occurred, or a change in hydrology has led to changes in wetland vegetation, for example. Even predation events by raccoon, mink, or red fox (to name a few) leave carcasses behind that biologists will eventually find during survey efforts. With illegal collection, it can take biologists a couple years or more to determine a collection event has occurred as surveys sometimes do not take place on an annual basis. Instances of illegal collection have been found in the southern population as documented by Tryon (1989, entire) and Herman (1989, entire). They described one incident where a series of study wetlands in North Carolina were decimated by a group of collectors who had specifically traveled south to capture bog turtles. Apart from removing large numbers of adults, these collectors seriously compromised at least one long-term mark and recapture study wetland by removing marked turtles (Herman 1989, entire). No other collection events in the southern population are known or suspected at this time (Cameron 2021, pers. comm.).

Klemens (1991, p. 9) reviewed trade data as it related to advertising of bog turtles for sale, illegal collection from known wetlands, and potential threats from hobbyists and pet trade owners. At the time of Klemens' (1991, p. 9) review, the southern population collection event was the only documented occurrence and he noted evidence of individuals and breeding pairs being advertised for sale. No information was provided specifically for these activities occurring in the northern population; however, since Klemens' review, it is assumed that illegal collection has occurred as anecdotal reports have been provided by state biologists over the last 40 years[16] (Erb 2019, pp. A7, B8, C7, D8, E8):

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[16] In most cases, the exact date of a purported poaching event could not be determined as the majority of bog turtle field surveys are not conducted on an annual basis. Dates that are stated in this section are estimates of when state

- at two extant individual populations in Pennsylvania between 2009 and 2014 in the Delaware Recovery Unit
- at one extant individual population in New York in 1990, four additional individual populations in New York (dates unknown), and at one additional extant individual population in New York in 2019 (J. Tesauro 2020, pers. comm.; population estimate of 50 turtles[17]) in the Hudson-Housatonic Recovery Unit
- at up to four extant individual populations in New Jersey in the Outer Coastal Plain Recovery Unit
- at one extant individual population in New York in the Prairie Peninsula-Lake Plain Recovery Unit
- at nine extant individual populations in Maryland between the years 1990 and 2004, as well as at another individual population in Maryland in 1980 in the Delaware Recovery Unit

We do know of one law enforcement case, in August 2018 in the Village of Allegany, Cattaraugus County, New York, involving an individual that was in possession of over 300 northeast native turtles of multiple species, including 17 bog turtles. It is unknown at this time from where the bog turtles were originally collected. Genetic analyses are pending, and a Federal case is ongoing. No charges were made by the state of New York.

In summary, while few individual bog turtle populations have been purportedly impacted by illegal collection to date, the threat is still high currently for all individual populations in the northern range. Due to their Federal status, we suspect that illegal activity is more covert as compared to the illegal collection of other native turtle species.

To address this issue, recent efforts have been made to increase communication and coordination between state biologist and law enforcement to better the tackle poaching issue among all northeast native turtle species. New Jersey and Pennsylvania are dedicating law enforcement officers specifically to handle the illegal trade in northeast turtles. However, since this is a new effort, we do not have any information regarding the implications of the increased focus on anti-poaching efforts in reducing bog turtle collection.

3.6 Predation

Predators include racoons (*Procyon lotor*), mink (*Neovison vison*), red foxes (*Vulpes vulpes*), northern short-tailed shrews (*Blarina brevicauda*), meadow voles (*Microtus pennsylvanicus*), snakes, birds, and skunks (*Mephitis mephitis*). Mesopredators (*e.g.*, racoons, skunks) appear to be the most common bog turtle predator (Bury 1979, p. 5; Whitlock 2002, pp. 55–56; Ernst and Lovich 2009, p. 270; Zappalorti *et al.* 2017, p. 199; Knoerr *et al.* 2020, p. 4). Predation can happen at any time during the year, but likely occurs most frequently during the nesting season (Whitlock 2002, p. 56; Zappalorti *et al.* 2017, p. 199). Predators eat eggs and hatchlings, reducing nesting success and recruitment. They also have been documented to kill healthy

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biologists thought a poaching event occurred based on the last date a field survey was completed. In other cases, no estimated date could be given due lack of information in field records.

[17] Population estimates for other bog turtle populations listed in this section where possible poaching has occurred is not available.

juveniles and adults. Juveniles and adults can become injured (*e.g*., missing limbs, chewed toes, shell punctures), which could also impact their ability to successfully breed, forage, or find shelter (Whitlock 2002, pp. 55–56; Sirois 2011, p. 22; Zappalorti *et al*. 2017, p. 199). Predators have likely always been part of the natural ecosystem throughout the species' range. It is plausible that predators did not significantly impact individual populations in the past or if they did and a given individual population was lost, recolonization was possible due to larger population sizes and connectivity between individual populations. Many predators benefit from supplemental foods associated with human-dominated habitats. For example, predators adjacent to bog turtle wetlands may be associated with agriculture activities (*e.g*., poultry farms, agricultural fields), which can provide food for predators (Oehler and Litvaitis 1996, p. 2078; Zappalorti *et al*. 2017, p. 199). Predators may also be associated with development (*e.g*., trash, food left out for domestic pets) and roads (travel corridors). In addition, habitat fragmentation that creates diverse landscapes and cover types saturates and concentrates populations of predators (Robinson and Wilcove 1994, pp. 238–239; Oehler and Litvaitis 1996, p. 2078).

Predators may have increased access to core habitat during flooding events (Sirois *et al.* 2014, p. 459). For example, Sirois (2021, pers. comm.) found that mink likely exploited flooded conditions and predated on bog turtles. Predation by raccoons increased along edges of ponds (Marchand and Litvaitis 2004; pp. 248–249), which may be comparable to flooding events where predators can exploit areas of bog turtle core habitat inundated by precipitation.

While it is difficult to quantify predation rates and whether they have increased across the range from historical conditions, predation is impacting resiliency through reduction of recruitment at several individual bog turtle populations (Whitlock 2002, pp. 55–56; Sirois 2011, p. 22; Zappalorti *et al.* 2017, p. 199; Byer *et al.* 2018, p. 231). This could result in extirpation of small, isolated bog turtle wetlands over time. These individual populations have the greatest risk of extirpation from predation (Shoemaker and Gibbs 2013; Sirois *et al*. 2014, p. 259).

Impacts of predation could be minimized through conservation efforts such as nest protection efforts and increasing the amount (area) of suitable nesting habitat to help offset the predation rate (Sirois *et al*. 2014, p. 459; Marchand and Litvaitis 2004, pp. 249–250). In coordination with state wildlife agencies, predator control or avoidance measures have successfully been used to reduce turtle mortalities at some bog turtle wetlands. Predation is not expected to result in species-level impacts currently.

3.7 Pollution/Contaminants

There are multiple potential sources of pollution/contaminants into bog turtle wetlands, including surface water runoff from residential and commercial development (primary mechanism; see Development), agricultural fields, and roads (see Roads); periodic chemical spills; and inadvertent returns associated with oil and gas pipeline installation or replacement.

Linear projects (*e.g*., water and sewer lines, electrical transmission lines) may occasionally intersect with bog turtle wetlands. However, this section focuses on oil and gas transmission pipelines projects where intersection with bog turtle wetlands is known and we are aware of potential impacts. For example, horizontal directional drilling (HDD) is a pipeline installation method commonly used to cross underneath wetlands and waterways to minimize direct impacts to these systems. However, there is a risk of an inadvertent return of drilling fluids used during pipeline installation, most commonly bentonite. Bentonite is a clay-like material that is inert and nontoxic but can bury wetland soils and plants in thick clay, alter hydrology, fill habitat crevasses and disrupt foraging behavior of bog turtles. In 1999, an HDD in Pennsylvania caused a bog turtle to be expelled from hibernation during an inadvertent return event.

Increased oil and gas pipeline building and repair activities in Pennsylvania in recent years has led to more than six State take permits and five biological opinions for bog turtle, and depending on the pipeline installation demand, inadvertent returns can be expected to occur within the range of this species in the future. While no known turtle mortality has occurred, overwintering individuals have been abruptly disturbed, and for at least one wetland, core habitat has been impacted by an inadvertent return. While few known impacts have resulted from HDD to date, this installation method poses significant concern as Pennsylvania has the highest concentration of bog turtle occurrences in the northern range and is currently the only state in the northeast where pipeline projects are regularly proposed, many in close proximity to known bog turtle occurrences. Oil and gas are extracted from various shale formations in Pennsylvania and is then conveyed out of state, which adds to the demand for pipeline construction and potential impacts to bog turtles (Shellenberger 2021, pers. comm.). Shellenberger (2021, pers. comm.) added that existing pipelines are aging (some are ≥ 50 years old) and the Service is currently seeing many proposed repair/maintenance projects. Potential impacts to the bog turtle are anticipated to continue from pipeline maintenance projects.

Project applicants work with state and Federal biologists to implement measures to minimize inadvertent returns from occurring; however, not all impacts are preventable, as many factors such as the local geology (including hard to detect subsurface cracks and fissures) and the pressure of the drilling fluid may lead to an inadvertent return (Shellenberger 2021, pers. comm.). One inadvertent return occurred in multiple locations in a cornfield along a pipeline HDD in between fingers of a known bog turtle wetland in Pennsylvania. This resulted in pockets of bentonite that inadvertently returned to the surface ranging in size from approximately 200 ft^2 to 450 ft^2. On the same pipeline installation project, but at another HDD location, another inadvertent return resulted in an estimated 10,000 gallons of bentonite fluid being released in a lake; about 700 ft from a bog turtle occurrence. These examples reinforce the unpredictability of where inadvertent returns will happen and how much material will be released.

Because predictability is difficult, it is also difficult to determine how bog turtles may be impacted until an inadvertent return happens. We do not know how disturbing individuals during the winter impacts their abilities during the active season to mate, nest, etc., but we can reasonably assume that if an inadvertent return occurs near a hibernaculum and it fills in with bentonite, that the clay material will harden and render the hibernaculum unusable. Also, it is difficult to predict impacts to bog turtle nests and nesting habitat. If an inadvertent return occurs within a nesting area, depending on the size of the area impacted, the amount of the fluid released and how high nests are off the ground, nests or nesting areas could be rendered useless (Shellenberger 2021, pers. comm.). Bentonite material can also smother seeds, berries, insects, slugs, worms, etc., that bog turtles feed on which can temporarily affect feeding.

Minimization measures such as completing the HDD during the bog turtle's active season can help to reduce threats to turtles while they are hibernating. Understanding and avoiding certain geology in which an HDD is proposed can also help to minimize inadvertent returns and having a driller that is experienced with HDD and understands the ecological concerns helps to reduce risks.

In summary, pipeline construction/maintenance and inadvertent returns are not currently impacting a large number of individual populations across the range. However, a significant portion of the northern range is in Pennsylvania (approximately 37%) and subject to potential impacts to individual populations at the local level from pipeline projects.

3.8 Disease

Health screenings of bog turtles have become standard practice over the past 10 years since being identified as a need in the Recovery Plan (Service 2001, p. 23). Through these screenings, we have learned that different diseases are present within individual bog turtle populations. Some of these diseases are novel to bog turtles, others are shared with other northeast native turtle species. While mortality events periodically occur at known individual populations, disease outbreaks have not been specifically linked to these events. This is largely due to the vast majority of test results being inconclusive due to predation on or extreme decay of deceased individuals found. Overall, we find that disease is not a current factor that is significantly impacting bog turtle individual or metapopulations, but it may be an issue in the future as either a catastrophic event or a change in the environment that populations may have to respond to. appendix B contains a summary of recent studies that have helped examine the prevalence of disease in wild individual bog turtle populations.

3.9 Ongoing Effects of Climate Change

Global average temperature has increased by 1.7 degrees F (0.9 degrees C) between 1901 and 2016 (Hayhoe *et al.* 2018, p. 76). Over the contiguous U.S., annual average temperature has increased by 1.2 degrees F (0.7 degrees C) for the period of 1986 to 2016 relative to 1901 to 1960 (Hayhoe *et al.* 2018, p. 86). Annual average temperature has increased in the northeast by 1.43 degrees F (0.8 degrees C) (Vose *et al.* 2017, pp. 186–187; Hayhoe *et al.* 2018, p. 86). Annual average precipitation has increased by 4% since 1901 across the entire U.S. including increases over the northeast (Hayhoe *et al.* 2018, p. 88). The frequency and intensity of heavy precipitation events across the U.S. have increased more than the increases in average precipitation (Hayhoe *et al.* 2018, p. 88).

It is widely accepted that climate change is having an impact on reptile conservation (Gibbons *et al*. 2000, p. 660), including freshwater turtles that are especially susceptible to changing conditions (Ihlow *et al*. 2012, p. 1521; Butler 2019, p. 1). In general, turtle species may not be capable of withstanding a rapidly changing climate, due to high juvenile mortality, low dispersal to other populations and long generation times (Butler 2019, p. 11). The NYNHP conducted a vulnerability assessment for multiple species in the state and ranked the bog turtle as "extremely vulnerable" to climate change (Schlesinger *et al.* 2011, p. 9). Extremely vulnerable species are those defined as having abundance and/or range extent within the geographical area assessed as extremely likely to substantially decrease or disappear by 2050 (Schlesinger *et al.* 2011, p. 36). Factors that led to this assessment ranking included low dispersal capabilities, reliance on specific thermal and hydrologic conditions, dependence on disturbance, low genetic variation, and general physiological thermal niche (*e.g.*, for temperature-dependent sex-determination of young) (Schlesinger *et al*. 2011, pp. 3, 53).

Changes in temperatures and precipitation (*e.g*., increase in flooding and/or drought events), have the potential to impact metapopulations; however, we lack a clear understanding of the degree of effects to individuals and populations or what strategies can be used to overcome any effects. See appendix B for more information.

3.10 Conservation Actions

Conservation actions associated with specific threats are discussed above. This section describes additional actions such as laws and regulations or broadscale actions that may reduce multiple threats.

As stated previously, the bog turtle has had Federal protection under the ESA since 1997. The Recovery Plan was finalized in 2001 and a variety of conservation actions have occurred throughout the range since that time.

3.10.1 Competitive State Wildlife Grant Projects

Several broad scale strategies have been implemented throughout the northern population range of the bog turtle to positively affect the recovery of the species using Competitive State Wildlife Grant (C-SWG) funding administered through the Service. This funding has helped develop consistent statewide monitoring of individual populations and habitat, identified and prioritized conservation actions to implement at wetlands, developed a regional database, explored the use of environmental DNA technology to detect bog turtles using water samples, coordinated with landowners to develop management plans and implement habitat restoration projects, implemented predator reduction methods at select wetlands and developed a regional Conservation Plan. Recently awarded C-SWG funds in 2019 will continue to support habitat management, landowner outreach, data input into the regional database, implementation of standardized population and habitat monitoring protocols, survey of potential and historical bog turtle wetlands, perform health assessments, draft best management practices for various activities that may impact bog turtle wetlands, perform a genetic assessment to refine recovery units, and revise the Conservation Plan, as necessary.

Several actions identified in the Conservation Plan (Erb 2019, entire) have been implemented including:

- prioritizing individual populations for conservation actions based on expert opinion and the best available data available – *prioritization of individual populations is complete.*
- identifying and mapping important habitat corridors to improve and/or maintain metapopulation dynamics for extant metapopulations – *mapping corridors is complete*.

- developing and implementing a standardized population and habitat monitoring program to evaluate individual population status and track individual population trends – *monitoring protocols are complete; implementation of protocols is ongoing.*
- developing and populating a standardized regional database to assist with the 5-year review and other regional assessments – *database is complete; data input is ongoing*.
- developing a communication strategy for outreach to landowners to facilitate surveys, population and habitat monitoring, habitat management and land protection – *strategy is complete; implementation is ongoing.*

3.10.2 Habitat Protection

Habitat protection can be in the form of land purchases, conservation easements, and mitigation banking, and be through state, Federal or private holdings. In addition, stewardship programs can increase oversight of management actions on public lands and can be advantageous to maintain or improve habitat on private lands. It is important to note that not all land protection is equal. For example, land trust and agricultural easements rarely maintain a mechanism for specific management actions that are beneficial for bog turtles.

Erb (2019, p. 48) estimates that 102 extant populations in the northern range have full and permanent protection of core habitat and 133 have full and permanent protection of both the core habitat and a 300-ft buffer (table 3.3). Fully protected individual populations are those where all landowner parcels that fall within the core habitat are protected in perpetuity by an easement or purchase by a conservation organization, as well as full or partial protection through an easement or purchase of the 300-ft buffer (as described in Service 2001, p. A2). Partially protected individual populations are those where both the core habitat and buffer are not fully protected by an easement or purchase by a conservation organization in perpetuity or where there is full protection in the core habitat and none in the buffer (Erb 2019, p. 11). Full and permanent protection of core habitat and a 300-ft buffer is critical in supporting habitat that may include essential dispersal, aestivation, and hydrological inputs. When buffers contain intact native vegetation, they are especially important to protect as they help preserve groundwater hydrology, and filter out road salt, sediment, pesticides, and nutrients before they enter the wetland.

Table 3.3. A breakdown of land protection type by state and by recovery unit (per Erb 2019, pp. A10, B11, C9, D11, E12).

	Type of Protection				
State	**Full Permanent Protection[18]: Core Habitat**	**Partial Permanent Protection: Core Habitat**	**Full Permanent Protection: 300-ft. Buffer**	**Partial Permanent Protection: 300-ft. Buffer**	**Partial Temporary Protection[19]**
DE	2	0	0	2	0
CT	1	1	0	4	0
MA	2	0	0	2	0
MD	15	33	4	62	0
NJ	32	32	7	26	0
NY	15	2	8	11	13
PA	35	34	12	62	2
Total	**102**	**102**	**31**	**169**	**15**
Recovery Unit					
Delaware	42	40	11	54	1
Hudson-Housatonic	28	18	9	28	12
Outer Coastal Plain	1	1	1	2	0
Prairie Peninsula-Lake Plain	5	0	3	2	1
Susquehanna-Potomac	26	43	7	83	1
Total	**102**	**102**	**31**	**169**	**15**

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[18] Fully protected populations are those where all landowner parcels that fall within the core habitat are protected in perpetuity by an easement(s) or a land purchase by a conservation organization, as well as full or partial protection through an easement(s) or land purchase of the buffer. Partially protected populations are those where both the core habitat and buffer are not fully protected by an easement(s) or land purchase in perpetuity or where there is full protection in the core habitat and none in the buffer, or the core habitat is fully protected and there is no protection in the buffer

[19] Partial temporary protection is not defined in the Conservation Plan, but it is assumed these refer to agreements or easements where they are time-limited (*e.g.*, the Service's Partners for Fish and Wildlife Program habitat management 10-year agreements or 30-year Wetland Reserve Easements through the Natural Resources Conservation Service.).

3.10.3 Habitat Management and Restoration

Habitat management increases the chance of long-term persistence of the bog turtle by controlling natural succession and the invasion of non-native plants. Without management actions, many of the core habitats will convert to thick shrub land and forest, eliminating important open canopy habitat needed for successful reproduction. Management actions may include restoring the natural flow of water through the wetland and removal of woody and invasive plants through grazing, chemical control, and mechanical methods. Management and restoration projects are undertaken by state, Federal and private entities. Table 3.4 provides a breakdown by state of the number of habitat management projects that have been completed or ongoing.

An example of a Federal entity that cooperates with private landowners on conservation easements is the NRCS, who has contributed significant resources, since 2012 through their Working Lands for Wildlife (WLFW) Initiative, to restore and protect wetland habitat to assist with bog turtle recovery in the northern range (Apodaca 2021). Table 3.5 reflects the number of individual projects, which generally consists of NRCS biologists working with private landowners to secure conservation easements on parcels containing wetlands within an extant bog turtle population, by state and recovery unit (Apodaca 2022). Data for individual easements are not broken down by full or partial protection or permanent versus temporary protection; however, temporary easements can range up to 30 years and many other easements receive permanent protection. The NRCS data presented corresponds with the Service's 2001 Conservation Zones[20] guidance (Service 2001, pp. A1–A3) that is used to encourage the protection and recovery of known bog turtle populations within the northern range. The intent of the conservation suggestions for each zone are to guide the evaluation of activities that may affect high-potential bog turtle habitat, potential travel corridors, and adjacent upland habitat that may serve to buffer bog turtles from potential adverse impacts from development. The NRCS has made protecting as much land as possible within each of these zones a high priority, especially within Zone 1.

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[20] As previously stated and described in the Service's 2001 Conservation Zones guidance (Service 2001, pp. A1–A3), Zone 1 is the entire wetland and not just the core bog turtle habitat. Zone 2 extends 300 feet from the entire wetland edge and Zone 3 includes the area up to a wetland drainage basin boundary or at least a half mile beyond Zone 2.

Table 3.4. A breakdown by state of the number of habitat management projects that have been completed or are ongoing (per Erb 2019, pp. A10, B12, C10, D11, E12).

State	Habitat Management Projects
DE	3
CT	1
MA	2
MD	25
NJ	14
NY	18
PA	64
Total	**127**

Table 3.5. NRCS habitat restoration projects and land protection easements by state and by recovery unit within the bog turtle northern population range (Apodaca 2022). The conservation zones are further described in the Service's Conservation Zones guidance (Service 2001, pp. A1–A3).[21]

Geographic Area	Zone 1	Zone 2	Zone 3
State			
CT	0	0	0
DE	0	0	0
MA	3	1	0
MD	7	5	4
NJ	2	2	2
NY	7	2	2
PA	36	17	10
Total	**55**	**27**	**18**
Recovery Unit			
Delaware	19	13	8
Hudson-Housatonic	10	3	3
Outer Coastal Plain	0	0	0
Prairie Peninsula-Lake Plain	0	0	0
Susquehanna-Potomac	26	11	7
Total	**55**	**27**	**18**

3.10.4 Laws and Regulations

Laws and regulations are vital for the recovery of the bog turtle. Besides the Federal listing of the bog turtle, the Clean Water Act (sections 401 and 404) are likely the most important conservation measures that helped to reduce the decline of this species by regulating the

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[21] The data contained in tables 3.4 and 3.5 may have small discrepancies (*e.g.*, Massachusetts data) that the Service acknowledges and will work to resolve with state agencies and NRCS for the final SSA.

discharge of dredged or fill material into waters of the U.S., including wetlands. Additional protections for bog turtles are afforded under state endangered species laws, state amphibian and reptile laws that regulate the possession, import/export, sale, propagation and release of species, and state wetland laws that regulate direct disturbance to wetlands and their adjacent buffers (see appendix B, table B3). However, even with these laws and any associated regulations, adverse impacts to the species may be permitted. For example, wetlands may be filled. In addition, some activities are challenging to regulate such as development within the upland landscape surrounding a bog turtle wetland, which can negatively impact bog turtle wetlands over time. The following is a list of current state laws and regulations regarding state listed endangered and threatened species, and wetlands and buffers. It is also important to note that many of the states have worked with the Service, the NRCS, and have utilized their own land conservation programs to protect some bog turtle wetlands and adjacent upland buffer in perpetuity.

Federal: Section 404 of the Clean Water Act only provides protection to wetlands from the placement of fill material. In 2020, the U.S. Army Corps of Engineers'(Corps) jurisdiction under section 404 of the Clean Water Act was significantly reduced under the Navigable Waters Protection Rule (85 FR 22250). Wetlands that do not directly abut or have a regular surface connection to a larger, protected water body are no longer regulated. This includes groundwater fed wetlands. Consequently, many bog turtle wetlands may no longer be subject to the Clean Water Act regulation. The Corps is currently reviewing the Navigable Waters Protection Rule in accordance with E.O. 13990 to determine if it conflicts with national objectives.

The bog turtle was given protection in 1973 by the Convention on International Trade in Endangered Species of Wild Flora and Fauna. It is the only global treaty to ensure that international trade in plants and animals does not threaten their survival in the wild. It provides a framework for cooperation and collaboration among nations to prevent decline in wild populations of animals and plants. Because bog turtles are federally listed, they are an Appendix I species, which includes species threatened with extinction and provides the greatest level of protection, including restrictions on commercial trade. If the species was not federally listed, it is likely that it would be covered as an Appendix II species, which includes species that although currently not threatened with extinction, may become so without trade controls. It also includes species that resemble other listed species and need to be regulated in order to effectively control the trade in those other listed species.

Connecticut: Under Connecticut's endangered species regulations, the bog turtle is listed as endangered; however, they rely almost completely on the Federal government to protect federally listed species since there is no habitat protection in their state law. In Connecticut, it is illegal to remove any bog turtle, including eggs, from the wild.

Delaware: This State relies almost completely on the Federal government to protect federally listed species. The only endangered species related regulations are at Delaware Code, Title 7, chapter 6, which states that it is unlawful to transport, import, possess, or sell endangered species or hides, parts or articles made thereof (without a permit). Delaware Division of Fish and Wildlife regulations include similar wording for native herptiles. New Castle County has a Unified Development Code that restricts what developers can do on "Critical Natural Areas." If there are bog turtles (or any state-listed species) confirmed on a proposed project area, their primary habitat cannot be developed. There is no added protection of upland buffers.

Maryland: Under Maryland's endangered species regulations, the bog turtle is listed as threatened. Under the State's Wetland Protection Act, there is a category of listed wetlands that are afforded legal protection. These are called Wetlands of Special State Concern (WSSC), and about two hundred are currently identified. If state or federally listed species are present, a wetland must be designated a WSSC. All WSSC are regulated by Maryland's Department of the Environment and are protected by a 100-ft buffer. However, over six years ago State biologists submitted all bog turtle wetlands to receive WSSC designation (as well as some other wetlands with other species), but no action has been taken with this information. Therefore, many of the Maryland bog turtle wetlands only receive a 25-ft protection zone. Regardless, State biologists have been able to effectively use the conservation zones from the Recovery Plan (Service 2001, pp. A1–A3) in most cases to establish a 300-ft, no-development buffer between bog turtle wetlands and proposed projects. Maryland's Nongame and Endangered Species regulations do not allow "take" of species listed as endangered; however, species listed as threatened may be taken under a special permit (although none have ever been issued). The regulations do provide some protection from take.

Massachusetts: Under the Massachusetts Endangered Species Act (MESA Chapter 131 A), the bog turtle is listed as endangered. Take is prohibited unless a permit has been issued by the Director of Fisheries and Wildlife. MESA offers protection to all state-listed Endangered, Threatened and, Special Concern Species, whether they occur on public or private lands. Wetland buffer zones are defined as 100 ft, and projects proposed within this area must be reviewed. However, this does not mean that work cannot occur, since individual town bylaws vary with regard to the limits of "do not disturb" restrictions within the 100-ft buffer area. A "Species Regulatory Polygon" is used to trigger environmental review under current regulations. Most agricultural practices, including crop production and mowing, are not reviewed by regulatory agencies. Other exemptions that may impact bog turtle habitat also exist.

New Jersey: Under New Jersey's endangered species regulations, the bog turtle is listed as endangered. The State is unique among the northern range states for its State-assumed wetland permitting program and its regulation of floodplains and stormwater. Wetlands are further protected by regional land-use regulations (*e.g.*, Highlands, Pinelands, Coastal Zone), which protect bog turtles not only against most direct habitat losses (*e.g.*, filling, clearing, draining), but also against some of the more immediate and severe aspects of habitat degradation caused by adjacent development.

In 1993, New Jersey assumed the Clean Water Act jurisdiction and regulation of freshwater wetlands in the State, including all wetlands supporting bog turtles. The Freshwater Wetlands Protection Act (N.J.S.A. 13:9B-1 *et seq.*) (FWPA) and its implementing regulations (N.J.A.C. 7:7A) are the basis for State assumption and must therefore be at least as protective as the Federal section 404 program. The FWPA also includes several provisions that are more restrictive than the Clean Water Act. For example, the FWPA regulates essentially all activities in wetlands (*e.g.*, disturbances to soils, vegetation, or the water table), while the Clean Water Act only regulates the placement of fill material. The FWPA also regulates "transition areas" or upland buffers, either 50 or 150 ft wide, while the Clean Water Act provides no regulation of uplands. As a State law, the FWPA retains full jurisdiction over isolated and non-navigable waters and wetlands, while Federal jurisdiction over these areas has been curtailed by recent court decisions. The FWPA requires the larger, 150-ft buffer on wetlands that support federally listed species or state-listed wildlife.

New Jersey Coastal Zone Management rules (covering two bog turtle occurrences) prohibit development of habitat of state-listed plants or wildlife, unless such habitat would not be adversely affected either directly or through secondary impacts. Habitat for listed species is defined to include a sufficient buffer area to ensure continued survival of the population (N.J.A.C. 7:7, E-3.38). The Pinelands Comprehensive Management Plan (covering two bog turtle occurrences) prohibits development unless it is designed to avoid irreversible adverse impacts upon the survival of any local populations of federally or state-listed plant or animal species (N.J.A.C. 7:50–6.27 and 6.33). The Highlands Water Protection and Planning Act (covering at least 27 bog turtle occurrences) requires 300-ft buffers on wetlands and open waters and prohibits major developments unless the proposed activity will not jeopardize the continued existence of or result in the likelihood of the destruction or adverse modification of habitat for, federally or state-listed plant or animal species (N.J.A.C. 7:38–3.11).

New York: The bog turtle is listed as endangered in New York, where wetlands containing threatened and endangered species are ranked as “Class 1” and receive more stringent standards for permits. New York also regulates a 100-ft upland buffer around all wetlands with or without threatened and endangered species. In New York, biologists as well as personnel from the U.S. Army Corps of Engineers and other agencies have been trained on the environmental project review process and assessing potential core habitat.

Regulated activities in New York include filling, including fills for agricultural purposes; draining and altering water levels, except as part of an agricultural activity; removing or breaching beaver dams; clear-cutting trees and other wetland vegetation; grading, dredging, or mining; constructing roads; drilling a water well to serve an individual residence; installing docks, piers, or wharfs; constructing bulkheads, dikes, or dams; constructing a residence or related structures or facilities; constructing commercial or industrial facilities, public buildings, or related structures; installing utility services; and applying pesticides. Unregulated activities include projects that are outside the 100-ft upland buffer and may impact the bog turtle wetland or that might affect connectivity or gene flow between wetlands within a metapopulation.

Pennsylvania: The bog turtle is listed as endangered under the State’s Wild Resources Conservation Act (25 Pa. Code, Chapter 82). In addition, wetlands supporting threatened and endangered species are considered "exceptional value" wetlands under the State’s wetland permitting regulations. As such, there are more stringent requirements to receive a permit for wetlands encroachment. Only encroachments for health and/or safety reasons are considered for permitting. However, no upland buffers around any wetlands are regulated or protected at the State level.

Most agricultural (crop production, tilling) and timber harvest practices are not reviewed under State wetland regulations, unless fill in the wetland is proposed (*e.g.*, for a road crossing) and a permit is sought. Upland activities that do not involve a wetland encroachment, including residential and commercial development, are typically not reviewed or regulated under State wetland laws, although some type of stormwater permit and/or earth disturbance permit may be necessary, in addition to complying with local municipal zoning requirements. A review for endangered and threatened species is only done for these upland activities that go through a permitting process and intersect with a bog turtle habitat suitability model.

Collectively, state regulations currently in effect have likely curtailed habitat degradation somewhat from adjacent development. However, current regulations are not sufficient to halt habitat degradation over the long term at all wetlands, and many bog turtle occurrences continue to be degraded by adjacent development that was constructed prior to more recent and stringent rules. In addition, even the largest (300-ft) upland buffers required by these regulatory programs are not likely to provide sufficient long-term habitat protection in all cases.

If bog turtles were no longer protected under the ESA, it would be up to each state to determine if they still thought the species met their definition of a threatened or endangered species. Without ESA protections, based on the continuation of current state regulations, potential impacts to the three conservation zones identified for bog turtle (Service 2001, pp. A1–A3) may be avoided through state wetland laws. However, impacts to Conservation Zones 2 and 3 may be permitted or go unregulated as not every state within the northern range has laws protecting wetland buffers or upland areas that may contain connecting corridors to other individual populations or contain the hydrology sources for bog turtle wetlands, for example.

3.10.5 Population Management

Population management includes captive rearing, population augmentation, and translocations. It is recognized as a potential conservation tool for recovery of the bog turtle, but most experts agree that this action is a low priority relative to other conservation measures. Partially for this reason, no population management has occurred in the northern population since the time of listing. Because habitat loss/degradation is the key threat to the species, captive management is not the ultimate solution to move bog turtles back into wetlands with poor habitat condition. Monitoring efforts have shown that bog turtles can naturally disperse back into newly restored habitat. However, there may be certain wetlands where core habitat is in excellent condition but lacks bog turtles. For these situations, states may consider population management in the future following the Service's Policy Regarding Controlled Propagation of Species Listed Under the Endangered Species Act (2000, pp. 56916–56922) and their own guidance. In addition, the states drafted a population management decision framework for the Conservation Plan (Erb 2019, pp. 73–78) to guide the decision-making process.

Key Uncertainties/Assumptions

Below are key assumptions and uncertainties that we made related to factors influencing the status of the species:

- the hydrology regime is poorly understood at bog turtle wetlands making it difficult for biologists to know exactly how the core habitat and individuals may be impacted by development over time. Impacts to wetlands are likely not observed for years after a development project is completed.

- we assume that predation within individual populations has increased with an increase in development adjacent to wetlands. Periodically, there are observations of multiple carcasses at an individual population where there is evidence of predation; however, individual populations are not surveyed on an annual basis and thus, predation may go undetected over time.

  the scope and scale of illegal collection of individual bog turtle populations is currently unknown due to the lack of evidence observed in the field and few confiscations made by law enforcement. We assume this threat is high given the significant global demand for turtle species that are rare, have bright coloration, are of small size, and the documented poaching of bog turtles and their congeners, such as spotted and wood turtles.

- the current impact of climate change is unknown as no detailed studies for bog turtle have been completed addressing this threat. Biologists have documented more frequent flooding and drought events, but it is unknown for most individual and metapopulations how they are being impacted. Populations that have experienced significant flooding or droughts have been impacted with temporary or permanent loss of habitat and death of individual turtles.

In summary, bog turtle individual populations and metapopulations are facing many threats. In particular, changes to core habitat characteristics (hydrology and/or vegetation) is impacting a high number of metapopulations across the northern range. There are a variety of sources of this threat (*e.g.*, development, roads, lack of habitat management). The remaining threats have a fair bit of uncertainty in terms of whether population-level effects are occurring. However, the potential high impact of illegal collection across the range cannot be overstated despite the lack of evidence. One poaching event may remove nearly all adults from an individual population and thus, could render that population functionally extinct. Impacts to core habitat is regulated under Federal and primarily state wetland laws; however, not all states have laws that include regulation of upland buffers adjacent to bog turtle wetlands. With these laws, impacts can still occur via permitting processes. In addition, activities in adjacent uplands are often not regulated and may impact core habitat over time.

Chapter 4. Current Condition

In this chapter, we consider the historical distribution, current distribution, and current condition of the bog turtle. We first reviewed the historical and current information on the range and distribution of the species. We then estimate the current condition of bog turtle metapopulations and address uncertainty. Finally, we discuss the condition and resiliency of the bog turtle across its range.

4.1. Historical Distribution and Extirpated Populations

Erb (2019, pp. 3–4) estimated a range reduction of 39% of the northern population within the past 30 years. Figure 4.1 shows the historical/extirpated range of bog turtles in the northern population. Individual populations once occurred in a small portion of western Pennsylvania (Mercer and Crawford Counties) and in Philadelphia County. Within New York, individual, isolated populations were once found in additional counties bordering Lake Ontario (Monroe and Wayne Counties), as well as in central New York (Onondaga, Otsego, and Tompkins Counties) and in eastern New York (Albany, Rensselaer, and Warren Counties). Additional range contractions have occurred in Connecticut (Fairfield County), Delaware (New Castle), and New Jersey (Atlantic, Bergen, Camden, Cape May, Middlesex, and Passaic Counties).

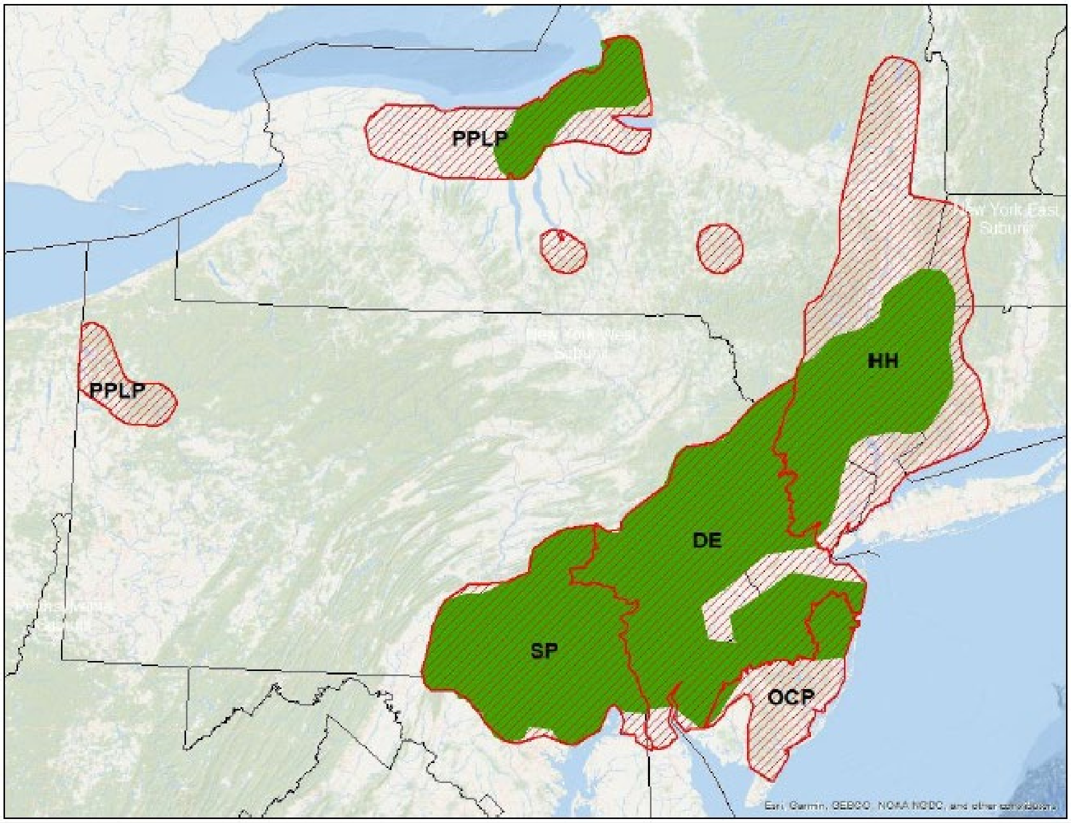

Figure 4.1. The historical (red hatch) and current (green) bog turtle northern population range including the Delaware (DE), Hudson-Housatonic (HH), Outer Coastal Plain (OCP), Prairie Peninsula-Lake Plain (PPLP), and Susquehanna-Potomac (SP) Recovery Units (from Erb 2019, p. 4).

Erb (2019, p. xi) describes historical and extirpated individual populations as follows and table 4.1 provides a breakdown by state and recovery unit:

- a **historical population** is one lacking confirmed observations in the past 30 or more years. However, most state biologists consider these as more likely than not to be extirpated.
- an **extirpated population** is one where a wetland with core habitat present has been altered and no appropriate bog turtle habitat remains at the site.

Forty individual populations are considered extirpated (suitable habitat is no longer present) and 37 are considered historical individual populations in the northern range (bog turtles have not been found in these populations for at least 30 years) (table 4.1). Most extirpations are a result of development that has eliminated core habitat. For example, an individual population in the Prairie Peninsula-Lake Plain Recovery Unit was ditched and drained for muck farming, altering the hydrology and vegetation community of the wetland. The last capture of a bog turtle was in 2000, and with extensive trapping since that time, no individuals have been found. Another bog turtle wetland in the Hudson-Housatonic Recovery Unit was destroyed by the construction of a multilane interstate highway built in the late 1960s to 1970s.

Table 4.1 Historical and extirpated individual populations by state and recovery unit in the bog turtle northern population range.

State	**Historical (Likely Extirpated) Populations**	**Extirpated Populations**
CT	1	9
DE	4	1
MA	0	2
MD	4	10
NJ	2	0
NY	23	10
PA	3	8
Total	**37**	**40**
Recovery Unit		
Delaware	5	6
Hudson-Housatonic	24	18
Outer Coastal Plain	2	0
Prairie Peninsula-Lake Plain	0	3
Susquehanna-Potomac	6	13
Total	**37**	**40**

4.2. Current Distribution

See section 2.4 and figure 4.1 for current distribution of bog turtles in the northern range.

4.3 Current Condition

This section summarizes the analyses that were conducted for current condition; greater detail can be found in appendix A.

4.3.1 Methods

The current condition assessment largely focuses on converting population-level condition metrics originally provided from the Conservation Plan (Erb 2019, pp. 10–12) to metapopulation-level condition metrics and then combining these into a single resiliency score (good, fair, poor) for each bog turtle metapopulation within the five recovery units (Delaware, Hudson-Housatonic, Outer Coastal Plain, Prairie Peninsula-Lake Plain, and Susquehanna-Potomac). We used the definitions of [individual] population and metapopulation from the Conservation Plan as the basis for the analyses (see section 2.7.2 for definitions). The foundation of this assessment uses a combination of field data, observations, and expert judgements to arrive at the current condition of the metapopulations. The data provided by the Conservation Plan reflected the best available knowledge through 2017 and was updated to reflect new information gained from field surveys and observations conducted between 2018 and 2020. The total number of individual populations and metapopulations through 2020 by state and recovery unit is in table 4.2 (table A1 in appendix A) below. As a reminder, for ease of reporting results, we describe the 330 extant populations as “metapopulations” which includes both connected populations, as well as isolated populations (poor scores for connectivity, ideally would be part of a metapopulation). In other words, there are 330 overall populations of bog turtles, 106 of these are metapopulations and 224 of these are single isolated populations.

Table 4.2. The number of individual populations and metapopulations in each recovery unit and state.

Recovery Unit	**State**	**Number of Individual Populations**	**Number of Metapopulations (whether made up of single population or multiple populations)**
Delaware	DE	3	2
Delaware	NJ	95	59
Delaware	PA	130	101
Subtotal		***228***	***162***
Hudson-Housatonic	CT	3	3
Hudson-Housatonic	CT/NY	2	1
Hudson-Housatonic	MA	2	2
Hudson-Housatonic	NJ	62	28
Hudson-Housatonic	NY	55	32
Subtotal		***124***	***66***
Outer Coastal Plain	NJ	3	3
Subtotal		***3***	***3***
Prairie Peninsula-Lake Plain	NY	5	5
Subtotal		***5***	***5***
Susquehanna-Potomac	MD	92	50
Susquehanna-Potomac	PA	56	44
Subtotal		***148***	***94***
Total		***508***	***330***

To determine the resiliency of each bog turtle metapopulation, we worked with species experts to assess demographic needs and habitat needs.

Demographic needs included three condition metrics:

1) sufficient number of adults (population size),
2) sufficient recruitment and age structure (recruitment), and
3) interconnectedness (part of a metapopulation with other populations of large size).

Habitat needs included three condition metrics:

1) suitable soils and associated vegetation for all life stages (lack of succession),
2) suitable soils and associated hydrology for all life stages (hydrology), and
3) intact upland buffer (lack of development).

For each condition metric, we developed qualitative thresholds and then scored individual populations based on available survey data and/or knowledge of each population. We then converted population-level condition metrics into metapopulation-level conditions metrics (see tables A3–A14 for details); table 4.3 [table A2 in appendix A]). See figure A1 in appendix A for the results of this exercise across all recovery units. To see the breakdown by recovery unit, see figures A2–A6.

Table 4.3. The metapopulation condition category (unknown, poor, fair, good) for each demographic and habitat condition metric. Population size and recruitment were categorized as poor or good condition, while interconnectedness, succession, hydrology, and development were categorized as poor, fair, or good condition. Unknown condition categories were used when data were not available, or population-level data were insufficient for rolling up to the metapopulation-level.

	Unknown	**Poor**	**Fair**	**Good**
Demographic Condition Metrics[1]				
Population Size	Unknown	< 30 individuals	NA	≥ 30 individuals
Recruitment	Unknown	No or potential evidence of recruitment[22]	NA	Some evidence of recruitment[23]
Interconnectedness	Unknown	Isolated, single population	Some interconnectedness	Strong interconnectedness
Habitat Condition Metrics[2]				
Succession	Unknown	High level of woody succession	Moderate level of woody succession	Low level of woody succession
Hydrology	Unknown	High disturbance	Moderate disturbance	Low disturbance
Development	Unknown	High development	Some development	No development

[1] Descriptions of each demographic condition metric category are in the sections below (see tables A3, A5, and A7, respectively).

[2] Descriptions of each habitat condition metric category are in the sections below (see tables A9, A11, and A13, respectively).

See appendix A for more details related to the methodology of the analyses.

4.3.2. Resiliency Scores

A total of 119 metapopulations had known conditions for all six metapopulation metrics (no unknowns). Among these metapopulations, the average resiliency score was 0.41 (median=0.36), with slightly higher average resiliency in the Hudson-Housatonic (0.48), Prairie Peninsula-Lake Plain (0.43) Recovery Units, and near average resiliency in Delaware (0.40) and Susquehanna-Potomac (0.38; resiliency could not be calculated for Outer Coastal Plain because there were too many unknowns) Recovery Units. Over half (N=79) of all metapopulations (without unknowns) had resiliency scores less than 0.5, with only 24 metapopulations exceeding a resiliency score of 0.7 (figure 4.2 [figure A7 in appendix A]; table A26).

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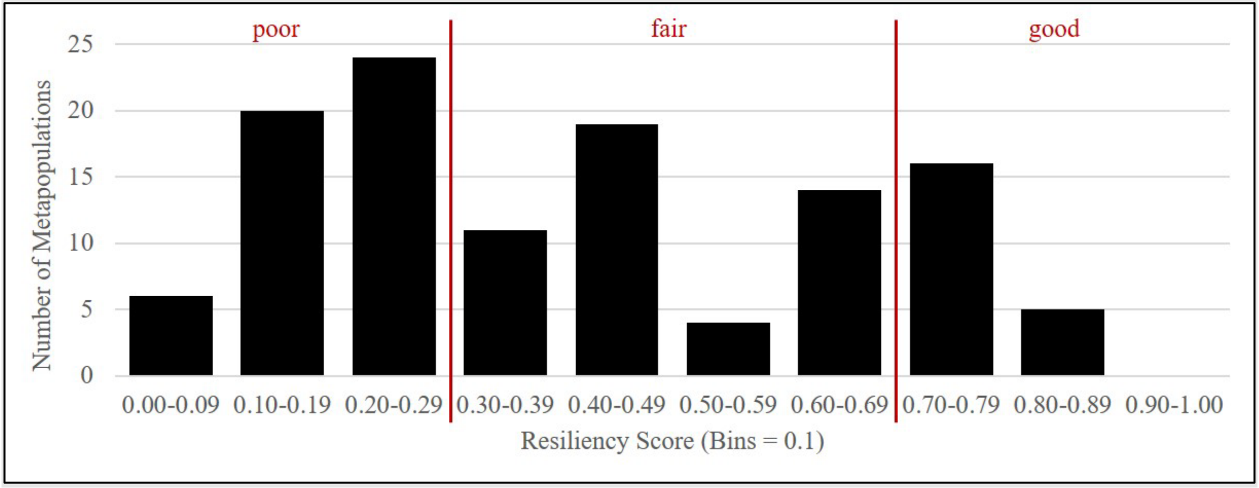
[22] "No or potential evidence of recruitment" means that either there is no recruitment found based on extensive survey efforts or gravid females, eggs, or nests have been observed.

[23] "Some evidence of recruitment" means hatchlings, yearlings, or juveniles, or multiple age classes have been observed.

Figure 4.2. The resiliency scores (range 0.00 to 1.00; bin size=0.1) for each metapopulation (N=119) with known condition for all demographic and habitat metrics (see "Resiliency" tab), for poor (0.0–0.29 scores), fair (0.30–0.69), and good (0.70–1.00) condition.



Due to the large number of unknowns across each metapopulation condition metric (153 had unknown metapopulation size, 138 had unknown recruitment, 17 had unknown interconnectedness, 65 had unknown succession, 53 had unknown hydrology, and nine had unknown development), it was not possible to calculate resiliency scores for a majority of metapopulations (64%; 211 of 330). To evaluate the range in *possible* resiliency scores if unknowns were resolved, we developed two scenarios. The first scenario represented if all unknown conditions were resolved and found to be in "good" condition. The second scenario represented if all unknown conditions were resolved and found to be in "poor" condition. These two scenarios provided a range of plausible resiliency scores for all metapopulations given unknowns are resolved through additional field observations.

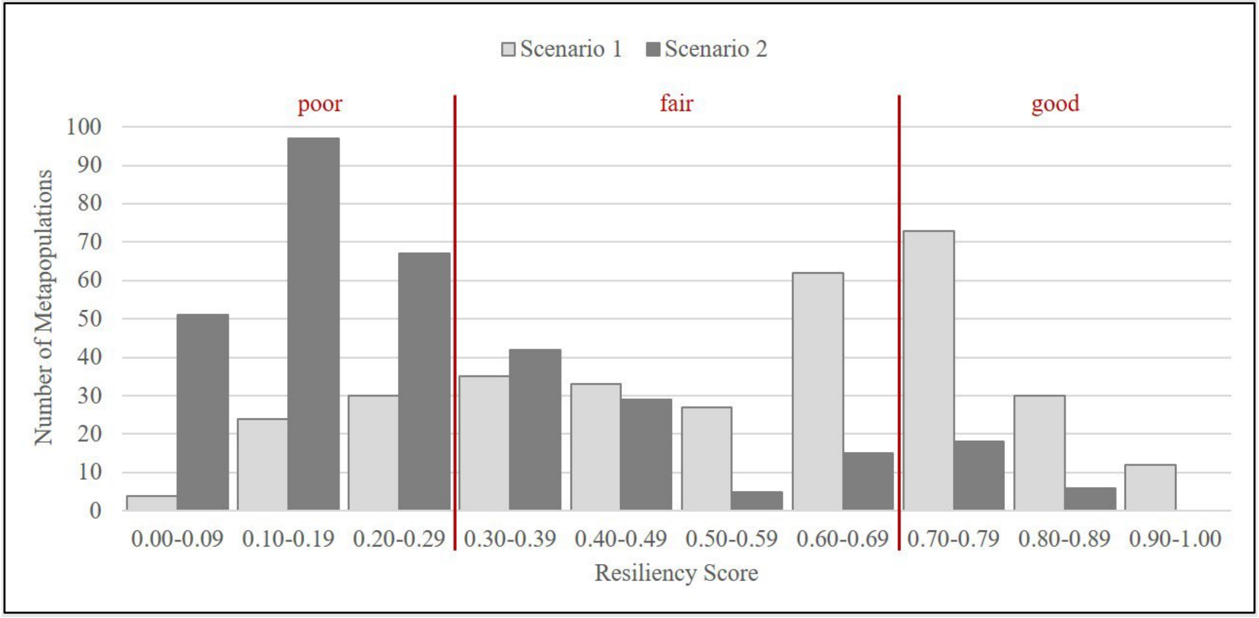
Note that the population size metric and interconnectedness metric are not independent but were treated as independent in the two scenarios when unknown. For example, if a metapopulation had an unknown population size, it was assigned to "good" condition (≥ 30 adults) in the first scenario and assigned "poor" condition (< 30 adults) in the second scenario. If a metapopulation had an unknown interconnectedness, it was assigned as "good" condition (strong interconnectedness in the first scenario) and "poor" condition (single, isolated population) in the second scenario. There may be a few metapopulations in which assigning unknowns to "poor" condition would not change the interconnectedness condition and vice versa, but the combination of each related unknown condition metrics was not explored in this analysis. As expected, the resiliency scores in the first scenario were, on average, larger than those in the second case scenario (0.54 and 0.26, respectively; table 4.4 [table A26 in appendix A]; figure 4.3 [figure A8 in appendix A).

Table 4.4. The number of metapopulations (and percent of total) with each resiliency score[1] (bins of 0.1) for metapopulations with all known condition metrics (known populations), for scenario 1 (all unknowns are hypothesized to be in good condition), and for scenario 2 (all unknowns metrics are hypothesized to be in poor condition). Red=poor condition, yellow=fair condition, and green=good condition.

	Known Metapopulations		**Scenario 1**		**Scenario 2**	
Resiliency Range	N	Percent	N	Percent	N	Percent
0. 00–0. 09	6	5%	4	1%	51	15%
0. 10–0. 19	20	17%	24	7%	97	29%
0. 20–0. 29	24	20%	30	9%	67	20%
0. 30–0. 39	11	9%	35	11%	42	13%
0. 40–0. 49	19	16%	33	10%	29	9%
0. 50–0. 59	4	3%	27	8%	5	2%
0. 60–0. 69	14	12%	62	19%	15	5%
0. 70–0. 79	16	13%	73	22%	18	5%
0. 80–0. 89	5	4%	30	9%	6	2%
0. 90–1. 00	0	0%	12	4%	0	0%
Total	**119**	**100%**	**330**	**100%**	**330**	**100%**

[1] Resiliency scores for scenarios 1 and 2 are provided in the "MetaPopData" section in appendix A with "_scenario1" or "_scenario2" after each corresponding condition metric and summarized on the "Resiliency" section.

Figure 4.3. The resiliency scores (range 0.00 to 1.00; bin size=0.1) for each metapopulation (N=330) under scenario 1 (if unknowns are in fact in "good" condition) and scenario 2 (if unknowns are in fact in "poor" condition; see "Resiliency" section in appendix A).

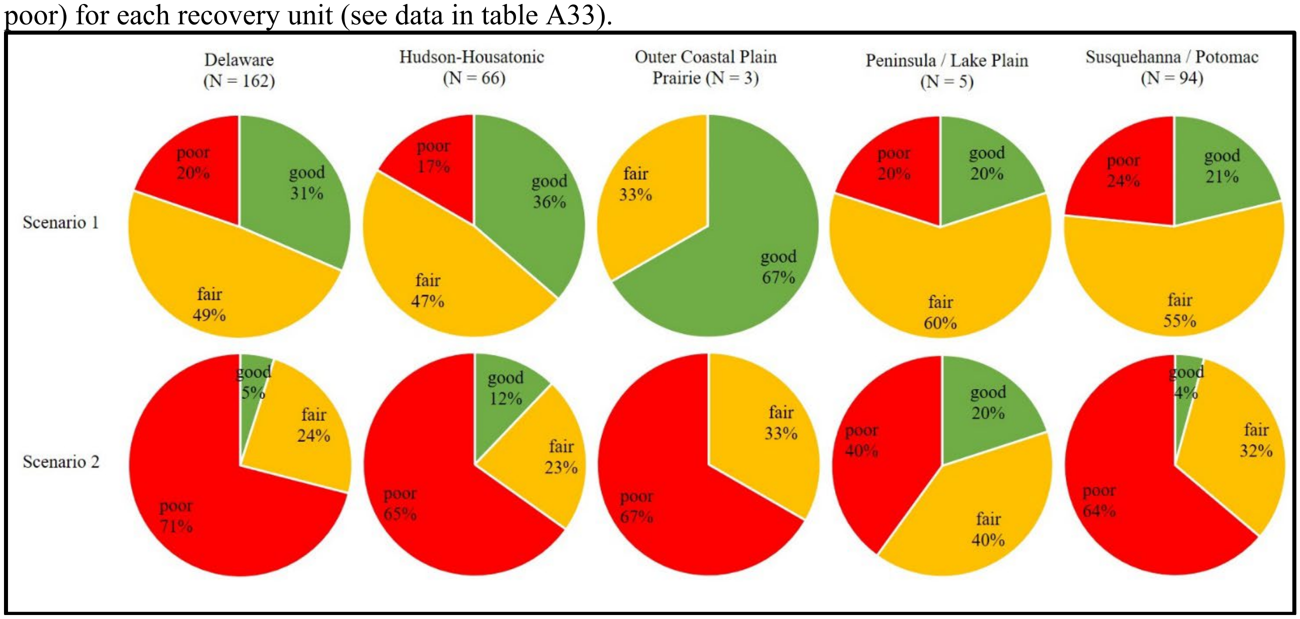


We assigned resiliency categories of "poor," "fair," and "good" to each metapopulation based on the corresponding resiliency score. Resiliency scores less than 0.3 were considered "poor" and represented metapopulations that are lacking many of the conditions needed for persistence (*e.g*., population size, recruitment, and/or hydrology). Resiliency scores between 0.3 and 0.7 were considered "fair" and represented populations lacking many of the conditions needed for persistence (*e.g*., interconnectedness, suitable vegetation, or suitable hydrology). Resiliency scores equal or greater than 0.7 were considered "good" and represented metapopulations that had most of the conditions needed for persistence (but could still have performed poorly in at least three of the less important condition metrics).

Across recovery units, a range of 21–98 metapopulations have good resiliency (6–30%), 87–166 metapopulations have fair resiliency (26–50%), and 66–222 metapopulations have poor resiliency (20–67%; figure 4.4; table A27). Approximately 153 (46%) of metapopulations have resiliency categories that were insensitive to unknowns (the category did not change based on if unknowns were potentially good [scenario 1] or poor [scenario 2]; table A28; table 34). The remaining 78 (54%) of metapopulations have resiliency scores that were sensitive to the potential condition of one or more unknown metrics (table A28; table A35). Accounting for unknown conditions, approximately 6–30% of metapopulations have good resiliency, 26–50% have fair resiliency, and 20–67% have poor resiliency across all recovery units (table A28). Twenty-one (6%) metapopulations have good resiliency regardless of the potential condition of unknown metrics, 65 (20%) had fair resiliency regardless of the potential condition of unknown metrics, and 66 (20%) have "poor" resiliency regardless of the potential condition of unknown metrics (grey boxes in table A28).

See appendix A for results by recovery unit.

Figure 4.4. The proportion of metapopulations in each resiliency category under scenario 1 (unknown condition metrics hypothesized as good) and scenario 2 (unknown condition metrics hypothesized as poor) for each recovery unit (see data in table A33).



Key Uncertainties/Assumptions

Below are key assumptions and uncertainties that we made related to the current condition of the bog turtle:

- the first scenario in determining resiliency scores represented if all unknown condition metrics were resolved and found to be in good condition.

- the second scenario in determining resiliency scores represented if all unknown conditions were resolved and found to be in poor condition.

- the first and second scenarios provided a range of plausible resiliency scores for all metapopulations until unknowns are resolved through additional field surveys.

4.4. Summary

Since the species was listed, progress has been made in finding new bog turtle individual populations (primarily in Pennsylvania) and managing the primary threat of habitat loss or alteration from altered hydrology and/or changes to vegetation (succession and invasive plants). We are now aware of 330 extant bog turtle metapopulations (made up of 508 individual populations; 244 of the metapopulations are single, isolated individual populations) across the range. Thirty-seven additional individual populations are considered historical as bog turtles have not been found in these populations for at least 30 years; however, state biologists consider these as likely to be extirpated. Finally, 40 additional individual populations are considered extirpated (due to suitable habitat no longer being present) across the range.

Bog turtles continue to occur throughout the northern population range with the majority of metapopulations found within the Delaware and Susquehanna-Potomac RUs. However, there was an historical range reduction, primarily in New York. There have been no discernible range reductions since the time of the listing. Instead, there has been an increase in the discovery of extant populations since the Federal listing with 317 individual populations located throughout the northern range. For example, Pennsylvania has seven new individual populations in new WBDHU 12-level watersheds.

Of the known extant metapopulations, 6–30% are considered to have good resiliency and should be able to continue to respond to environmental stochasticity. The remaining metapopulations are considered to have poor to fair resiliency due to their small population size or degradation of habitat and/or isolation. Many of these metapopulations have the potential for higher resiliency in the future if habitat was restored and managed. Overall, we know that 127 habitat management projects have been accomplished within the northern range, but many are at the parcel-level coordinating with individual landowners and not the entire core habitat.

Smaller populations or individual populations with reduced reproductive success due to degraded habitat conditions are at greater risk of extirpation associated with additional development on the landscape, predation, pollution and contaminants, and from flooding and drought events. They are also at greater risk of extirpation associated with collection or disease, although these kinds of catastrophic events could occur at larger sites as well.

Any future loss of metapopulations can reduce overall genetic and ecological diversity of the species, further limiting the species' representation. Small, isolated populations of bog turtles have the potential to retain sufficient genetic diversity; therefore, preservation of these metapopulations may be important to maintaining range-wide genetic diversity (Sirois *et al.* 2014, p. 459).

Due to its specific habitat requirements and limited dispersal capacity and behavior, it is unlikely that bog turtles will frequently be able to move from current fen locations to other wetlands. In addition, it is likely that if they moved to another wetland that it would also be in a degraded condition given the high percentage of wetlands in that situation.

We will assess future condition and overall viability of the bog turtle as part of phase 3 of the SSA.

Table 4.5 summarizes the resiliency at the species-level across the northern range of the bog turtle.

Table 4.5. A summary of bog turtle current condition.

3 Rs	Requisites	Description	Current Condition
Resiliency (*able to withstand stochastic events*)	Healthy populations	Populations with: • sufficient number of adults • presence of males and females • high adult survival • sufficient recruitment and age structure • interconnectedness of habitat (part of metapopulation) • suitable soils and associated vegetation • intact hydrology and ecological processes • intact upland buffer	Rangewide 6–30% of metapopulations have "good" resiliency 26–50% have "fair" resiliency, and 20–67% have "poor" resiliency 37 historical (individual populations) 40 extirpated (individual populations)
Representation (*to maintain evolutionary capacity*)	Maintain adaptive diversity	Healthy populations distributed across areas of unique adaptive diversity (*e.g.*, across latitudinal gradients) with sufficient connectivity for periodic genetic exchange.	Metapopulations occur throughout the range. However, most are in poor to fair condition within each recovery unit (RU). **Delaware RU** 162 metapopulations poor (20–71%) fair (24–49%) good (5–31%) **Hudson-Housatonic RU** 66 metapopulations poor (17–65%) fair (23–47%) good (12–36%) **Outer Coastal Plain RU** 1 metapopulation=fair 2 metapopulations=poor or good (too many unknowns) **Prairie Peninsula-Lake Plain RU** 1 metapopulation=poor 2 metapopulations=fair 1 metapopulation=good 1 metapopulation=poor or fair (too many unknowns) **Susquehanna-Potomac RU** 94 metapopulations

			poor (23–64%) fair (32–55%) good (4–21%)
Redundancy (*to withstand catastrophic events*)	Sufficient distribution of healthy populations	Sufficient distribution to guard against catastrophic events (*e.g.*, novel disease, drought, and floods) significantly compromising species adaptive diversity.	Bog turtles continue to have a large distribution with extant metapopulations known throughout the range and within each RU. However, most are in poor to fair condition. In addition, there was an historical range contraction with most losses at the northern extent of the range (primarily in New York).
	Sufficient number of healthy populations	Adequate number of healthy populations to buffer against catastrophic losses of adaptive diversity.	Most bog turtle metapopulations are in poor to fair condition.

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Appendix A. Current Condition Resiliency Assessment

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A1.1. Acknowledgements

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A1.2. Purpose

This appendix describes the methods and results of an assessment of the current condition of bog turtle metapopulations within the northern range of the species. The assessment largely focuses on converting population-level condition metrics, which were originally provided for the bog turtle Conservation Plan for the northern population (hereafter "Conservation Plan"; Erb 2019, pp. 10–12) to metapopulation-level condition metrics, and then combining these into a single resiliency score (i.e., good, fair, and poor) for each bog turtle metapopulation (N=330) within five recovery units (Delaware, Hudson-Housatonic, Outer Coastal Plain Prairie, Peninsula-Lake Plain, and Susquehanna/Potomac), which span the states of Delaware, Maryland, New Jersey, Pennsylvania, New York, Connecticut, and Massachusetts (table A1). The foundation of this assessment uses a combination of field data, observations, and expert judgements for each population. The assessment includes the following steps:

- Data Quality Control,
- Metapopulation Condition Metrics,
- Normalizing Scores,
- Assigning Relative Importance, and
- Calculating Resiliency.

Table A1. The number of metapopulations and individual populations in each recovery unit and state (completed 2021-03-15).

Recovery Unit	State	Number of individual populations	Number of metapopulations
DE	DE	3	2
DE	NJ	95	59
DE	PA	130	101
Subtotal		228	162
HH	CT	3	3
HH	CT/NY	2	1
HH	MA	2	2
HH	NJ	62	28
HH	NY	55	32
Subtotal		124	66
OCP	NJ	3	3
Subtotal		3	3
PPLP	NY	5	5
Subtotal		5	5
SP	MD	92	50
SP	PA	56	44
Subtotal		148	94
Total		508	330

A1.3. Data Quality Control

To ensure appropriate conversion from individual population conditions metrics provided in the Conservation Plan to metapopulation condition metrics needed for this assessment, data were reviewed for quality control prior to starting the assessment. The Conservation Plan (Erb 2019, pp. 10–12) identified six metrics related to individual population health and resiliency (see Metapopulation Condition Metrics below). Data provided in the Conservation Plan reflected the best available knowledge through 2017 and needed to be revised to reflect new information gained from field surveys and observations conducted from 2018–2020. Data quality issues were first resolved with assistance from L. Erb and then state biologists updated data when new information was available (see appendix1_Data.xlsx, DataQualityControl tab, QC_ChangeLog_RKLE_Dec2020 and QC_ChangeLog_StateBiologist_March2021). Examples of updated data:

- renamed a metapopulation that had two separate names because one individual population was in CT and the other was in NY. The new metapopulation name is CT_Meta_1andNY5815,
- renamed two individual populations that had the same name in NJ (population 001.4 was separated into population 001.4a and population 001.4b),
- re-assigned metapopulation (instead of populations) to each recovery unit because some spanned multiple recovery units,

- re-assigned all blanks as “unknown,” and added an “unknown” category value if it did not already exist for the metric,
- re-assigned metapopulation interconnectedness scores when individual populations in the same metapopulation were assigned different scores because interconnectedness is a metapopulation-level attribute,
- added 14 individual populations (1 in MD, 2 in NY, 9 in PA, and 2 in NJ) because recent (2018 through 2020) field data or observations indicate turtles were present,
- removed 6 individual populations (2 in DE, 1 in MD, 1 in PA, and 2 in NJ) based on the fact that recent (2018 through 2020) field studies (high effort) yielded no turtle captures, remaining turtles will be re-located to another population, or original data were inaccurate (no turtles were ever documented at the wetland). These individual populations were added to the list of historical populations in the regional database, and
- updated population condition for 156 individual populations, recruitment condition for 53 individual populations, interconnectedness condition for 4 individual populations, succession condition for 9 individual populations, hydrology condition for 6 individual populations, and development condition for 0 populations (see Metapopulation Condition Metrics section below for descriptions of each).

A1.4. Metapopulation Condition Metrics

To determine the resiliency of each bog turtle metapopulation, species experts first assessed two categories of condition metrics at the population level: demographic needs and habitat needs. Demographic needs included three condition metrics: 1) sufficient number of adults (population size), 2) sufficient recruitment and age structure (recruitment), and 3) interconnectedness (part of a metapopulation with other populations of large size). Habitat needs included three condition metrics: 1) suitable soils and associated vegetation for all life stages (succession), 3) suitable soils and associated hydrology for all life stages (hydrology), and 3) intact upland buffer (development). For each condition metric, a range of three to six categories were defined, and each population was assigned a category and associated numeric score by experts for individual populations based on available survey data and/or knowledge of each population. See chapters 2 and 4 for additional rationale for the selecting metrics to assessing population and metapopulation resiliency. We rolled population-level condition metrics into metapopulation-level condition metrics using a series of rulesets (see tables A3–A14 for details), which resulted in two potential conditions for population size and recruitment (poor and good condition) and three potential conditions for all other metrics (poor, fair, and good condition; table A2).

Table A2. The metapopulation condition categories (unknown, poor, fair, good) for each demographic and habitat condition metric. Population size and recruitment were categorized as poor or good condition, while interconnectedness, succession, hydrology, and development were categorized as poor, fair, or good condition. Unknown condition categories were used when data were not available, or population-level data were insufficient for rolling up to the metapopulation-level.

	Unknown	**Poor**	**Fair**	**Good**
Demographic Condition Metrics[1]				
Population Size	Unknown	< 30 individuals	NA	≥ 30 individuals
Recruitment	Unknown	No or potential evidence of recruitment	NA	Some evidence of recruitment
Interconnectedness	Unknown	Isolated, single population	Some interconnectedness	Strong interconnectedness
Habitat Condition Metrics[2]				
Succession	Unknown	High level of woody succession	Moderate level of woody succession	Low level of woody succession
Hydrology	Unknown	High disturbance	Moderate disturbance	Low disturbance
Development	Unknown	High development	Some development	No development

[1] Descriptions of each demographic condition metric category are in the sections below (see tables A3, A5, and A7, respectively).
[2] Descriptions of each habitat condition metric category are in the sections below (see tables A9, A11, and A13, respectively).

A1.4.1 Demographic Metrics

A1.4.1.1. Population Size

The population size metric reflected the need to have "sufficient number of adults" present within each metapopulation. Individual populations were categorized based on the number of adult individual bog turtles observed, known, or estimated over the past 30 years. Data were compiled using the Conservation Plan (1990–2018 data; Erb 2019) and revised using any new information collected from 2018–2020. Species experts assigned each individual population to one of five potential categories, with a corresponding score (population scores 1–5; table A3). We then converted population-level scores to metapopulation-level scores using the rule sets below (metapopulation scores 1–3; table A3). When the metapopulation condition was unknown, it was assigned a score of 3 to represent an unknown condition and the higher score (*i.e.*, 3) does not indicate a more preferred condition (see Normalizing Scores section).

Table A3. Population size scores and descriptions at the population- and metapopulation-levels.

Population[1]		Metapopulation[2]	
Score	Description	Score	Description
1	Up to 5 adults (based on ≥ full regional phase 2 survey effort)	1	< 30 adults
2	Unknown (has not been surveyed well)	2	≥ 30 adults
3	6–15 adults	3	Unknown
4	16–29 adults		
5	30 or more adults		

[1] Population scores are located in the "Pop_Size_StateQC" column of the "DataQualityControl" tab.
[2] Metapopulation scores are located in the "Metapop_Size_Score" column of the "MetaPopData" tab.

This rule set was straightforward to apply to metapopulations with a single individual population (population scores of 1, 3, or 4=metapopulation score of 1, population score of 2=metapopulation value of 3, population score of 5=metapopulation score of 2). We applied the following rules when there were multiple populations:

- if at least 1 individual population in the metapopulation had at least 30 adults, the metapopulation had at least 30 adults.
- if the sum of the minimum potential population sizes had at least 30 adults, the metapopulation had 30+ adults, even if there are still individual populations of unknown size.
- if the sum of all maximum potential population sizes was less than 30 adults, the metapopulation had less than 30 adults, but only if all population sizes are known.
- if there were only two individual populations, both with 6–15 adults, the metapopulation has less than 30 adults, despite a small chance of having exactly 15 adults in each individual population (and thus exactly 30 adults).
- if the above metapopulation rules could not apply and there were no individual populations of unknown size, the lowest and highest potential metapopulation sizes were calculated. If the minimum value was less than 30 adults, then the metapopulation had less than 30 adults and minimum value was equal or greater than 30 adults, then the metapopulation had equal or greater than 30 adults. This assumed that all values within the population range were equally likely.
- if a metapopulation contained more than 1 individual population and at least one individual population of unknown size and the above rules could not apply, the metapopulation was scored as having an unknown size.

A total of 136 (41%) metapopulations had less than 30 adults, 41 (13%) metapopulations had equal or greater than 30 adults, and 156 (46%) metapopulations had unknown sizes (table A4; figures A1–A6). Unknown population sizes occurred in NJ (62), PA (46), MD (27), CT (1) and NY (17). Unknown population sizes comprise 48%, 52%, 100%, 0%, and 41% of each recovery unit (DE, HH, OCP, PPLP, SP), respectively.

Table A4. A summary of metapopulation population size condition by recovery unit and state (completed 2021-03-12).

		Metapopulation Size Condition		
Recovery Unit	State	< 30 adults (score of 1)	> 30 adults (score of 2)	Unknown (score of 3)
DE	DE	1	1	0
DE	NJ	12	4	43
DE	PA	58	9	34
Subtotal (N=162)		71	14	77
HH	CT	2	0	1
HH	CT/NY	0	1	0
HH	MA	0	2	0
HH	NJ	9	3	16
HH	NY	10	5	17
Subtotal (N=66)		21	11	34
OCP	NJ	0	0	3
Subtotal (N=3)		0	0	3
PPLP	NY	4	1	0
Subtotal (N=5)		4	1	0
SP	MD	13	10	27
SP	PA	27	5	12
Subtotal (N=94)		40	15	39
Total (N=330)		**136**	**41**	**153**
Percent Total		**41%**	**13%**	**46%**

A1.4.1.2. Recruitment

The recruitment metric reflected the need to have "sufficient recruitment and age structure" present within each metapopulation. Individual populations were categorized based on observations of recruitment over the past 28 years (1990–2018; Erb 2019). Species experts assigned each individual population to one of five potential categories, with a corresponding score (population scores 1–5; table A5). We then converted population-level scores to metapopulation-level scores using the rule sets below (metapopulation scores 1–3; table A5). When the metapopulation condition was unknown, it was assigned a score of 3 to represent an unknown condition and the higher score (*i.e.*, 3) does not indicate a more preferred condition (see Normalizing Scores section).

Table A5. Recruitment scores and descriptions at the population- and metapopulation-levels.

Population[1]		Metapopulation[2]	
Score	Description	Score	Description
1	None (based on ≥ full regional phase 2 survey effort)	1	No or potential evidence of recruitment
2	Unknown (has not been surveyed well)	2	Some evidence of recruitment
3	Gravid female(s), egg(s) or nest(s) observed	3	Unknown
4	Hatchlings, yearlings (1 yr) or juveniles (2–5 yrs) observed		
5	Subadults (6–9 yrs) and/or multiple age classes observed		

[1] Population scores are located in the "Recruitment_StateQC" column of the "DataQualityControl" tab.

[2] Metapopulation scores are located in the "Metapop_Recruitment_Score" column of the "MetaPopData" tab.

This rule set was straightforward to apply when the metapopulation consisted of a single population (population score of 1=metapopulation score of 1, population scores of 3, 4, or 5=metapopulation score of 2, and population score of 2=metapopulation score of 3). We applied the following rules when there were multiple populations:

- if all individual populations have no recruitment (population score of 1), the metapopulation has no recruitment (metapopulation score of 1).
- if all individual populations have unknown recruitment (population score of 2), the metapopulation has unknown recruitment (metapopulation score of 3).
- if at least 1 individual population in the metapopulation has some evidence of recruitment (population score of 4 or 5), the metapopulation has some evidence of recruitment (metapopulation score of 2), despite the number of populations with unknown recruitment status.
- if at least 1 individual population in the metapopulation has unknown recruitment (population score of 2) and all other individual populations have either no recruitment population (score of 1) or only gravid females, eggs, or nests (population score of 3), the metapopulation has unknown recruitment instead of assuming none (metapopulation score of 3).

A total of 54 (16%) metapopulations had no or potential evidence of recruitment, 138 (42%) metapopulations had some evidence of recruitment, and 138 (42%) metapopulations had unknown recruitment status (table A6; figures A1–A6). Metapopulations with unknown recruitment status occur in NJ (59), PA (54), MD (12), and NY (13). Unknown recruitment status composed 49%, 41%, 100%, 20%, and 29% of each recovery unit (DE, HH, OCP, PPLP, SP), respectively.

Table A6. A summary of metapopulation recruitment condition by recovery unit and state (completed 2021-03-12).

		Metapopulation Recruitment Condition		
Recovery Unit	State	No or potential evidence of recruitment (score of 1)	Some evidence of recruitment (score of 2)	Unknown (score of 3)
DE	DE	0	2	0
DE	NJ	1	17	41
DE	PA	24	38	39
Subtotal (N=162)		25	57	80
HH	CT	1	2	0
HH	CT/NY	0	1	0
HH	MA	0	2	0
HH	NJ	3	10	15
HH	NY	4	16	12
Subtotal (N=66)		8	31	27
OCP	NJ	0	0	3
Subtotal (N=3)		0	0	3
PPLP	NY	1	3	1
Subtotal (N=5)		1	3	1
SP	MD	10	28	12
SP	PA	10	19	15
Subtotal (N=94)		20	47	27
Total (N=330)		**54**	**138**	**138**
Percent Total		**16%**	**42%**	**42%**

A1.4.1.3. Interconnectedness

The interconnectedness metric reflected the need to have “interconnectedness (part of a metapopulation)” present within each metapopulation and was represented by the composition and proximity of individual populations within the designated metapopulation (Erb 2019). Species experts assigned each individual population to one of three potential categories, with a corresponding score (population scores 1, 3, and 5; table A7). We then converted population-level scores to metapopulation-level scores using the rule sets below (metapopulation scores 1–4; table A7). When the metapopulation condition was unknown, it was assigned a score of 4 to represent an unknown condition and the higher score (*i.e.*, 4) does not indicate a more preferred condition (see Normalizing Scores section).

Table A7. Interconnectedness scores and descriptions at the population- and metapopulation-levels.

Population[1]		Metapopulation[2]	
Score	Description	Score	Description
1	Isolated population (not part of a metapopulation)	1	Isolated, single population
3	Some (part of a metapopulation with one other small-sized population (15 or fewer individuals))	2	Some interconnectedness (at least 2 individual populations, no large population ≥ 30)
5	Strong (part of a metapopulation with a large population of (>15 individuals) or more than one other small population)	3	Strong interconnectedness (at least 2 individual populations with at least one large population ≥ 30 individuals or multiple small populations)
		4	Unknown

[1] Population scores are located in the "Interconnectedness_StateQC" column of the "DataQualityControl" tab.
[2] Metapopulation scores are located in the "Metapop_Interconnectedness_Score" column of the "MetaPopData" tab.

This rule set was straightforward to apply when the metapopulation consisted of a single population (population score 1=metapopulation score 1). When population sizes were available for all individual populations, population size scores were used along with the number of individual populations in the metapopulation to assign interconnectedness scores. We applied the following rules when there were multiple populations:

- if the metapopulation consists of a single population, the metapopulation is considered isolated (metapopulation score of 1), regardless of population size or unknown population size.
- if the metapopulation consists of multiple individual populations, at least 1 of those populations contains ≥ 30 individuals, then the metapopulation interconnectedness is strong (metapopulation score of 3).
- if the metapopulation consists of multiple individual populations, and no individual population has ≥30 individuals and/or half or more (but not 100%) of the populations have unknown population size, then the metapopulation has some interconnectedness (metapopulation score of 2).
- if the metapopulation consists of multiple individual populations, all (100%) with unknown population sizes, then the metapopulation interconnectedness is unknown (metapopulation score of 4).

A total of 244 (74%) metapopulations were isolated, single populations, 41 (12%) metapopulations had some level of interconnectedness, 28 (9%) metapopulations have strong interconnectedness, and 17 (5%) metapopulations have unknown interconnectedness (table A8; figures A1–A6). Only a few metapopulations had unknown recruitment status, including NJ (6), PA (5), MD (4), and NY (2). Unknown recruitment status composed 6%, 6%, 0%, 0%, and 4% of each recovery unit (DE, HH, OCP, PPLP, SP), respectively.

Table A8. A summary of metapopulation interconnectedness condition by recovery unit and state (completed 2021-03-15).

		Metapopulation Interconnectedness Condition			
Recovery Unit	State	Isolated, single population (score of 1)	Some interconnectedness (score of 2)	Strong interconnectedness (score of 3)	Unknown (score of 4)
DE	DE	1	0	1	0
DE	NJ	43	8	4	4
DE	PA	83	9	4	5
Subtotal (N=162)		127	17	9	9
HH	CT	3	0	0	0
HH	CT/NY	0	0	1	0
HH	MA	2	0	0	0
HH	NJ	20	3	3	2
HH	NY	18	8	4	2
Subtotal (N=66)		43	11	8	4
OCP	NJ	3	0	0	0
Subtotal (N=3)		3	0	0	0
PPLP	NY	5	0	0	0
Subtotal (N=5)		5	0	0	0
SP	MD	28	10	8	4
SP	PA	38	3	3	0
Subtotal (N=94)		66	13	11	4
Total (N=330)		**244**	**41**	**28**	**17**
Percent Total		**74%**	**12%**	**9%**	**5%**

A1.4.2. Habitat Metrics

A1.4.2.1. Succession

The succession metric reflected the need to have “suitable soils and associated vegetation for all life stages” and was represented by the level of succession in each core habitat designated for each metapopulation (Erb 2019). Species experts used site photos and/or GIS analysis to assign each individual population to one of five potential succession categories, with a corresponding score (population scores of 1–5; table A9). We created a sixth population category of “unknown” when experts did not have information to assign a specific succession score (population score 6; table A9). We then converted population-level scores to metapopulation-level scores using the rule sets below (metapopulation scores 1–4; table A9). When the metapopulation condition was unknown, it was assigned a score of 4 to represent an unknown condition and the higher score (*i.e.*, 4) does not indicate a more preferred condition (see Normalizing Scores section).

To convert population to metapopulation-level succession scores, we re-defined categories to represent the succession condition using the following steps. First, each individual population was assigned a midpoint estimate value for each value category to represent the site condition (midpoint estimate; table A9). Second, the mean midpoint estimate for each metapopulation was calculated, ignoring all individual populations with an unknown vegetation state (these were not included in the mean calculation). Then, the mean midpoint estimates were used to create three succession vegetation states: low, moderate, and high. Low woody succession was represented by less than 5% mean coverage, moderate woody succession was represented by 6%–49% mean coverage, and high woody succession was represented by greater than 50% mean coverage (metapopulation scores 1–3; table A9).

Table A9. Succession scores and descriptions at the population- and metapopulation-levels.

Population[1]			Metapopulation[2]	
Score	Description	Midpoint Estimate	Score	Description
1	≥41 cover (41–60% coverage OR >60% coverage)	70%	1	High level of woody succession (mean coverage ≥ 50%)
2	26–40% coverage and unknown	33%	2	Moderate level of woody succession (mean coverage 6%–49 %)
3	11–25% coverage	18%	3	Low level of woody succession (mean coverage ≤ 5%)
4	<10% coverage	5%	4	Unknown
5	0% coverage	0%		
6[3]	Unknown	NA		

[1] Population scores are located in the "Succession_StateQC" column and midpoint estimates are located in the "Succession_Midpoint" of the "DataQualityControl" tab.
[2] Metapopulation scores are located in the "Metapop_Succession_Score" column of the "MetaPopData" tab.
[3] Population score of 6 was added to reflect populations with unknown woody vegetation states.

This rule set was straightforward to apply when the metapopulation consisted of a single population (population score of 1=metapopulation score of 1, population score of 2 or 3=metapopulation score of 2, population score of 4 or 5=metapopulation score of 3, population score of 6=metapopulation score of 4). We could not determine if population scores of 2 reflected 26–40% coverage or reflected unknown coverage, as both conditions received a score of 2 in the Conservation Plan (Erb 2019). For this assessment, we assumed all population scores of 2 indicated 26–40% cover. We applied the following rules when there were multiple populations:

- if at least half of the individual populations within the metapopulation have unknown succession values (population score of 6), the metapopulation has an unknown succession value (metapopulation value of 4).
- if at least half of the individual populations within the metapopulation have a known succession (population scores 1, 2, 3, 4, or 5) and less than half of the populations have unknown succession (population score of 6), then the metapopulation succession score was assigned based on the metapopulation mean point estimate of the known populations.

A total of 49 (15%) metapopulations had high levels of woody succession, 152 (46%) metapopulations had moderate levels of woody succession, 64 (19%) metapopulations had low levels of woody succession, and 65 (20%) metapopulations had unknown levels of woody succession (table A10; figures A1–A6). Metapopulations with unknown woody succession status occurred in NJ (39), PA (16), and NY (10). Unknown woody succession status composed 26%, 26%, 33%, 20%, and 4% of each recovery unit (DE, HH, OCP, PPLP, SP), respectively.

Table A10. A summary of metapopulation succession condition by recovery unit and state (completed 2021-03-15).

		Metapopulation Succession Condition			
Recovery Unit	State	High woody succession (score of 1)	Moderate woody succession (score of 2)	Low woody succession (score of 3)	Unknown (score of 4)
DE	DE	0	1	1	0
DE	NJ	4	21	4	30
DE	PA	14	54	21	12
Subtotal (N=162)		18	76	26	42
HH	CT	0	3	0	0
HH	CT/NY	0	1	0	0
HH	MA	0	2	0	0
HH	NJ	1	15	4	8
HH	NY	1	13	9	9
Subtotal (N=66)		2	34	13	17
OCP	NJ	1	0	1	1
Subtotal (N=3)		1	0	1	1
PPLP	NY	0	0	4	1
Subtotal (N=5)		0	0	4	1
SP	MD	25	23	2	0
SP	PA	3	19	18	4
Subtotal (N=94)		28	42	20	4
Total (N=330)		**49**	**152**	**64**	**65**
Percent Total		**15%**	**46%**	**19%**	**20%**

A1.4.2.2. Hydrology

The hydrology metric reflected the need to have "suitable soils and associated hydrology for all life stages" and was represented by the level of hydrologic disturbance in each core habitat (*e.g.*, beaver activity, ditching, fill material, pipeline, roads/culverts, man-made ponding, and multiple disturbance types; Erb 2019). Species experts assigned each individual population to one of five potential categories, with a corresponding score (population scores 1–5; table A11). We created a sixth population category of "unknown" when experts did not assign a specific hydrology score (population score 6; table A11). We then converted population-level scores to metapopulation-level scores using the rule sets below. When the metapopulation condition was unknown, it was assigned a score of 4 to represent an unknown condition and the higher score (*i.e.*, 4) does not indicate a more preferred condition (see table A16 and Normalizing Scores section).

We redefined metapopulation categories to represent the average hydrologic conditions when there are multiple populations in a metapopulation. Each population score was assumed to be ranked in order of preference from worst (score of 1: full disturbance) to best (score of 5: none), and a mean score across individual populations was considered representative of the metapopulation hydrologic condition, while ignoring individual populations with unknown hydrology scores (score of 6). High disturbance was represented by mean score equal or less than 2, moderate disturbance was represented by mean scores greater than 2 but less than 5, and low disturbance was represented by mean scores equal to 5 (no disturbance at any metapopulation; metapopulation scores 1–3; table A11).

Table A11. Hydrology scores and descriptions at the population- and metapopulation-levels.

Population[1]		Metapopulation[2]	
Score	Description	Score	Description
1	Full disturbance (throughout most of the site)	1	High disturbance (mean ≤ 2)
2	Partial disturbance including ditching, fill material, multiple types	2	Moderate disturbance (mean 3-5)
3	Partial disturbance including man-made ponding, roads/culverts, other	3	Low disturbance (mean=5)
4	Partial disturbance including beaver activity, pipeline, sedimentation	4	Unknown
5	None		
6[3]	Unknown		

[1] Population scores are located in the “Hydrology_StateQC” of the “DataQualityControl” tab.

[2] Metapopulation scores are located in the “Metapop_Hydrology_Score” column of the “MetaPopData” tab.

[3] Population score of 6 was added to reflect populations with unknown succession.

This rule set was straightforward to apply when the metapopulation consisted of a single population (population score 1 or 2=metapopulation score 1; population score 3 or 4=metapopulation score 2, population score 5=metapopulation score 3, population score of 6=metapopulation score of 4). We applied the following rules when there were multiple individual populations with some populations having unknown hydrology states, including:

- if less than half of the individual populations in the metapopulation have unknown hydrology values (population score of 6), then the metapopulation hydrology value is based on the mean hydrology value of the remaining individual populations.
- if half or more of the individual populations in the metapopulation have unknown hydrology values (population score of 6), the metapopulation has an unknown hydrology value (metapopulation score of 4).

A total of 118 (36%) metapopulations had high hydrologic disturbance, 113 (34%) metapopulations had moderate hydrologic disturbance, 46 (14%) metapopulations had low hydrologic disturbance, and 53 (16%) metapopulations had unknown levels of hydrologic disturbance table A12; figures A1–A6). Metapopulations with unknown hydrologic disturbance status occurred in PA (44), NY (7), and NJ (2) and unknown hydrologic status composed 20%, 12% 0%, 0%, and 14% of each recovery unit (DE, HH, OCP, PPLP, SP), respectively.

Table A12. A summary of metapopulation hydrology condition by recovery unit and state (completed 2021-03-15).

		Metapopulation Hydrology Condition			
Recovery Unit	State	High disturbance (score of 1)	Moderate disturbance (score of 2)	Low disturbance (score of 3)	Unknown (score of 4)
DE	DE	0	1	1	0
DE	NJ	23	26	9	1
DE	PA	27	27	16	31
Subtotal (N=162)		50	54	26	32
HH	CT	2	1	0	0
HH	CT/NY	1	0	0	0
HH	MA	1	0	1	0
HH	NJ	9	11	7	1
HH	NY	14	11	0	7
Subtotal (N=66)		27	23	8	8
OCP	NJ	1	0	2	0
Subtotal (N=3)		1	0	2	0
PPLP	NY	1	3	1	0
Subtotal (N=5)		1	3	1	0
SP	MD	25	23	2	0
SP	PA	14	10	7	13
Subtotal (N=94)		39	33	9	13
Total (N=330)		**118**	**113**	**46**	**53**
Percent Total		**36%**	**34%**	**14%**	**16%**

A1.4.2.3. Development

The development metric reflected the need to have an "intact upland buffer" and was represented by development pressure within 91 meters (300 feet) of an individual population, which aligns with the "Zone 2" (Erb 2019). A GIS exercise was used to initially score each individual population in terms of three potential categories (population scores 1–3; table A13; L. Erb, *pers. comm*.). Next, species experts validated or corrected development scores from the GIS exercise. We created a fourth population category of "unknown" when the GIS exercise or experts could not provide a specific development score (population score 4; table A13), which could be updated with additional GIS effort. We then converted population-level scores to metapopulation-level scores using the rule sets below (metapopulation scores 1–3; table A13). When the metapopulation condition was unknown, it was assigned a score of 4 to represent an unknown condition and the higher score (*i.e.*, 4) does not indicate a more preferred condition (see Normalizing Values section).

Table A13. Development scores and descriptions at the population- and metapopulation-levels.

Population		Metapopulation	
Score	Description	Score	Description
1	In both 300-foot buffer and core habitat, and in wetland only (all development types)	1	High development (in buffer and core)
2	In 300-foot buffer (roads, residential, agricultural, and multiple types) (assumes none in core)	2	Some development (in buffer, none in core)
3	None OR Zone 2 – manicured lawns or barns (assumes none in core)	3	No development (in buffer and core)
4[3]	Unknown	4[3]	Unknown

[1] Population scores are located in the "Development_StateQC" of the "DataQualityControl" tab.
[2] Metapopulation scores are located in the "Metapop_Development_Score" column of the "MetaPopData" tab.
[3] Population and metapopulation score of 4 was added to reflect unknown development.

This rule set was straightforward to apply when the metapopulation consisted of a single population (population score of 1=metapopulation score of 1, population score of 2=metapopulation score of 2, population score of 3=metapopulation score of 3, and population score of 4=metapopulation score of 4). We applied the following rules when there were multiple individual populations with diverse levels of development, including:

- if at least 1 individual population within the metapopulation had development within the buffer and core (population score of 1), then the metapopulation has high development (metapopulation score of 1).
- if all individual populations within the metapopulation had no development within the buffer and/or core (population score of 3), then the metapopulation has no development (metapopulation score 3).
- if at least one individual population with the metapopulation had some development in the buffer (population score of 2), but the remaining individual populations had no development in the buffer and/or core (population score of 3), the metapopulation had some development in buffer (metapopulation score of 2).
- if at least half of the individual populations with the metapopulation had unknown development (population score of 4), the metapopulation had unknown development score (population score of 4).

A total of 115 (35%) metapopulations had high development (in buffer and core), 190 (57%) metapopulations had some development (in buffer, none in core), 16 (5%) metapopulations had no development in core and buffer, and 9 (3%) metapopulations had unknown levels of development (table A14; figures A1–A6). Metapopulations with unknown development status occurred in PA (8) and NJ (1), and unknown development status composed 4%, 0%, 33%, 0%, and 1% of each recovery unit (DE, HH, OCP, PPLP, SP), respectively.

Table A14. A summary of metapopulation development condition recovery unit and state (completed 2021-03-15).

		Metapopulation Development Condition			
Recovery Unit	State	High development (score of 1)	Some development (score of 2)	No development (score of 3)	Unknown (score of 4)
DE	DE	0	1	1	0
DE	NJ	26	33	0	0
DE	PA	16	72	6	7
Subtotal (N=162)		42	106	7	7
HH	CT	0	3	0	0
HH	CT/NY	0	1	0	0
HH	MA	0	2	0	0
HH	NJ	14	12	2	0
HH	NY	26	4	2	0
Subtotal (N=66)		40	22	4	0
OCP	NJ	1	0	1	1
Subtotal (N=3)		1	0	1	1
PPLP	NY	3	2	0	0
Subtotal (N=5)		3	2	0	0
SP	MD	20	29	1	0
SP	PA	9	31	3	1
Subtotal (N=94)		29	60	4	1
Total (N=330)		**115**	**190**	**16**	**9**
Percent Total		**35%**	**57%**	**5%**	**3%**

A1.4.3. Missing Data

Based on the available data, 119 (36%) metapopulations had a score for each metapopulation metric (complete data set=3 habitat metrics and 3 demographic metrics). A total of 211 (64%) metapopulations were missing at least 1 metapopulation-level metric (represented as unknown score). Most metapopulations with an incomplete data set were missing either 1 or 2 metrics (73 and 72 metapopulations, respectively), fewer were lacking 3 metrics (52 metapopulations), and only 14 were lacking data for 4 or more metrics (8, 6, and 0 metapopulations, respectively; table A15). Metapopulations lacking 3 or more metrics primarily occurred in PA (89), NJ (71), MD (27) and NY (23) (table A16).

Table A15. The number of metapopulations with "unknown" condition for 1, 2, 3, 4, 5, or all 6 condition metrics by state (completed 2021-03-17).[1]

	Number of metapopulations								
Number of unknown condition metrics	CT	CT/NY	DE	MA	MD	NJ	NY	PA	**Total**
0 (all metrics are known)	2	1	2	2	23	19	14	56	**119**
1	1	0	0	0	13	11	6	42	**73**
2	0	0	0	0	12	27	9	24	**72**
3	0	0	0	0	2	29	7	14	**52**
4	0	0	0	0	0	3	1	4	**8**
5	0	0	0	0	0	1	0	5	**6**
6 (all metrics are unknown)	0	0	0	0	0	0	0	0	**0**
Total	**3**	**1**	**2**	**2**	**50**	**90**	**37**	**145**	**330**

[1] Values are summarized in the "MissingDataSummary" tab.

Table A16. Metapopulations lacking three or more metapopulation-level condition metrics by recovery unit (RU) and state, with an X indicating the metric state is unknown (completed 2021-03-17).[1]

RU	State	Meta-population	Population Size	Recruitment	Inter-connectedness	Succession	Hydrology	Development
DE	NJ	016	X	X		X		
DE	NJ	017	X	X		X		
DE	NJ	019	X	X		X		
DE	NJ	022	X	X	X	X		
DE	NJ	039	X	X		X		
DE	NJ	042	X	X		X		
DE	NJ	043	X	X		X		
DE	NJ	044	X	X		X		
DE	NJ	066	X	X		X		
DE	NJ	068	X	X		X		
DE	NJ	087	X	X		X		
DE	NJ	093	X	X		X		
DE	NJ	105	X	X		X		
DE	NJ	109	X	X		X		
DE	NJ	139	X	X		X		
DE	NJ	150	X	X	X	X		
DE	NJ	152	X	X		X		
DE	NJ	154	X	X		X		
DE	NJ	155	X	X		X		
DE	NJ	156	X	X		X		
DE	NJ	162	X	X	X			
DE	NJ	163	X	X	X	X	X	
DE	NJ	167	X	X		X		
DE	NJ	169	X	X		X		
DE	PA	PA-10066	X	X		X	X	X
DE	PA	PA-10354	X	X			X	

DE	PA	PA-10458	X	X	X			X
DE	PA	PA-10727	X	X			X	
DE	PA	PA-10800	X	X		X		X
DE	PA	PA-1143	X	X			X	
DE	PA	PA-11928	X	X		X		
DE	PA	PA-14817	X	X			X	
DE	PA	PA-14821	X	X	X			
DE	PA	PA-15045	0	X		X	X	
DE	PA	PA-17336	X	X			X	
DE	PA	PA-22742	X	X		X	X	
DE	PA	PA-23253	X	X			X	
DE	PA	PA-23411	X	X	X		X	
DE	PA	PA-25603	X	X		X	X	X
DE	PA	PA-2588	X	X		X	X	X
DE	PA	PA-4671	X	X		X	X	X
DE	PA	PA-4879	X	X	X			
DE	PA	PA-919	X		X		X	
HH	NJ	006	X	X		X	X	
HH	NJ	010	X	X		X		
HH	NJ	027	X	X		X		
HH	NJ	056	X	X		X		
HH	NJ	078	X	X		X		
HH	NJ	099	X	X	X			
HH	NJ	122	X	X	X			
HH	NY	NY10977	X	X		X		
HH	NY	NY11364	X		X		X	
HH	NY	NY11469	X	X		X		
HH	NY	NY11471	X			X	X	
HH	NY	NY11475	X	X			X	
HH	NY	NY11563	X	X		X	0	

HH	NY	NY12068	X	X	X		X	
HH	NY	NY5092	X	X		X		
OCP	NJ	018	X	X		X		
OCP	NJ	172	X	X				X
SP	MD	MD-27	X	X	X			
SP	MD	MD-81	X	X	X			
SP	PA	PA-13459	X	X		X	X	X
SP	PA	PA-19706	X	X			X	
SP	PA	PA-24475	X	X			X	
SP	PA	PA-6853	X	X			X	

[1] Values are summarized from the “Number of missing metrics” column (representing unknowns) of the “MetaPopData” tab.

Figure A1. The proportion of metapopulations (N=330) assigned to each condition metric (demographic metrics: population size, recruitment, interconnectedness, habitat metrics: succession, hydrology, and development) across all recovery units. Red represents the poor condition, yellow represents the moderate condition (if applicable), green represents the good condition, and grey represents unknown condition. Definitions for each condition can be found in the Metapopulation Condition Metrics section. This graphic was created from pivot tables in the "ConditionMetricSummary" tab, using the "MetaPopData" tab data.

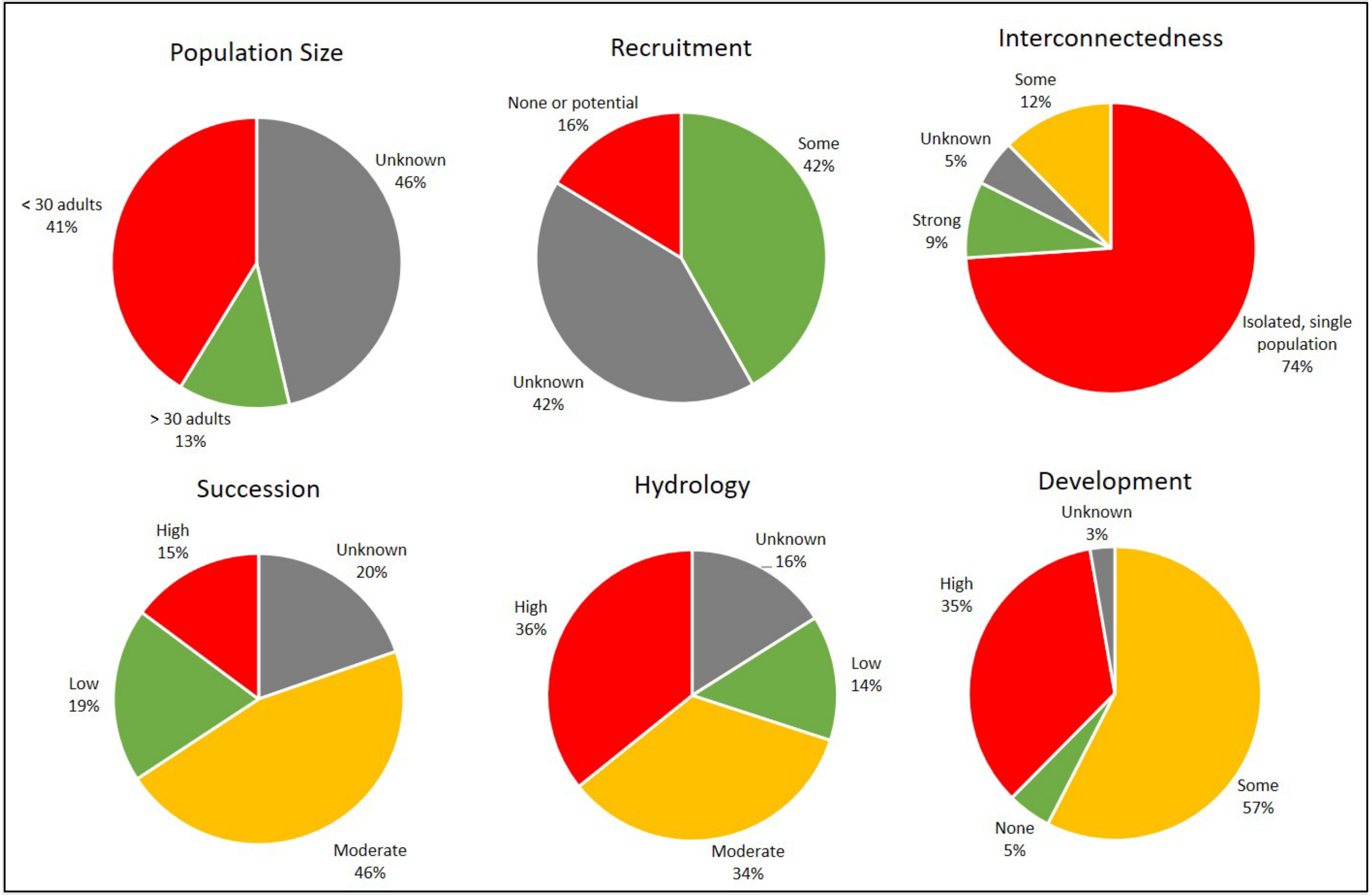


Figure A2. The proportion of metapopulations (N=162) assigned to each condition metric (population size, recruitment, interconnectedness, succession, hydrology, and development) across the Delaware Recovery Unit. Red represents the poor condition, yellow represents the moderate condition (if applicable), green represents the good condition, and grey represents unknown condition. Definitions for each metric can be found in the Metapopulation Condition Metrics section. This graphic was created from pivot tables in the “ConditionMetricSummary_DE” tab, using the “MetaPopData” tab data.

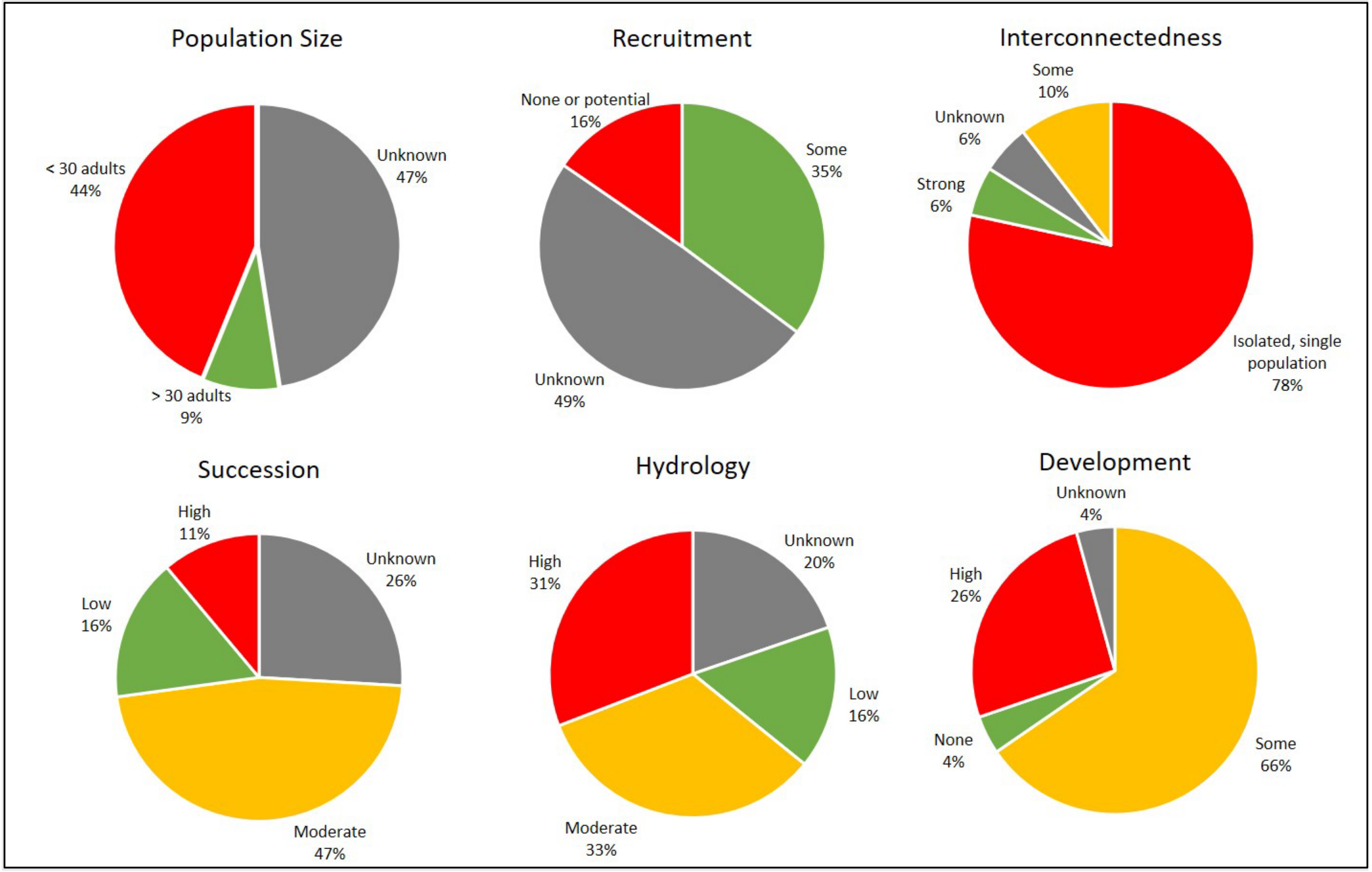


Figure A3. The proportion of metapopulations (N=66) assigned to each condition metric (population size, recruitment, interconnectedness, succession, hydrology, and development) across the Hudson-Housatonic Recovery Unit. Red represents the poor condition, yellow represents the moderate condition (if applicable), green represents the good condition, and grey represents unknown condition. Definitions for each metric can be found in the Metapopulation Condition Metrics section. This graphic was created from pivot tables in the "ConditionMetricSummary_HH" tab, using the "MetaPopData" tab data.

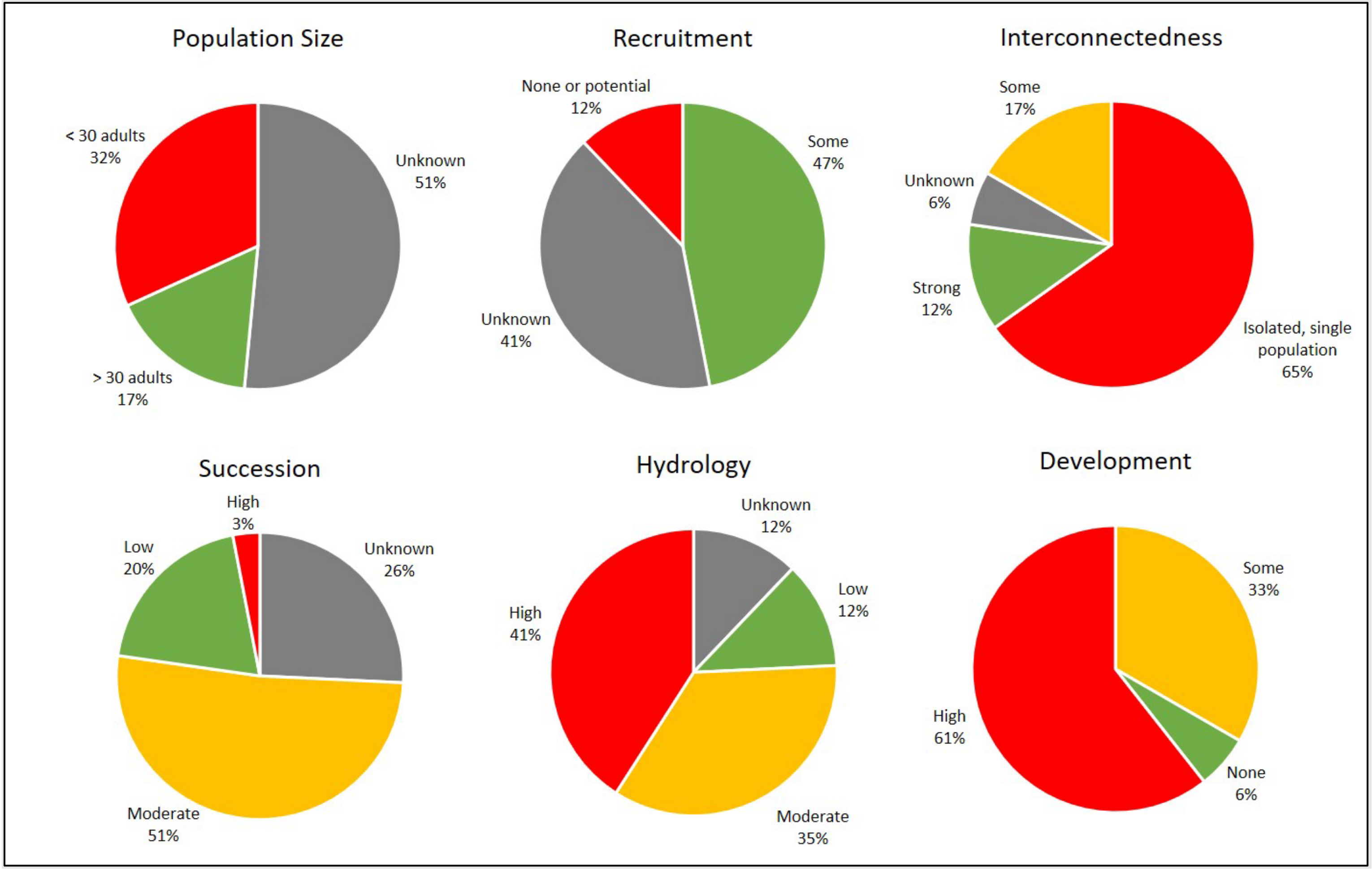
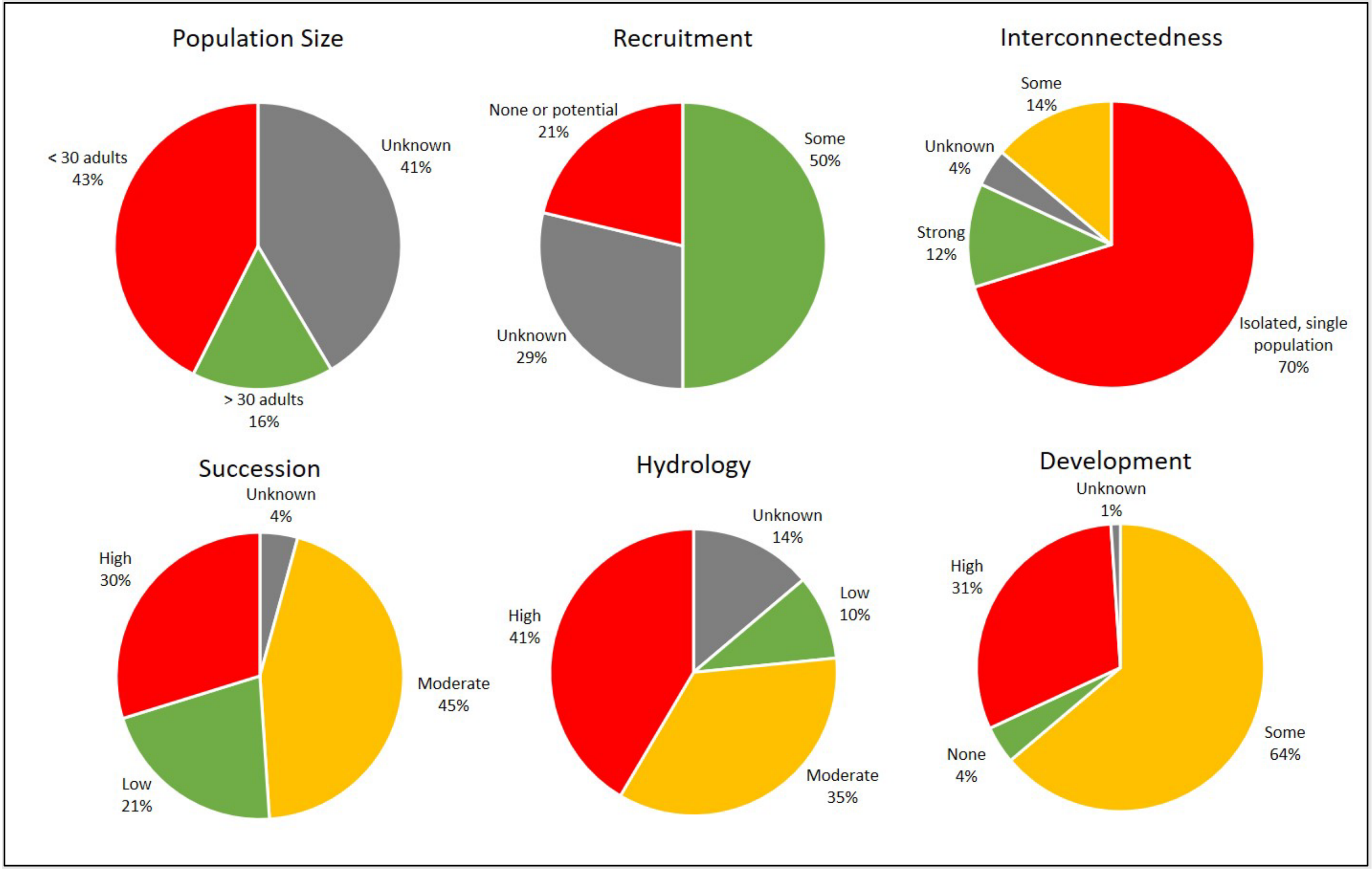


Figure A4. The proportion of metapopulations (N=3) assigned to each condition metric (population size, recruitment, interconnectedness, succession, hydrology, and development) across the Outer Coastal Plain Recovery Unit. Red represents the poor condition, yellow represents the moderate condition (if applicable), green represents the good condition, and grey represents unknown condition. Definitions for each metric can be found in the Metapopulation Condition Metrics section. This graphic was created from pivot tables in the "ConditionMetricSummary_OCP" tab, using the "MetaPopData" tab data.

Figure A5. The proportion of metapopulations (N=5) assigned to each condition metric (population size, recruitment, interconnectedness, succession, hydrology, and development) across the Prairie Peninsula-Lake Plain Recovery Unit. Red represents the poor condition, yellow represents the moderate condition (if applicable), green represents the good condition, and grey represents unknown condition. Definitions for each metric can be found in the Metapopulation Condition Metrics section. This graphic was created from pivot tables in the "ConditionMetricSummary_PPLP" tab, using the "MetaPopData" tab data.

Figure A6. The proportion of metapopulations (N=94) assigned to each condition metric (population size, recruitment, interconnectedness, succession, hydrology, and development) across the Susquehanna/Potomac Recovery Unit. Red represents the poor condition, yellow represents the moderate condition (if applicable), green represents the good condition, and grey represents unknown condition. Definitions for each metric can be found in the Metapopulation Condition Metrics section. This graphic was created from pivot tables in the "ConditionMetricSummary_SP" tab, using the "MetaPopData" tab data.



A1.5. Normalizing Scores

Scores for each metapopulation metric were normalized before each could be weighted by its relative importance and combined into a single resiliency score. Normalizing scores included re-scaling each metapopulation metric to the same scale (0 to 1). Normalized reflected the least preferred condition (0=fair condition) and the most preferred condition (1=good condition), and when applicable the moderately preferred condition (0.5=fair condition). Two metapopulation metrics included only good and poor conditions, which rescaled to 0 and 1, respectively (table A17). Four metapopulation metrics included good, fair, and poor conditions, which were rescaled to 0.0, 0.50, and 1.0, respectively (table A17). Unknowns were not included in the normalizing process, but instead were assigned either as good or poor condition during the Sensitivity Analysis to explore the influence of resolving unknowns on the assessment of resiliency for each metapopulation.

Table A17. The normalized metapopulation value used for each metapopulation condition metric value, with the metapopulation definition. A value of 1.0 indicates the good condition, while a value of 0.0 indicates the poor condition, and a value of 0.5 indicates a fair condition.

Metapopulation Condition Metric	Metapopulation Score	Metapopulation Definition[1]	Normalized Metapopulation Score[2]
Demographic Condition Metrics			
Population Size	1	≥ 30 adults	0.0
	2	< 30 adults	1.0
	3	Unknown	-
Recruitment	1	No or potential evidence of recruitment	0.0
	2	Some evidence of recruitment	1.0
	3	Unknown	-
Interconnectedness	1	Isolated, single population	0.0
	2	Some interconnectedness	0.5
	3	Strong interconnectedness	1.0
	4	Unknown	-
Habitat Condition Metrics			
Succession	1	High level of woody succession	0.0
	2	Moderate level of woody succession	0.5
	3	Low level of woody succession	1.0
	4	Unknown	-
Hydrology	1	High disturbance	0.0
	2	Moderate disturbance	0.5
	3	Low disturbance	1.0
	4	Unknown	-
Development	1	High development	0.0
	2	Some development	0.5
	3	No development	1.0
	4	Unknown	-

[1] Metapopulation definition details can be found in the Metapopulation Condition Metrics section.

[2] Normalized metapopulation values are provided in the “MetaPopData” tab with “_Normalizedvalue” after each corresponding condition metric.

A1.6. Assigning Relative Importance

A relative importance weighting method was used to combine metapopulation metrics into a single resiliency score for each metapopulation. A total of six persons (*e.g.*, state biologists) provided expert judgements regarding the relative importance of each metric to overall resiliency. First, experts collectively agreed that demographic metrics were more important than habitat metrics and allocated 60% of the overall weight (out of 100%) to demographic metrics and then the remaining 40% to habitat metrics. Next, each expert was instructed to use a total of 100 points and allocated a proportion of those points across the three demographic metrics and across habitat metrics to indicate their relative importance in relation to each other (table A18). Note that 1) the word "reproduction" in the original relative importance weighting tables was replaced with the word "recruitment" to match the revised metric names, 2) "habitat size" was a potential habitat metric that was removed because of its hypothesized small influence on overall condition, and 3) "population" metrics were changed to "demographic" metrics for internal consistency of this document (table A18). Additionally, person 1 did not provide a relative importance value for "interconnectedness," resulting in the sum of the values used for demographic and habitat metrics being less than the potential 100 points. Because of these errors, the relative importance weights were corrected so that they sum to 100 for each condition category (table A18), with a value of 20 being assumed for interconnectedness for person 1 (sum of population now 100) and all habitat condition metric values being re-scaled based on the total sum of points used. For example, person 1 used a total of 120 points across habitat metrics and one person used 99. Corrected relative importance weights were calculated by dividing the relative importance value for each metric by the total used across metrics within each category, without including habitat size (table A19).

The final step was to calculate relative importance in terms of weights (with all values between 0 and 1, 0 indicated low weight and 1 indicated high weight, summing to 1 across all metrics). Each categorical-specific relative importance weight (table A20) was multiplied by the relative weight of the population and habitat metric as whole (0.60 and 0.40, respectively) to rescale the relative importance weights to account for the fact that population metrics are slightly more important in overall resiliency. This resulted in the final relative importance weights (table A21). Then, summary statistics were calculated across experts and the average weight was used in the final weighting of metrics (table A22). Note that relative importance of hydrology varied the most among experts, with 3 experts indicating that was 60% more important as the 3 other experts (weight range=0.13 to 0.26). Lastly, weights were compared to those provided in the Bog Turtle Conservation Plan (2019) and re-scaled for comparison showing slightly higher importance given to population size and hydrology in this analysis compared to the BTCP and lower importance given to recruitment, interconnectedness, and succession in this analysis compared to BTCP, and equal importance for development (table A23).

Table A18. The original elicited relative importance weights.

Category	Condition Metric	P1	P2	P3	P4	P5	P6
Demographic	Population Size	50	46	60	60	60	60
Demographic	Recruitment	30	35	20	25	25	25
Demographic	Interconnectedness	NA	19	20	15	15	15
Demographic Sum		**80**	**100**	**100**	**100**	**100**	**100**
~~Habitat~~	~~Habitat size~~	~~10~~	~~0~~	~~0~~	~~15~~	~~35~~	~~0~~
Habitat	Succession	40	33	15	15	15	30
Habitat	Hydrology	40	33	50	55	40	40
Habitat	Development	30	33	35	15	10	30
Habitat Sum		**120**	**99**	**100**	**100**	**100**	**100**

Table A19. The corrected elicited relative importance weights.

Category	Condition Metric	P1	P2	P3	P4	P5	P6
Demographic	Population Size	50	46	60	60	60	60
Demographic	Recruitment	30	35	20	25	25	25
Demographic	Interconnectedness	20	19	20	15	15	15
Demographic Sum		**100**	**100**	**100**	**100**	**100**	**100**
Habitat	Succession	36	33	15	18	23	30
Habitat	Hydrology	36	33	50	65	62	40
Habitat	Development	27	33	35	18	15	30
Habitat Sum		**100**	**100**	**100**	**100**	**100**	**100**

Table A20. The category-specific relative importance weights.

Category	Condition Metric	P1	P2	P3	P4	P5	P6
Demographic	Population Size	0.50	0.46	0.60	0.60	0.60	0.60
Demographic	Recruitment	0.30	0.35	0.20	0.25	0.25	0.25
Demographic	Interconnectedness	0.20	0.19	0.20	0.15	0.15	0.15
Demographic Sum		**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Habitat	Succession	0.36	0.33	0.15	0.18	0.23	0.30
Habitat	Hydrology	0.36	0.33	0.50	0.65	0.62	0.40
Habitat	Development	0.27	0.33	0.35	0.18	0.15	0.30
Habitat Sum		**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Table A21. The final relative importance weights.

Category	Condition Metric	P1	P2	P3	P4	P5	P6
Demographic	Population Size	0.30	0.28	0.36	0.36	0.36	0.36
Demographic	Recruitment	0.18	0.21	0.12	0.15	0.15	0.15
Demographic	Interconnectedness	0.12	0.11	0.12	0.09	0.09	0.09
Demographic Sum		**0.60**	**0.60**	**0.60**	**0.60**	**0.60**	**0.60**
Habitat	Succession	0.15	0.13	0.06	0.07	0.09	0.12
Habitat	Hydrology	0.15	0.13	0.20	0.26	0.25	0.16
Habitat	Development	0.11	0.13	0.14	0.07	0.06	0.12
Habitat Sum		**0.40**	**0.40**	**0.40**	**0.40**	**0.40**	**0.40**
Overall Sum		**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Table A22. The relative importance weight summary.

Category	Condition Metric	Average	Median	Minimum	Maximum	SD	Consensus
Demographic	Population Size	0.34	0.36	0.28	0.36	0.04	moderate
Demographic	Recruitment	0.16	0.15	0.12	0.21	0.03	moderate
Demographic	Interconnectedness	0.10	0.10	0.09	0.12	0.02	high
Demographic Sum		**0.60**					
Habitat	Succession	0.10	0.11	0.06	0.15	0.03	moderate
Habitat	Hydrology	0.19	0.18	0.13	0.26	0.05	low
Habitat	Development	0.11	0.11	0.06	0.14	0.03	moderate
Habitat Sum		**0.40**					
Overall Sum		**1.00**					

Table A23. A comparison of relative importance in this analysis (table 22) compared to the Bog Turtle Conservation Plan (2019; tables 2 and 3).

Category	Condition Metric	This analysis table 22)	Conservation Plan (table 2 and 3)	Conservation Plan Rescaled
Demographic	Population Size	0.34	0.46	0.28 (0.46 x 0.6)
Demographic	Recruitment	0.16	0.35	0.21 (0.35 x 0.6)
Demographic	Interconnectedness	0.10	0.19	0.11 (0.19 x 0.6)
Demographic Sum		**0.60**	**1.00**	**0.60**
Habitat	Succession	0.10	0.15	0.12 (0.15 / 0.49 x 0.4)
Habitat	Hydrology	0.19	0.21	0.17 (0.21 / 0.49 x 0.4)
Habitat	Development	0.11	0.13	0.11 (0.13 / 0.49 x 0.4)
Habitat Sum		**0.40**	**0.49**	**0.40**
Overall Sum		**1.00**	**1.49**	**1.00**

A1.7. Calculating Resiliency

Resiliency was calculated for each metapopulation using all normalized demographic and habitat scores, weighted by their relative importance (*i.e*., a weighted average). Resiliency was computed by multiplying each normalized score (0, 0.5 or 1.0; table A17) by the corresponding average relative importance weight (table A22) and then summed across all metrics for each metapopulation. The highest possible resiliency score was 1.0 and represented a metapopulation with all six metrics in "good" condition (table A24). A score of 0.60 most often represented a metapopulation with all three demographic metrics in "good" condition, but then all three habitat metrics in "poor" condition (table A25). The lowest possible resiliency score was 0.0 and represented a metapopulation with all size metrics in "poor" condition.

Table A24. An example resiliency score (weighted average=sum (normalized value x average weight) for a metapopulation with all good condition metrics.

Metapopulation Condition Metric	Good Condition (table 17)	Normalized Value (table 17)	Average Weight (table 22)	Weighted Average[1]
Population Size	$\geq$ 30 adults	1.0	0.34	0.34
Recruitment	Some evidence of recruitment	1.0	0.16	0.16
Interconnectedness	Strong interconnectedness	1.0	0.10	0.10
Succession	Low level of woody succession	1.0	0.10	0.10
Hydrology	Low disturbance	1.0	0.19	0.19
Development	No development	1.0	0.11	0.11
Resiliency Score (Weighted Average)				**1.00**

[1] Weighted average values are provided in the "MetaPopData" tab with "_Weighted" after each corresponding condition metric.

Table A25. An example resiliency score (weighted average=sum (normalized value x average weight) for a metapopulation with all good demographic condition metrics and poor habitat condition metrics.

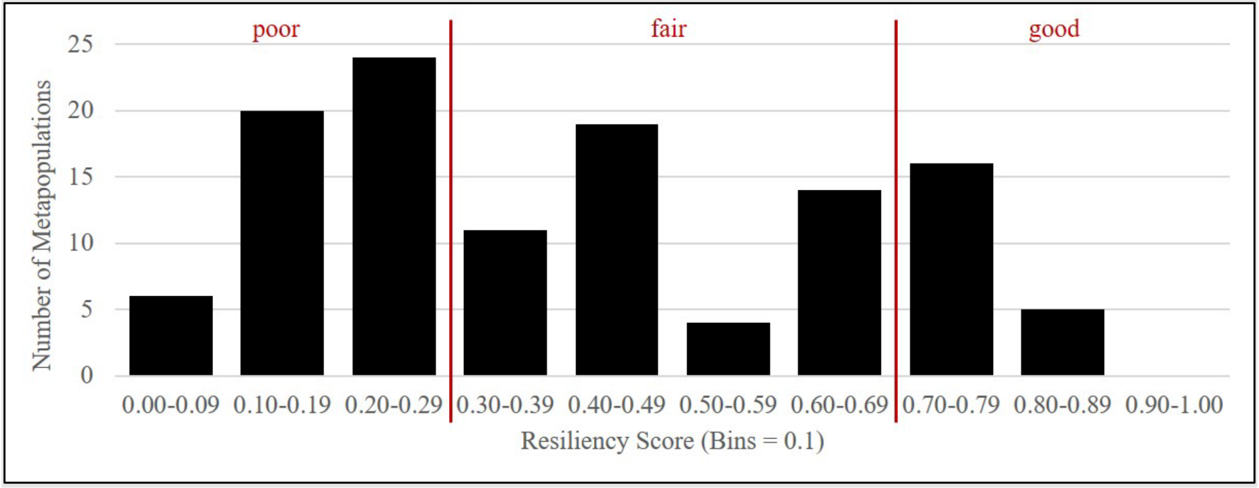
Metapopulation Condition Metric	Good Condition (table 17)	Normalized Value (table 17)	Average Weight (table 22)	Weighted Average[1]
Population Size	$\geq$ 30 adults	1.0	0.34	0.34
Recruitment	Some evidence of recruitment	1.0	0.16	0.16
Interconnectedness	Strong interconnectedness	1.0	0.10	0.10
Succession	High level of woody succession	0.0	0.10	0.00
Hydrology	High disturbance	0.0	0.19	0.00
Development	High development	0.0	0.11	0.00
Resiliency Score (Weighted Average)				**0.60**

[1] Weighted average values are provided in the "MetaPopData" tab with "_Weighted" after each corresponding condition metric.

A1.7.1. Resiliency Scores

A total of 119 metapopulations had known conditions for all six metapopulation metrics (no unknowns). Among these metapopulations, the average resiliency score was 0.41 (median=0.36), with slightly higher average resiliency in HH (0.48), PPLP (0.43) Recovery Units, and near average resiliency in DE (0.40) and SP (0.38; resiliency could not be calculated for OCP because there were too many unknowns). Over half (N=79) of all metapopulations (without unknowns) had resiliency scores less than 0.5, with only 24 metapopulations exceeding a resiliency score of 0.7 (figure A7; table A26).

Figure A7. The resiliency scores (range 0.00 to 1.00; bin size=0.1) for each metapopulation (N=119) with known condition for all demographic and habitat metrics (see "Resiliency" tab), for poor (0.0–0.29 scores), fair (0.30–0.69), and good (0.70–1.00) condition.



Due to the large number of unknowns across each metapopulation condition metric (153 had unknown metapopulation size, 138 had unknown recruitment, 17 had unknown interconnectedness, 65 had unknown succession, 53 had unknown hydrology, and 9 had unknown development; figure A1), it was not possible to calculate resiliency scores for a majority of metapopulations (64%; 211 of 330). To evaluate the range in *possible* resiliency scores if unknowns were resolved, we developed two scenarios. The first scenario represented if all unknown conditions were resolved and found to be in good condition. The second scenario represented if all unknown conditions were resolved and found to be in poor condition. These two scenarios provided a range of plausible resiliency scores for all metapopulations given unknowns are resolved through additional field observations.

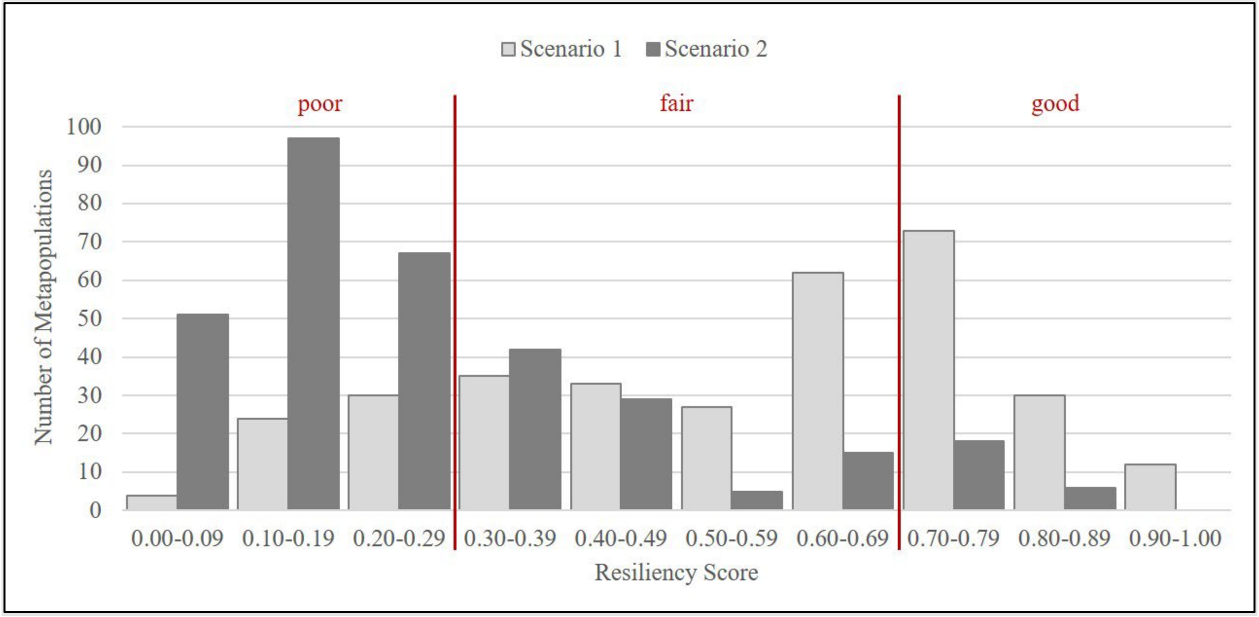
Note that the population size metric and interconnectedness metric are not independent but were treated as independent in the two scenarios when unknown. For example, if a metapopulation had an unknown individual population size, it was assigned to good condition (≥ 30 adults) in the first scenario and assigned poor condition (< 30 adults) in the second scenario. If a metapopulation had an unknown interconnectedness, it was assigned as good condition (strong interconnectedness in the first scenario) and poor condition (single, isolated population) in the second scenario. There may be a few metapopulations in which assigning unknowns to poor condition would not change the interconnectedness condition and vice versa, but the combination of each related unknown condition metrics was not explored in this analysis. As expected, the resiliency scores in the first scenario were, on average, larger than those in the second case scenario (0.54 and 0.26, respectively; table A26; figure A8).

Table A26. The number of metapopulations (and percent of total) with each resiliency score[1] (bins of 0.1) for metapopulations with all known condition metrics (known populations), for scenario 1 (all unknowns are hypothesized to be in good condition), and for scenario 2 (all unknowns metrics are hypothesized to be in poor condition; completed 2021-03-23).

	Known Metapopulations		Scenario 1		Scenario 2	
Resiliency Range	Number of Metapopulations	Percent	Number of Metapopulations	Percent	Number of Metapopulations	Percent
0.00–0.09	6	5%	4	1%	51	15%
0.10–0.19	20	17%	24	7%	97	29%
0.20–0.29	24	20%	30	9%	67	20%
0.30–0.39	11	9%	35	11%	42	13%
0.40–0.49	19	16%	33	10%	29	9%
0.50–0.59	4	3%	27	8%	5	2%
0.60–0.69	14	12%	62	19%	15	5%
0.70–0.79	16	13%	73	22%	18	5%
0.80–0.89	5	4%	30	9%	6	2%
0.90–1.00	0	0%	12	4%	0	0%
Total	**119**	**100%**	**330**	**100%**	**330**	**100%**

[1] Resiliency scores for scenarios 1 and 2 are provided in the "MetaPopData" tab with "_scenario1" or "_scenario2" after each corresponding condition metric and summarized on the "Resiliency" tab.

Figure A8. The resiliency scores (range 0.00 to 1.00; bin size=0.1) for each metapopulation (N=330) under scenario 1 (if unknowns are in fact in good condition) and scenario 2 (if unknowns are in fact in poor condition; see "Resiliency" tab).



We assigned resiliency categories of "poor," "fair," and "good" to each metapopulation based on the corresponding resiliency score. Resiliency scores less than 0.3 were considered poor and represented metapopulations that are lacking many of the conditions needed for persistence (*e.g.*, population size, recruitment, and/or hydrology). Resiliency scores between 0.3 and 0.7 were considered fair and represented populations lacking many of the conditions needed for persistence (*e.g.*, interconnectedness, suitable vegetation, or suitable hydrology). Resiliency scores equal or greater than 0.7 were considered good and represented metapopulations that had most of the conditions needed for persistence (but could still have performed poorly in at least three of the less important condition metrics).

Across recovery units, a range of 21–98 metapopulations have good resiliency (6–30%), 87–166 metapopulations have fair resiliency (26–50%), and 66–222 metapopulations have poor resiliency (20–67%; table A27). Approximately 153 (46%) of metapopulations have resiliency categories that were insensitive to unknowns (the category did not change based on if unknowns were potentially good [scenario 1] or poor [scenario 2]; table A28; table 34). The remaining 78 (54%) of metapopulations have resiliency scores that were sensitive to the potential condition of one or more unknown metrics (table A28; table A35). Accounting for unknown conditions, approximately 6–30% of metapopulations have "good" resiliency, 26–50% have "fair" resiliency, and 20–67% have "poor" resiliency across all recovery units (table A28). Twenty-one (6%) metapopulations have "good" resiliency regardless of the potential condition of unknown metrics, 65 (20%) had "fair" resiliency regardless of the potential condition of unknown metrics, and 66 (20%) have "poor" resiliency regardless of the potential condition of unknown metrics (grey boxes in table A28).

Most metapopulations (range=20%–71%) in the Delaware Recovery Unit (N=162) have poor resiliency (table A29). Note that the number of metapopulations will range depending on the scenario used to account for unknowns (scenario 1 hypothesizes that all unknowns are in good condition, while scenario 2 hypothesizes that all unknowns are in poor condition). Many metapopulations (range=24%–49%) have fair resiliency, and few metapopulations had good resiliency (5%–31%; table A29; figure 9A). Only 44% of metapopulations are insensitive to unknowns (did not change resiliency category under scenario 1 vs. scenario 2; poor=32, fair=31, and good=8; grey boxes in table 28A), while the remaining 56% of metapopulations change resiliency category based on the hypothesized condition of unknown metrics.

Most metapopulations (range=17%–65%) in the Hudson-Housatonic Recovery Unit (N=66) have poor resiliency table A29). Many metapopulations (range=23%–47%) have fair resiliency, and few metapopulations have good resiliency (12%–36%; table A30; figure 9A). Only 42% of metapopulations were insensitive to unknowns (did not change resiliency category under scenario 1 vs. scenario 2; poor=11, fair=9, and good=8; grey boxes in table A30), while the remaining 58% of metapopulations change resiliency category based on the hypothesized condition of unknown metrics.

The Outer Coastal Plain Recovery Unit metapopulations (N=3) include 1 metapopulation with fair resiliency, and two metapopulations with either poor or good resiliency due to the fact that there were too many unknown condition metrics to be certain (table A31; figure 9A).

Four metapopulations in the Peninsula-Lake Plain Recovery Unit (N=5) were insensitive to unknowns. One metapopulation had poor resiliency, two metapopulations had fair resiliency, and one metapopulation had good resiliency (grey boxes in table A32; figure 9A). One metapopulation was sensitive to unknowns and could have either "poor" or "fair" resiliency (table A32).

Most metapopulations (range=23%–64%) in the Susquehanna/Potomac Recovery Unit (N=94) had poor resiliency (table A33). Many metapopulations (range=32%–55%) had fair resiliency, and only a few metapopulations had good resiliency (4%–21%; table A33; figure 9A). Only 52% of metapopulations were insensitive to unknowns (did not change resiliency category under scenario 1 vs. scenario 2; poor=22, fair=23, and good=4; grey boxes in table A33), while the remaining 48% of metapopulations changed resiliency category based on the hypothesized condition of unknown metrics.

Table A27. The number of metapopulations in each resiliency category under scenario 1 (unknown condition metrics hypothesized as good) and scenario 2 (unknown condition metrics hypothesized as poor) for each recovery unit (completed 2021-03-23).[1]

	Recovery Unit					
Resiliency Category	Delaware	Hudson-Housatonic	Outer Coastal Plain	Prairie Peninsula-Lake Plain	Susquehanna/ Potomac	Total
Scenario 1 (unknown condition metrics hypothesized as good)						
Good	51	24	2	1	20	98
Fair	79	31	1	3	52	166
Poor	32	11	0	1	22	66
Scenario 2 (unknowns condition metrics hypothesized as poor)						
Good	8	8	0	1	4	21
Fair	39	15	1	2	30	87
Poor	115	43	2	2	60	222

[1]Resiliency categories are summarized in the "ResiliencybyRU" tab, using the columns with "_Resiliencycategory_Scenario1" and "_Resiliencycategory_Scenario2" from the "MetaPopData" tab.

Table A28. The number of metapopulations (and percent) for each resiliency category under scenario 1 (if unknowns are in fact in good condition) and scenario 2 (if unknowns are in fact in poor condition) across all recovery units.[1] Grey boxes indicate the number of metapopulations that did not change resiliency categories under each scenario. completed 2021-03-23

		Scenario 1				
	Category	Poor	fair	good	Total	Percent
Scenario 2	poor	66	101	55	222	67%
	fair		65	22	87	26%
	good			21	21	6%
	Total	66	166	98	330	
	Percent	20%	50%	30%		

[1]Resiliency categories are summarized in the "ResiliencybyRU" tab, using the columns with "_Resiliencycategory_Scenario1" and "_Resiliencycategory_Scenario2" from the "MetaPopData" tab.

Table A29. The number of metapopulations (and percent) for each resiliency category under scenario 1 (if unknowns are in fact in good condition) and scenario 2 (if unknowns are in fact in poor condition) in the Delaware Recovery Unit.[1] Grey boxes indicate the number of metapopulations that did not change resiliency categories under each scenario (completed 2021-03-23).

		Scenario 1				
	Category	Poor	fair	good	Total	Percent
Scenario 2	poor	32	48	35	115	71%
	fair		31	8	39	24%
	good			8	8	5%
	Total	32	79	51	162	
	Percent	20%	49%	31%		

[1] Resiliency categories are summarized in the "ResiliencybyRU" tab, using the columns with "_Resiliencycategory_Scenario1" and "_Resiliencycategory_Scenario2" from the "MetaPopData" tab.

Table A30. The number of metapopulations (and percent) for each resiliency category under scenario 1 (if unknowns are in fact in good condition) and scenario 2 (if unknowns are in fact in poor condition) in the Hudson-Housatonic Recovery Unit.[1] Grey boxes indicate the number of metapopulations that did not change resiliency categories under each scenario (completed 2021-03-23).

		Scenario 1				
	Category	Poor	fair	good	Total	Percent
Scenario 2	poor	11	22	10	43	65%
	fair		9	6	15	23%
	good			8	8	12%
	Total	11	31	24	66	
	Percent	17%	47%	36%		

[1] Resiliency categories are summarized in the "ResiliencybyRU" tab, using the columns with "_Resiliencycategory_Scenario1" and "_Resiliencycategory_Scenario2" from the "MetaPopData" tab.

Table A31. The number of metapopulations (and percent) for each resiliency category under scenario 1 (if unknowns are in fact in good condition) and scenario 2 (if unknowns are in fact in poor condition) in the Outer Coastal Plain Recovery Unit.[1] Grey boxes indicate the number of metapopulations that did not change resiliency categories under each scenario (completed 2021-03-23).

		Scenario 1				
	Category	Poor	fair	good	Total	Percent
Scenario 2	poor	0	1	1	2	67%
	fair		0	1	1	33%
	good			0	0	0%
	Total	0	1	2	3	
	Percent	0%	33%	67%		

[1] Resiliency categories are summarized in the "ResiliencybyRU" tab, using the columns with "_Resiliencycategory_Scenario1" and "_Resiliencycategory_Scenario2" from the "MetaPopData" tab.

Table A32. The number of metapopulations (and percent) for each resiliency category under scenario 1 (if unknowns are in fact in good condition) and scenario 2 (if unknowns are in fact in poor condition) in the Peninsula-Lake Plain Recovery Unit.[1] Grey boxes indicate the number of metapopulations that did not change resiliency categories under each scenario (completed 2021-03-23).

		Scenario 1				
	Category	Poor	fair	good	Total	Percent
Scenario 2	poor	1	1	0	2	40%
	fair		2	0	2	40%
	good			1	1	20%
	Total	1	3	1	5	
	Percent	20%	60%	20%		

[1] Resiliency categories are summarized in the "ResiliencybyRU" tab, using the columns with "_Resiliencycategory_Scenario1" and "_Resiliencycategory_Scenario2" from the "MetaPopData" tab.

Table A33. The number of metapopulations (and percent) for each resiliency category under scenario 1 (if unknowns are in fact in good condition) and scenario 2 (if unknowns are in fact in poor condition) in the Susquehanna/Potomac Recovery Unit.[1] Grey boxes indicate the number of metapopulations that did not change resiliency categories under each scenario (completed 2021-03-23).

		Scenario 1				
	Categories	Poor	fair	good	Total	Percent
Scenario 2	poor	22	29	9	60	64%
	fair		23	7	30	32%
	good			4	4	4%
	Total	22	52	20	94	
	Percent	23%	55%	21%		

[1] Resiliency categories are summarized in the "ResiliencybyRU" tab, using the columns with "_Resiliencycategory_Scenario1" and "_Resiliencycategory_Scenario2" from the "MetaPopData" tab.

Figure A9. The proportion of metapopulations in each resiliency category under scenario 1 (unknown condition metrics hypothesized as good) and scenario 2 (unknown condition metrics hypothesized as poor) for each recovery unit (see data in table A33).

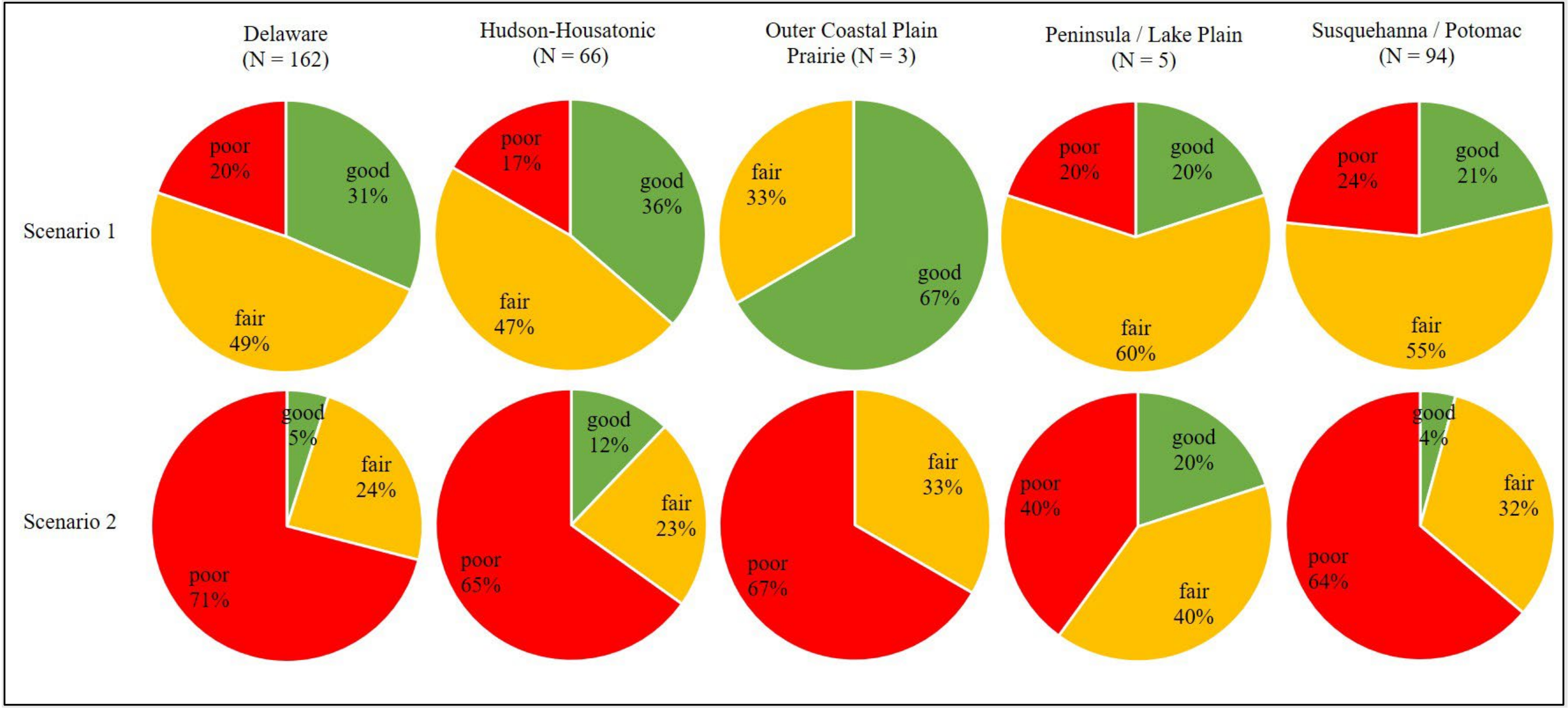


Table A34. Metapopulations that were insensitive to unknowns (same resiliency category under scenario 1 [all unknowns hypothesized as good condition] and scenario 2 [all unknowns hypothesized as poor condition]). Resiliency scores (poor=0.00–0.29, fair=0.30–0.69, good=0.70–1.00) for each scenario and the condition of each demographic and habitat condition metric, with the relative importance weight (w) of each metric.[1]

		Resiliency Score		Demographic Condition Metrics			Habitat Condition Metrics		
State	Metapopulation	Scenario 1	Scenario 2	Population Size (w=0.34)	Recruitment (w=0.16)	Interconnectedness (w=0.10)	Succession (w=0.10)	Hydrology (w=0.19)	Development (w=0.11)
Good Resiliency Under Both Scenarios									
DE	DE_Meta_2	0.90	0.90	> 30 adults	Some evidence	Strong	Moderate	Low	Some
DE	040	0.84	0.84	> 30 adults	Some evidence	Strong	Moderate	Low	High
DE	046	0.75	0.75	> 30 adults	Some evidence	Strong	Moderate	Moderate	High
DE	052	0.75	0.75	> 30 adults	Some evidence	Strong	Moderate	Moderate	High
DE	PA-19626	0.75	0.75	> 30 adults	Some evidence	Isolated, single	Low	Moderate	Some
DE	PA-6813	0.80	0.80	> 30 adults	Some evidence	Strong	Moderate	Moderate	Some
DE	PA-7475	0.75	0.75	> 30 adults	Some evidence	Isolated, single	Low	Moderate	Some
DE	PA-760	0.80	0.80	> 30 adults	Some evidence	Strong	Moderate	Moderate	Some
HH	MA-01	0.79	0.79	> 30 adults	Some evidence	Isolated, single	Moderate	Low	Some
HH	001	0.75	0.75	> 30 adults	Some evidence	Strong	Moderate	Moderate	High
HH	011	0.75	0.75	> 30 adults	Some evidence	Strong	Moderate	Moderate	High
HH	031	0.75	0.75	> 30 adults	Some evidence	Strong	Moderate	Moderate	High
HH	NY11363	0.75	0.75	> 30 adults	Some evidence	Strong	Moderate	Moderate	High
HH	NY11465	0.80	0.80	> 30 adults	Some evidence	Strong	Low	Moderate	High
HH	NY13027	0.75	0.75	> 30 adults	Some evidence	Strong	Moderate	Moderate	High
HH	CT_Meta_1andNY5815	0.70	0.70	> 30 adults	Some evidence	Strong	Moderate	High	Some
PPLP	NY900	0.75	0.75	> 30 adults	Some evidence	Isolated, single	Low	Moderate	Some
SP	MD-23	0.75	0.75	> 30 adults	Some evidence	Strong	Moderate	Moderate	High
SP	MD-58	0.70	0.70	> 30 adults	Some evidence	Strong	Moderate	High	Some
SP	MD-67	0.75	0.75	> 30 adults	Some evidence	Strong	Moderate	Moderate	High
SP	PA-19822	0.85	0.85	> 30 adults	Some evidence	Strong	Low	Moderate	Some
Fair Resiliency Under Both Scenarios									
DE	DE_Meta_3	0.46	0.46	< 30 adults	Some evidence	Isolated, single	Low	Moderate	None
DE	041	0.40	0.40	< 30 adults	Some evidence	Isolated, single	Moderate	Low	High
DE	049	0.51	0.40	< 30 adults	Some evidence	Isolated, single	Unknown	Low	Some
DE	051	0.40	0.40	< 30 adults	Some evidence	Isolated, single	Moderate	Low	High
DE	055	0.70	0.36	Unknown	Some evidence	Some	Moderate	Moderate	High
DE	061	0.31	0.31	< 30 adults	Some evidence	Isolated, single	Moderate	Moderate	High
DE	071	0.40	0.40	< 30 adults	Some evidence	Isolated, single	Moderate	Low	High
DE	101	0.45	0.45	< 30 adults	Some evidence	Some	Moderate	Low	High

DE	137	0.51	0.40	< 30 adults	Some evidence	Isolated, single	Unknown	Low	Some
DE	149	0.65	0.65	> 30 adults	Some evidence	Strong	Moderate	High	High
DE	PA-16364	0.40	0.40	< 30 adults	Some evidence	Isolated, single	High	Low	Some
DE	PA-16433	0.46	0.46	< 30 adults	Some evidence	Isolated, single	Moderate	Low	Some
DE	PA-18704	0.41	0.41	< 30 adults	Some evidence	Isolated, single	Low	Moderate	Some
DE	PA-18947	0.45	0.35	< 30 adults	Some evidence	Isolated, single	Unknown	Low	High
DE	PA-19066	0.55	0.55	> 30 adults	Some evidence	Isolated, single	Moderate	High	High
DE	PA-19752	0.70	0.70	> 30 adults	Some evidence	Isolated, single	Moderate	Moderate	Some
DE	PA-19818	0.35	0.35	< 30 adults	None/Potential	Isolated, single	Low	Low	Some
DE	PA-20893	0.65	0.65	> 30 adults	Some evidence	Strong	Moderate	High	High
DE	PA-21987	0.41	0.31	< 30 adults	Some evidence	Isolated, single	Unknown	Moderate	Some
DE	PA-2288	0.46	0.46	< 30 adults	Some evidence	Isolated, single	Moderate	Low	Some
DE	PA-23405	0.51	0.35	< 30 adults	Unknown	Isolated, single	Low	Low	Some
DE	PA-23409	0.36	0.36	< 30 adults	Some evidence	Isolated, single	Moderate	Moderate	Some
DE	PA-23412	0.36	0.36	< 30 adults	Some evidence	Isolated, single	Moderate	Moderate	Some
DE	PA-23600	0.51	0.51	< 30 adults	Some evidence	Some	Moderate	Low	Some
DE	PA-24786	0.51	0.32	< 30 adults	Some evidence	Isolated, single	Low	Unknown	Some
DE	PA-4098	0.41	0.41	< 30 adults	Some evidence	Isolated, single	Low	Moderate	Some
DE	PA-4365	0.51	0.51	< 30 adults	Some evidence	Some	Moderate	Low	Some
DE	PA-4411	0.37	0.37	< 30 adults	Some evidence	Some	Low	High	Some
DE	PA-4415	0.64	0.64	> 30 adults	Some evidence	Isolated, single	Moderate	Moderate	High
DE	PA-6437	0.64	0.31	Unknown	Some evidence	Some	High	Moderate	High
DE	PA-8291	0.51	0.32	< 30 adults	Some evidence	Some	Moderate	Unknown	Some
HH	CT_Meta_2	0.70	0.36	Unknown	Some evidence	Isolated, single	Moderate	Moderate	Some
HH	MA-02	0.60	0.60	> 30 adults	Some evidence	Isolated, single	Moderate	High	Some
HH	005	0.46	0.46	< 30 adults	Some evidence	Isolated, single	Moderate	Low	Some
HH	075	0.70	0.36	Unknown	Some evidence	Some	Moderate	Moderate	High
HH	083	0.40	0.40	< 30 adults	Some evidence	Isolated, single	Moderate	Low	High
HH	NY11055	0.41	0.41	< 30 adults	Some evidence	Isolated, single	Low	Moderate	Some
HH	NY11361	0.60	0.60	> 30 adults	Some evidence	Isolated, single	Low	High	High
HH	NY11362	0.41	0.41	< 30 adults	Some evidence	Some	Low	Moderate	High
HH	NY11370	0.65	0.65	> 30 adults	Some evidence	Strong	Moderate	High	High
PPLP	NY5220	0.45	0.45	< 30 adults	Some evidence	Isolated, single	Low	Low	High
PPLP	NY9812	0.36	0.36	< 30 adults	Some evidence	Isolated, single	Low	Moderate	High
SP	MD-30	0.64	0.31	Unknown	Some evidence	Some	High	Moderate	High
SP	MD-36	0.64	0.31	Unknown	Some evidence	Some	High	Moderate	High
SP	MD-39	0.70	0.70	> 30 adults	Some evidence	Strong	High	Moderate	High
SP	MD-43	0.70	0.36	Unknown	Some evidence	Some	Moderate	Moderate	High

SP	MD-50	0.32	0.32	< 30 adults	Some evidence	Isolated, single	Low	High	Some
SP	MD-51	0.60	0.60	> 30 adults	Some evidence	Strong	High	High	High
SP	MD-55	0.65	0.65	> 30 adults	Some evidence	Strong	Moderate	High	High
SP	MD-71	0.65	0.65	> 30 adults	Some evidence	Isolated, single	Low	High	Some
SP	MD-78	0.60	0.60	> 30 adults	Some evidence	Strong	High	High	High
SP	MD-84	0.50	0.50	> 30 adults	Some evidence	Isolated, single	High	High	High
SP	MD-91	0.70	0.70	> 30 adults	Some evidence	Strong	High	Moderate	High
SP	PA-10779	0.32	0.32	< 30 adults	Some evidence	Isolated, single	Low	High	Some
SP	PA-11478	0.65	0.65	> 30 adults	Some evidence	Strong	Moderate	High	High
SP	PA-15750	0.35	0.35	< 30 adults	None/Potential	Isolated, single	Low	Low	Some
SP	PA-15909	0.46	0.46	< 30 adults	Some evidence	Isolated, single	Moderate	Low	Some
SP	PA-25940	0.56	0.46	< 30 adults	Some evidence	Isolated, single	Unknown	Low	None
SP	PA-26094	0.41	0.41	< 30 adults	Some evidence	Isolated, single	Moderate	Moderate	None
SP	PA-4596	0.36	0.36	< 30 adults	Some evidence	Isolated, single	Moderate	Moderate	Some
SP	PA-5825	0.41	0.41	< 30 adults	Some evidence	Isolated, single	Low	Moderate	Some
SP	PA-7786	0.60	0.60	> 30 adults	Some evidence	Isolated, single	Moderate	High	Some
SP	PA-8325	0.36	0.36	< 30 adults	Some evidence	Isolated, single	Low	Moderate	High
SP	PA-9107	0.65	0.32	Unknown	Some evidence	Some	Low	High	High
SP	PA-30943	0.65	0.32	Unknown	Some evidence	Isolated, single	Low	High	Some
Poor Resiliency Under Both Scenarios									
DE	032	0.26	0.26	< 30 adults	Some evidence	Isolated, single	Moderate	High	Some
DE	057	0.26	0.10	< 30 adults	Unknown	Isolated, single	Moderate	High	Some
DE	067	0.16	0.16	< 30 adults	Some evidence	Isolated, single	High	High	High
DE	138	0.10	0.00	< 30 adults	None/Potential	Isolated, single	Unknown	High	High
DE	PA-10770	0.16	0.16	< 30 adults	Some evidence	Isolated, single	High	High	High
DE	PA-1425	0.26	0.26	< 30 adults	Some evidence	Isolated, single	Moderate	High	Some
DE	PA-14739	0.16	0.16	< 30 adults	None/Potential	Isolated, single	Moderate	High	None
DE	PA-15101	0.10	0.10	< 30 adults	None/Potential	Isolated, single	Moderate	High	Some
DE	PA-15379	0.30	0.10	< 30 adults	None/Potential	Isolated, single	Moderate	Unknown	Some
DE	PA-15872	0.16	0.16	< 30 adults	None/Potential	Isolated, single	Low	High	Some
DE	PA-17334	0.05	0.05	< 30 adults	None/Potential	Isolated, single	High	High	Some
DE	PA-17338	0.30	0.10	< 30 adults	None/Potential	Isolated, single	Moderate	Unknown	Some
DE	PA-17689	0.16	0.16	< 30 adults	None/Potential	Isolated, single	Low	High	Some
DE	PA-18776	0.26	0.10	< 30 adults	Unknown	Isolated, single	Moderate	High	Some
DE	PA-19129	0.10	0.10	< 30 adults	None/Potential	Isolated, single	Low	High	High
DE	PA-19244	0.26	0.26	< 30 adults	Some evidence	Isolated, single	Moderate	High	Some
DE	PA-19245	0.21	0.11	< 30 adults	None/Potential	Isolated, single	Unknown	High	None
DE	PA-19865	0.26	0.26	< 30 adults	Some evidence	Isolated, single	Moderate	High	Some

DE	PA-20714	0.26	0.26	< 30 adults	Some evidence	Some	Moderate	High	High
DE	PA-20891	0.21	0.05	< 30 adults	Unknown	Isolated, single	Moderate	High	High
DE	PA-21957	0.30	0.30	< 30 adults	None/Potential	Isolated, single	Moderate	Low	Some
DE	PA-24151	0.21	0.21	< 30 adults	Some evidence	Isolated, single	High	High	Some
DE	PA-26216	0.16	0.16	< 30 adults	None/Potential	Isolated, single	Moderate	High	None
DE	PA-4093	0.10	0.10	< 30 adults	None/Potential	Isolated, single	Moderate	High	Some
DE	PA-500	0.30	0.10	< 30 adults	None/Potential	Isolated, single	Moderate	Unknown	Some
DE	PA-6453	0.30	0.10	< 30 adults	None/Potential	Isolated, single	Moderate	Unknown	Some
DE	PA-7020	0.20	0.20	< 30 adults	None/Potential	Isolated, single	Moderate	Moderate	Some
DE	PA-7310	0.21	0.21	< 30 adults	Some evidence	Isolated, single	Moderate	High	High
DE	PA-7992	0.05	0.05	< 30 adults	None/Potential	Isolated, single	Moderate	High	High
DE	PA-9720	0.24	0.05	< 30 adults	None/Potential	Isolated, single	High	Unknown	Some
DE	PA-30945	0.20	0.20	< 30 adults	None/Potential	Isolated, single	Moderate	Moderate	Some
DE	PA-29253	0.20	0.20	< 30 adults	None/Potential	Isolated, single	Moderate	Moderate	Some
HH	CT_Meta_3	0.10	0.10	< 30 adults	None/Potential	Isolated, single	Moderate	High	Some
HH	CT_Meta_4	0.26	0.26	< 30 adults	Some evidence	Isolated, single	Moderate	High	Some
HH	003	0.20	0.10	< 30 adults	None/Potential	Isolated, single	Unknown	Moderate	High
HH	004	0.26	0.10	< 30 adults	Unknown	Isolated, single	Low	High	High
HH	081	0.21	0.21	< 30 adults	Some evidence	Isolated, single	High	High	Some
HH	144	0.10	0.10	< 30 adults	None/Potential	Some	Moderate	High	High
HH	160	0.25	0.25	< 30 adults	None/Potential	Isolated, single	Low	Moderate	Some
HH	NY11359	0.26	0.26	< 30 adults	Some evidence	Some	Moderate	High	High
HH	NY458	0.16	0.00	< 30 adults	Unknown	Isolated, single	High	High	High
HH	NY8612	0.15	0.15	< 30 adults	None/Potential	Isolated, single	Moderate	Moderate	High
HH	NY2694	0.05	0.05	< 30 adults	None/Potential	Isolated, single	Moderate	High	High
PPLP	NY11078	0.16	0.16	< 30 adults	None/Potential	Isolated, single	Low	High	Some
SP	MD-10	0.21	0.21	< 30 adults	Some evidence	Isolated, single	Moderate	High	High
SP	MD-11	0.24	0.24	< 30 adults	None/Potential	Isolated, single	High	Low	Some
SP	MD-26	0.25	0.25	< 30 adults	None/Potential	Some	Moderate	Moderate	Some
SP	MD-29	0.10	0.10	< 30 adults	None/Potential	Isolated, single	Moderate	High	Some
SP	MD-33	0.15	0.15	< 30 adults	None/Potential	Isolated, single	High	Moderate	Some
SP	MD-38	0.15	0.15	< 30 adults	None/Potential	Isolated, single	High	Moderate	Some
SP	MD-41	0.15	0.15	< 30 adults	None/Potential	Isolated, single	High	Moderate	Some
SP	MD-44	0.15	0.15	< 30 adults	None/Potential	Isolated, single	High	Moderate	Some
SP	MD-57	0.20	0.20	< 30 adults	None/Potential	Isolated, single	Moderate	Moderate	Some
SP	MD-70	0.10	0.10	< 30 adults	None/Potential	Isolated, single	High	Moderate	High
SP	MD-77	0.05	0.05	< 30 adults	None/Potential	Isolated, single	High	High	Some
SP	MD-82	0.21	0.21	< 30 adults	Some evidence	Isolated, single	High	High	Some

SP	PA-12207	0.26	0.26	< 30 adults	Some evidence	Isolated, single	Moderate	High	Some
SP	PA-12932	0.30	0.30	< 30 adults	None/Potential	Isolated, single	Moderate	Low	Some
SP	PA-15749	0.30	0.30	< 30 adults	None/Potential	Isolated, single	Moderate	Low	Some
SP	PA-17975	0.10	0.10	< 30 adults	None/Potential	Isolated, single	High	Moderate	High
SP	PA-18992	0.21	0.05	< 30 adults	Unknown	Isolated, single	High	High	Some
SP	PA-24092	0.16	0.16	< 30 adults	None/Potential	Isolated, single	Low	High	Some
SP	PA-24377	0.21	0.05	< 30 adults	Unknown	Isolated, single	Moderate	High	High
SP	PA-3319	0.30	0.10	< 30 adults	None/Potential	Isolated, single	Moderate	Unknown	Some
SP	PA-6387	0.16	0.16	< 30 adults	None/Potential	Isolated, single	Low	High	Some
SP	PA-7476	0.24	0.24	< 30 adults	None/Potential	Isolated, single	High	Low	Some

[1] Resiliency categories and metapopulation conditions are in the “MetaPopData” tab.

Table A35. Metapopulations that were sensitive to unknowns (different resiliency category under scenario 1 [all unknowns hypothesized as good condition] and scenario 2 [all unknowns hypothesized as poor condition]). Resiliency scores (poor=0.00–0.29, fair=0.30–0.69, good=0.70–1.00) for each scenario and the condition of each demographic and habitat condition metric, with the relative importance weight (w) of each metric.[1]

		Resiliency Score		Demographic Condition Metrics			Habitat Condition Metrics		
State	Metapopulation	Scenario 1	Scenario 2	Population Size (w=0.34)	Recruitment (w=0.16)	Interconnectedness (w=0.10)	Succession (w=0.10)	Hydrology (w=0.19)	Development (w=0.11)
Good Resiliency (S1) or Poor Resiliency (S2)									
NJ	017	0.75	0.15	Unknown	Unknown	Isolated, single	Unknown	Moderate	Some
NJ	022	0.76	0.05	Unknown	Unknown	Unknown	Unknown	High	Some
NJ	037	0.75	0.25	Unknown	Unknown	Isolated, single	Low	Moderate	Some
NJ	039	0.75	0.15	Unknown	Unknown	Isolated, single	Unknown	Moderate	Some
NJ	042	0.75	0.15	Unknown	Unknown	Isolated, single	Unknown	Moderate	Some
NJ	105	0.75	0.15	Unknown	Unknown	Isolated, single	Unknown	Moderate	Some
NJ	150	0.85	0.15	Unknown	Unknown	Unknown	Unknown	Moderate	Some
NJ	152	0.84	0.24	Unknown	Unknown	Isolated, single	Unknown	Low	Some
NJ	154	0.75	0.15	Unknown	Unknown	Isolated, single	Unknown	Moderate	Some
NJ	155	0.75	0.15	Unknown	Unknown	Some	Unknown	Moderate	High
NJ	162	0.80	0.20	Unknown	Unknown	Unknown	Moderate	Moderate	Some
NJ	163	0.95	0.05	Unknown	Unknown	Unknown	Unknown	Unknown	Some
NJ	167	0.75	0.15	Unknown	Unknown	Isolated, single	Unknown	Moderate	Some
NJ	169	0.75	0.15	Unknown	Unknown	Isolated, single	Unknown	Moderate	Some
PA	PA-10066	0.90	0.00	Unknown	Unknown	Isolated, single	Unknown	Unknown	Unknown
PA	PA-10354	0.84	0.16	Unknown	Unknown	Isolated, single	Low	Unknown	Some
PA	PA-10458	1.00	0.29	Unknown	Unknown	Unknown	Low	Low	Unknown
PA	PA-10727	0.79	0.10	Unknown	Unknown	Isolated, single	Moderate	Unknown	Some
PA	PA-10800	0.80	0.10	Unknown	Unknown	Isolated, single	Unknown	Moderate	Unknown
PA	PA-1143	0.84	0.16	Unknown	Unknown	Isolated, single	Low	Unknown	Some
PA	PA-1144	0.79	0.27	Unknown	Some evidence	Isolated, single	High	Unknown	None
PA	PA-11928	0.84	0.24	Unknown	Unknown	Isolated, single	Unknown	Low	Some
PA	PA-14817	0.84	0.16	Unknown	Unknown	Isolated, single	Low	Unknown	Some
PA	PA-14821	0.75	0.15	Unknown	Unknown	Unknown	Moderate	Moderate	High
PA	PA-17336	0.84	0.16	Unknown	Unknown	Some	Moderate	Unknown	Some
PA	PA-19634	0.79	0.30	Unknown	Unknown	Isolated, single	Moderate	Low	Some
PA	PA-22742	0.84	0.05	Unknown	Unknown	Isolated, single	Unknown	Unknown	Some
PA	PA-23253	0.79	0.10	Unknown	Unknown	Isolated, single	Moderate	Unknown	Some
PA	PA-23411	0.84	0.05	Unknown	Unknown	Unknown	Moderate	Unknown	High
PA	PA-25603	0.90	0.00	Unknown	Unknown	Isolated, single	Unknown	Unknown	Unknown
PA	PA-2588	0.90	0.00	Unknown	Unknown	Isolated, single	Unknown	Unknown	Unknown

PA	PA-27752	0.74	0.24	Unknown	Unknown	Isolated, single	High	Low	Some
PA	PA-4671	0.90	0.00	Unknown	Unknown	Isolated, single	Unknown	Unknown	Unknown
PA	PA-4879	0.90	0.30	Unknown	Unknown	Unknown	Moderate	Low	Some
PA	PA-919	0.84	0.21	Unknown	None/Potential	Unknown	Low	Unknown	None
NJ	006	0.79	0.00	Unknown	Unknown	Isolated, single	Unknown	Unknown	High
NJ	007	0.79	0.30	Unknown	Unknown	Isolated, single	Moderate	Low	Some
NJ	027	0.79	0.19	Unknown	Unknown	Isolated, single	Unknown	Low	High
NJ	073	0.75	0.25	Unknown	Unknown	Isolated, single	Low	Moderate	Some
NJ	099	0.70	0.10	Unknown	Unknown	Unknown	Low	High	High
NJ	122	0.80	0.20	Unknown	Unknown	Unknown	Moderate	Moderate	Some
NY	NY11364	0.89	0.26	Unknown	Some evidence	Unknown	Low	Unknown	High
NY	NY11469	0.75	0.15	Unknown	Unknown	Some	Unknown	Moderate	High
NY	NY11475	0.84	0.16	Unknown	Unknown	Some	Moderate	Unknown	Some
NY	NY12068	0.84	0.05	Unknown	Unknown	Unknown	Moderate	Unknown	High
NJ	172	0.79	0.19	Unknown	Unknown	Isolated, single	High	Low	Unknown
MD	MD-27	0.75	0.15	Unknown	Unknown	Unknown	High	Moderate	Some
MD	MD-53	0.75	0.25	Unknown	Unknown	Some	Moderate	Moderate	Some
MD	MD-54	0.70	0.26	Unknown	Some evidence	Unknown	Moderate	High	Some
MD	MD-81	0.75	0.15	Unknown	Unknown	Unknown	Moderate	Moderate	High
PA	PA-13459	0.90	0.00	Unknown	Unknown	Isolated, single	Unknown	Unknown	Unknown
PA	PA-18623	0.75	0.25	Unknown	Unknown	Isolated, single	Low	Moderate	Some
PA	PA-19706	0.84	0.16	Unknown	Unknown	Isolated, single	Low	Unknown	Some
PA	PA-24475	0.79	0.10	Unknown	Unknown	Isolated, single	Moderate	Unknown	Some
PA	PA-6853	0.79	0.10	Unknown	Unknown	Isolated, single	Moderate	Unknown	Some
Good Resiliency (S1) or Fair Resiliency (S2)									
NJ	014	0.75	0.31	Unknown	Some evidence	Some	Unknown	Moderate	High
NJ	095	0.75	0.31	Unknown	Some evidence	Some	Unknown	Moderate	High
NJ	147	0.80	0.36	Unknown	Some evidence	Some	Unknown	Moderate	Some
NJ	NJ-X	0.84	0.35	Unknown	Unknown	Isolated, single	Low	Low	Some
PA	PA-15384	0.84	0.51	Unknown	Some evidence	Some	Moderate	Low	Some
PA	PA-2038	0.84	0.65	> 30 adults	Some evidence	Strong	Moderate	Unknown	High
PA	PA-2284	0.79	0.46	Unknown	Some evidence	Isolated, single	Moderate	Low	Some
PA	PA-29255	0.75	0.41	Unknown	Some evidence	Isolated, single	Low	Moderate	Some
NJ	002	0.75	0.31	Unknown	Some evidence	Some	Unknown	Moderate	High
NJ	065	0.84	0.35	Unknown	Unknown	Isolated, single	Moderate	Low	None
NJ	113	0.74	0.40	Unknown	Some evidence	Isolated, single	Moderate	Low	High
NJ	127	0.84	0.35	Unknown	Unknown	Isolated, single	Moderate	Low	None
NY	NY11466	0.84	0.32	Unknown	Some evidence	Some	Low	Unknown	High

NY	NY11471	0.95	0.32	Unknown	Some evidence	Some	Unknown	Unknown	None
NJ	058	0.90	0.40	Unknown	Unknown	Isolated, single	Low	Low	None
MD	MD-16	0.79	0.46	Unknown	Some evidence	Isolated, single	High	Low	None
MD	MD-72	0.75	0.31	Unknown	Some evidence	Unknown	Moderate	Moderate	High
MD	MD-83	0.75	0.41	Unknown	Some evidence	Some	Moderate	Moderate	Some
MD	MD-87	0.75	0.41	Unknown	Some evidence	Some	Moderate	Moderate	Some
PA	PA-20889	0.75	0.41	Unknown	Some evidence	Isolated, single	Low	Moderate	Some
PA	PA-27944	0.84	0.65	> 30 adults	Some evidence	Isolated, single	Low	Unknown	Some
PA	PA-3643	0.95	0.65	> 30 adults	Some evidence	Strong	Unknown	Unknown	Some
Fair Resiliency (S1) or Poor Resiliency (S2)									
NJ	012	0.32	0.05	< 30 adults	Unknown	Isolated, single	Unknown	High	Some
NJ	013	0.50	0.00	Unknown	Unknown	Isolated, single	High	High	High
NJ	016	0.65	0.05	Unknown	Unknown	Isolated, single	Unknown	High	Some
NJ	019	0.60	0.00	Unknown	Unknown	Isolated, single	Unknown	High	High
NJ	025	0.70	0.20	Unknown	Unknown	Some	Moderate	Moderate	High
NJ	036	0.60	0.10	Unknown	Unknown	Isolated, single	Low	High	High
NJ	038	0.64	0.15	Unknown	Unknown	Isolated, single	High	Moderate	Some
NJ	043	0.65	0.05	Unknown	Unknown	Isolated, single	Unknown	High	Some
NJ	044	0.65	0.05	Unknown	Unknown	Isolated, single	Unknown	High	Some
NJ	048	0.60	0.10	Unknown	Unknown	Isolated, single	Moderate	High	Some
NJ	059	0.65	0.16	Unknown	Unknown	Isolated, single	Low	High	Some
NJ	060	0.70	0.20	Unknown	Unknown	Isolated, single	Moderate	Moderate	Some
NJ	066	0.69	0.10	Unknown	Unknown	Isolated, single	Unknown	Moderate	High
NJ	068	0.69	0.10	Unknown	Unknown	Isolated, single	Unknown	Moderate	High
NJ	070	0.64	0.15	Unknown	Unknown	Isolated, single	High	Moderate	Some
NJ	087	0.65	0.05	Unknown	Unknown	Isolated, single	Unknown	High	Some
NJ	089	0.60	0.10	Unknown	Unknown	Isolated, single	Moderate	High	Some
NJ	093	0.65	0.05	Unknown	Unknown	Isolated, single	Unknown	High	Some
NJ	109	0.69	0.10	Unknown	Unknown	Isolated, single	Unknown	Moderate	High
NJ	123	0.70	0.20	Unknown	Unknown	Some	Moderate	Moderate	High
NJ	131	0.55	0.05	Unknown	Unknown	Isolated, single	Moderate	High	High
NJ	139	0.65	0.05	Unknown	Unknown	Isolated, single	Unknown	High	Some
NJ	151	0.55	0.05	Unknown	Unknown	Isolated, single	Moderate	High	High
NJ	156	0.60	0.00	Unknown	Unknown	Isolated, single	Unknown	High	High
NJ	173	0.60	0.10	Unknown	Unknown	Isolated, single	Moderate	High	Some
PA	PA-10215	0.35	0.16	< 30 adults	None/Potential	Isolated, single	Low	Unknown	Some
PA	PA-11021	0.36	0.20	< 30 adults	Unknown	Isolated, single	Moderate	Moderate	Some
PA	PA-13054	0.70	0.20	Unknown	Unknown	Isolated, single	Moderate	Moderate	Some

PA	PA-14011	0.40	0.05	< 30 adults	Unknown	Isolated, single	High	Unknown	Some
PA	PA-15045	0.51	0.05	< 30 adults	Unknown	Isolated, single	Unknown	Unknown	Some
PA	PA-15374	0.70	0.20	Unknown	Unknown	Isolated, single	Moderate	Moderate	Some
PA	PA-15376	0.35	0.16	< 30 adults	None/Potential	Isolated, single	Low	Unknown	Some
PA	PA-15398	0.36	0.20	< 30 adults	Unknown	Isolated, single	Moderate	Moderate	Some
PA	PA-15462	0.42	0.21	< 30 adults	Some evidence	Some	Unknown	High	Unknown
PA	PA-15880	0.35	0.16	< 30 adults	None/Potential	Isolated, single	Low	Unknown	Some
PA	PA-17407	0.46	0.10	< 30 adults	Unknown	Isolated, single	Moderate	Unknown	Some
PA	PA-17651	0.65	0.16	Unknown	Unknown	Isolated, single	Low	High	Some
PA	PA-18784	0.46	0.26	< 30 adults	Some evidence	Isolated, single	Moderate	Unknown	Some
PA	PA-18821	0.70	0.20	Unknown	Unknown	Isolated, single	Moderate	Moderate	Some
PA	PA-19792	0.31	0.15	< 30 adults	Unknown	Isolated, single	Moderate	Moderate	High
PA	PA-22761	0.64	0.15	Unknown	Unknown	Isolated, single	High	Moderate	Some
PA	PA-23068	0.55	0.05	Unknown	Unknown	Isolated, single	High	High	Some
PA	PA-244	0.31	0.15	< 30 adults	Unknown	Isolated, single	High	Moderate	Some
PA	PA-24813	0.70	0.20	Unknown	Unknown	Isolated, single	Moderate	Moderate	Some
PA	PA-4670	0.55	0.05	Unknown	Unknown	Isolated, single	High	High	Some
PA	PA-8805	0.51	0.16	< 30 adults	Unknown	Isolated, single	Moderate	Unknown	None
PA	PA-9039	0.35	0.16	< 30 adults	Some evidence	Isolated, single	High	Unknown	High
PA	PA-30939	0.60	0.10	Unknown	Unknown	Isolated, single	Moderate	High	Some
NJ	010	0.65	0.05	Unknown	Unknown	Isolated, single	Unknown	High	Some
NJ	033	0.31	0.15	< 30 adults	Unknown	Isolated, single	Moderate	Moderate	High
NJ	045	0.32	0.21	< 30 adults	Some evidence	Isolated, single	Unknown	High	Some
NJ	056	0.65	0.05	Unknown	Unknown	Isolated, single	Unknown	High	Some
NJ	078	0.65	0.05	Unknown	Unknown	Isolated, single	Unknown	High	Some
NJ	100	0.60	0.10	Unknown	Unknown	Isolated, single	Moderate	High	Some
NJ	164	0.70	0.20	Unknown	Unknown	Isolated, single	Moderate	Moderate	Some
NY	NY10607	0.49	0.05	Unknown	None/Potential	Isolated, single	Unknown	High	Some
NY	NY10977	0.60	0.00	Unknown	Unknown	Isolated, single	Unknown	High	High
NY	NY11467	0.60	0.16	Unknown	Some evidence	Isolated, single	Unknown	High	High
NY	NY11470	0.60	0.26	Unknown	Some evidence	Some	Moderate	High	High
NY	NY11477	0.55	0.05	Unknown	Unknown	Isolated, single	Moderate	High	High
NY	NY11563	0.60	0.00	Unknown	Unknown	Isolated, single	Unknown	High	High
NY	NY12066	0.45	0.26	< 30 adults	Some evidence	Some	Moderate	Unknown	High
NY	NY3362	0.44	0.00	Unknown	None/Potential	Isolated, single	Unknown	High	High
NY	NY3569	0.51	0.16	< 30 adults	Unknown	Isolated, single	Low	Unknown	Some
NY	NY5092	0.60	0.00	Unknown	Unknown	Isolated, single	Unknown	High	High
NY	NY5813	0.36	0.26	< 30 adults	Some evidence	Isolated, single	Unknown	Moderate	High

NY	NY7011	0.69	0.20	Unknown	Unknown	Isolated, single	Low	Moderate	High
NY	NY7944	0.41	0.25	< 30 adults	Unknown	Isolated, single	Moderate	Moderate	None
NY	NY9347	0.60	0.26	Unknown	Some evidence	Isolated, single	Low	High	High
NY	NY15126	0.64	0.15	Unknown	Unknown	Isolated, single	Moderate	Moderate	High
NJ	018	0.60	0.00	Unknown	Unknown	Isolated, single	Unknown	High	High
NY	NY3077	0.36	0.10	< 30 adults	Unknown	Isolated, single	Unknown	Moderate	High
MD	MD-14	0.64	0.15	Unknown	Unknown	Isolated, single	High	Moderate	Some
MD	MD-24	0.55	0.05	Unknown	Unknown	Isolated, single	High	High	Some
MD	MD-35	0.64	0.15	Unknown	Unknown	Some	High	Moderate	High
MD	MD-40	0.70	0.20	Unknown	Unknown	Some	High	Moderate	Some
MD	MD-42	0.55	0.21	Unknown	Some evidence	Isolated, single	Moderate	High	High
MD	MD-46	0.55	0.05	Unknown	Unknown	Isolated, single	High	High	Some
MD	MD-47	0.60	0.10	Unknown	Unknown	Isolated, single	Moderate	High	Some
MD	MD-59	0.60	0.26	Unknown	Some evidence	Some	Moderate	High	High
MD	MD-60	0.60	0.26	Unknown	Some evidence	Isolated, single	Moderate	High	Some
MD	MD-61	0.55	0.05	Unknown	Unknown	Isolated, single	High	High	Some
MD	MD-63	0.55	0.21	Unknown	Some evidence	Isolated, single	Moderate	High	High
MD	MD-66	0.60	0.26	Unknown	Some evidence	Isolated, single	Moderate	High	Some
MD	MD-74	0.55	0.21	Unknown	Some evidence	Isolated, single	High	High	Some
MD	MD-88	0.50	0.00	Unknown	Unknown	Isolated, single	High	High	High
MD	MD-9	0.60	0.26	Unknown	Some evidence	Isolated, single	Moderate	High	Some
MD	MD-92	0.60	0.10	Unknown	Unknown	Isolated, single	Moderate	High	Some
PA	PA-14596	0.46	0.30	< 30 adults	Unknown	Isolated, single	Moderate	Low	Some
PA	PA-16363	0.35	0.16	< 30 adults	None/Potential	Isolated, single	Low	Unknown	Some
PA	PA-19246	0.40	0.11	< 30 adults	None/Potential	Isolated, single	Unknown	Unknown	None
PA	PA-22734	0.45	0.26	< 30 adults	Some evidence	Some	Moderate	Unknown	High
PA	PA-23603	0.32	0.16	< 30 adults	Unknown	Isolated, single	Low	High	Some
PA	PA-23796	0.60	0.10	Unknown	Unknown	Isolated, single	Low	High	High
PA	PA-24091	0.46	0.10	< 30 adults	Unknown	Isolated, single	Moderate	Unknown	Some
PA	PA-26084	0.60	0.26	Unknown	Some evidence	Isolated, single	Moderate	High	Some
PA	PA-27850	0.51	0.16	< 30 adults	Unknown	Isolated, single	Low	Unknown	Some
PA	PA-4762	0.36	0.20	< 30 adults	Unknown	Some	Moderate	Moderate	High
PA	PA-7056	0.45	0.26	< 30 adults	Some evidence	Isolated, single	Low	Unknown	High
PA	PA-32261	0.60	0.10	Unknown	Unknown	Isolated, single	Moderate	High	Some
PA	PA-32247	0.70	0.20	Unknown	Unknown	Isolated, single	Moderate	Moderate	Some

[1] Resiliency categories and metapopulation conditions are in the “MetaPopData” tab.

Appendix B. Additional Information on Threats

Disease

In 2011, the Wildlife Conservation Society/Bronx Zoo conducted an initial health screening on 45 live bog turtles from Connecticut, Massachusetts, and New York in response to an unusually high number of carcasses found during spring surveys (Raphael 2011, entire). Additional health screenings on 387 live bog turtles, as well as other sympatric turtle species (*e.g*., spotted turtle [*Clemmys guttata*], wood turtle [*Glyptemys insculta*]), across six northern states, including Delaware, Massachusetts, Maryland, New Jersey, and Pennsylvania, were conducted by the Wildlife Conservation Society/Bronx Zoo between 2012 and 2017 (Raphael *et al*. 2018, entire).

From these screenings, significant findings included a high incidence of herpesvirus in wild bog turtles in the northeast. Herpesviruses are known to cause ulcerative rhinitis, mild to severe conjunctivitis, lethargy, oral lesions, pneumonia, genital lesions, and nasal and oral discharges, among other symptoms in Atlantic loggerhead sea turtles (*Caretta caretta*), Greek tortoises (*Testudo graeca*), and eastern box turtles (*Terrapene carolina carolina*) (Origgi *et al*. 2004, p. 55; Stacy *et al*. 2008, pp. 66–67; Sim *et al*. 2015, p. 220). Three turtle herpesviruses were identified during the bog turtle health screenings and described by Ossiboff *et al.* (2015a, p. 5). Two of these were found to infect bog turtles, *Glyptemys* herpesvirus 1 (the predominant virus detected in bog turtles in the northeast) and *Emydid* herpesvirus 2 (specific to New Jersey). All bog turtles were asymptomatic during handling and appear to have only mild infections suggesting the herpesviruses are host-adapted to this species. However, Ossiboff *et al*. (2015a, p. 7) warn that significant disease could result if a species were immunocompromised and exposed to a host-adapted virus of a closely related species.

Ossiboff *et al*. (2015b, p. 469) also observed a high incidence of the *Mycoplasma* bacterium in wild individual bog turtle populations, with 70% being positive of 83 individuals tested in the northeast. The *Mycoplasma* bacterium is known to cause chronic upper respiratory tract disease in tortoises (*e.g*., desert tortoise [*Gopherus agassizzi*; Brown *et al*. 1994, p. 4582]; gopher tortoise [*Gopherus polyphemus*; Brown *et al*. 1999, p. 2264]) and eastern box turtles (Feldman *et al*. 2006, p. 281). Ossiboff *et al*. (2015b, p. 469) found no clinical signs of *Mycoplasma* on bog turtles indicating a commensal relationship of the bacterium on the positive individuals.

Ranavirus is another disease that has been implicated in the rapid deterioration of health and mortality of turtles, such as the eastern box turtle, with symptoms that include loss of muscle, lethargy, congested lungs, eyelid paralyzation, and oral and nasal discharges among others (Belzer and Seibert 2011, pp. 18–21). Ranavirus has also been detected on wild bog turtles in the northeast. Raphael *et al*. (2018, p. 5) found that out of 274 bog turtles tested, 1% were positive, but no information is available as to whether the individuals were symptomatic.

Also, a bacterial pneumonia infection was the leading cause of death in two fresh carcasses of wild bog turtles in North Carolina and Virginia (Carter *et al*. 2005, pp. 171–172), within the southern population. Bacterial pneumonia has not been detected in northern populations to date.

Lastly, in 2020, two bog turtles found dead at an individual population in Massachusetts were diagnosed with liver cancer through histopathology conducted at the Wildlife Conservation Society/Bronx Zoo. No other records exist of bog turtles with cancer. While it is unknown whether this diagnosis caused the mortality, it raises the question about the prevalence and potential cause of cancer within this particular bog turtle population. Some research exists on this topic within wildlife conservation (McAloose and Newton 2009; entire), but little is found regarding turtles. Duffy *et al*. (2018, pp. 2–3) state that green sea turtles (*Chelonia mydas*) are highly susceptible to fibropapillomatosis, an oncogenic herpesvirus, and there is conservation concern for this species as a result. McAloose and Newton (2009, p. 517) advise that wildlife cancers can be related to viruses, carcinogens, or could be of novel transmission that may lead to decreased reproduction and ultimately population declines. We know that bog turtles are exposed to viruses, including herpesviruses, and are found on landscapes in proximity to the application of agricultural chemicals; however, more research is needed to better understand the potential link to mortality.

In response to the discovery of these diseases, disinfection protocols and procedures are now required by many state agencies within the northern population to implement before or after conducting field work to reduce the spread of disease from wetland to wetland. For now, we can say that disease is not expected to result in rangewide impacts to metapopulations currently.

Climate Change

Butler (2019, pp. 2–5) reviewed and summarized current impacts of climate change at the individual, population and community-levels of turtles (table B1). While not all of the potential impacts may be applicable to bog turtles, some could be affecting the resiliency of individual populations currently. For example, at the individual-level, bog turtles may be experiencing changes to hatchling growth rates and survivorship due to changes in precipitation and temperature. Further, sex ratios may be changing at the population-level due to changes in temperature. We have no detailed studies to assess whether bog turtles are experiencing these effects from climate change, but a query of biologists and researchers in both the northern and southern populations resulted in anecdotal observations for potential ongoing impacts from climate change—especially those related to ongoing changes in temperature and increased drought and flooding conditions (table B2).

Table B1. A general review and summary of current impacts to turtle species at the individual-, population-, and community-levels as a result of climate change based on Butler (2019, pp. 2–5) and the original source of information. Community-level is generally defined for this review as other turtle species inhabiting the same geographic area (*i.e.*, floodplain area, wetland, river system).

Individual	Population	Community
Resource availability may be changing by reducing or changing prey base which may affect individual growth rates or survivorship (Butler 2019, p. 3).	An expansion or contraction of population distribution may be resulting due to distances traveled to lay eggs in optimal conditions (Pike 2013, pp. 3090–3091; Franch *et al*. 2015, p. 138).	Community composition may be changing due to precipitation changes (*i.e.*, drought) that may lead to increased predation pressure (Chessman 2011, p. 669).
Nest site selection may be changing where a change in the thermal environment can affect embryo survivorship, sex of offspring, and embryo growth rate (Wilson 1998, p. 1890; Kolbe and Janzen 2002, pp. 277–278; Cordero *et al*. 2018, p. 45).	Seasonal movements may be changing due to temperature changes (*e.g.*, traveling from warmer to cooler locations; warmer temperatures can lead to earlier nest-laying) (Pilcher *et al*. 2014, pp. 195–196; Mitchell *et al*. 2017, pp.277–279).	Climate change may be causing an increase in the presence of invasive turtle species (*e.g.*, red-eared slider [*Trachemys scripta elegans*]) which can lead to a change in community composition due to competition for basking sites, change in prey-base (Ramsay *et al*. 2007, p. 163) and increased transmission of diseases and parasites (Ramsay *et al*. 2007, p. 164).
Temperature and precipitation changes may be affecting hatchling growth rates and survivorship (McCallum *et al*. 2009, pp.261–262; Butler 2019, p. 3).	Sex-ratios may be changing due to increased temperatures that could lead to more feminization in populations (Schwanz *et al*. 2010, p. 3023; Jensen *et al*. 2018, p. 154; Butler 2019, p. 4).	
Egg-laying dates or size of eggs may be changing with a change in temperature (Visser 2008, p. 652).	Fecundity may be changing due to a change in accessibility of nesting substrate (*e.g.*, due to flooding) (Eisemberg *et al*. 2016, pp. 7–8).	
	Survivorship may be changing (*e.g.*, due to increase in predation, decrease in precipitation) (Lovich *et al*. 2014, pp. 220–221; Fernández-Chacón *et al*. 2011, p. 3084).	

Table B2. Summary of potential current climate change anecdotal observations made by biologists and researchers in the northern and southern bog turtle populations.

Population	Potential Current Climate Change Anecdotal Observations
Northern	**Flooding:** A site that was visited in 2019 had a classic core habitat patch of tussock sedge nesting habitat and another patch in the wetland that was taken over by reed canary grass (*Phalaris arundinacea*). The nesting habitat is situated adjacent to a road and a stream/culvert that crosses that road at the north (upstream) end of the wetland. I visited the site twice that year, once to confirm there was habitat present (early spring) and the site looked great at that point. Then I revisited the site some weeks later with a group of surveyors and the site looked like it had been torn apart. That second visit was just after a particularly bad flash flood event. That flood water breached the stream bank and came rushing through the nesting habitat. The force of the water had ripped up and rolled matts of vegetation, and there was only bare soil in a large section where the vegetation was ripped up (Erb 2021, pers. comm.).
	Flooding: We are seeing an increase in the frequency and amplitude of damaging floods. This is most exemplified by what occurred at one of the best core habitats in Maryland; a site the Department of Natural Resources (DNR) purchased in 2015 because it had at that time the largest bog turtle population in the state (>130 individual turtles). On May 15, 2018, Beth Schlimm (DNR) led a Phase II survey team there and they caught 16 bog turtles (14 live, 2 dead). That was the last "good" survey conducted there to date because on August 31, 2018, a 500–1000-year storm occurred, where about 10 inches of rain fell on the area in a short amount of time. A wall of water proceeded down the stream valley and when it got to the wetland, it jumped the stream bank and entered the wetland. About 1/3 of the wetland (the area with the highest density of turtle captures) was blown out and turned into a pond, sedge mats from that area were found 6–8 feet up in trees the next day. An adjacent area (about 20% of the wetland) was buried under stream rocks and coarse sand. On September 2, 2018, I walked the area and downstream looking/smelling for dead or injured turtles but found none. In 2019, we conducted four full Phase II surveys and found zero bog turtles. This caused grave concern. In 2020, we were slated to trap the site, but this did not occur due to the Covid pandemic. Scott McDaniel did walk the site in April 2020 twice (at least) and found a recently dead bog turtle (predation) and a live one (unmarked adult female). So, there is some cause for hope. The pond is filling in nicely with sediment and native wetland vegetation, so it is recovering. We will trap it in May 2021 and see what we find. The hope is turtles either had left the site pre-storm (there is an area within 0.25 mile they use) or survived but were swept downstream and it may take some years for them to return. I am not hopeful because I don't see how anything could have survived the energy of that flood. Two humans lost their life downstream, and a car with driver was swept off the road a few 100 yards upstream of the wetland and was pinned to a tree—the person had to be rescued and easily could have been killed. These bog turtle sites are in flood plains and they are annually flooded, and the turtles evolved with this occurrence, but the frequency and ferocity of major storms in today's changing world bode ill for bog turtles (Smith 2021, pers. comm.).
	Drought: Pronounced drops in water levels are more frequently occurring. Dry periods in the summer are normal, but it seems that the water tables are not as high or full as they used to be—at any time of the year even with a lot of rainfall—possibly due to warmer winters. In a warm winter there's less snow, and even if it does snow, it melts (and runs off) fast, as opposed to a slow melt and gradual infiltration into the water table, particularly during a slow spring thaw. Spring-fed wetlands thus may be becoming less drought resilient (Tesauro 2021, pers. comm.).
	Drought: Dry conditions are paving the way for Japanese stiltgrass (*Microstegium vimineum*) in some sites, which had mostly been restricted to seasonally wet wetlands (*e.g.*, meadows, floodplains). Similar observations in Pennsylvania have been made for small carpetgrass (*Axonopus* spp.) and mile-a-minute (*Persicaria perfoliata*). None of these species readily germinate (or thrive) in perennially saturated soils but are quick to exploit drought conditions (Tesauro 2021, pers. comm.).
	Flooding: Streambank destabilization, which appears to threaten bog hydrology at some sites, is definitely exacerbated by extreme rain events. It's something we are seeing a fair bit. Flooding events are also drowning bog turtle nests, and appear to force atypical nesting placement (for

Southern	example, we had a hurricane hit during peak nesting period years ago, four of our turtles nested within the bog, a few of which flooded, the other four moved out of the bog and nested in the cattle pasture adjacent to the wetland (which is not typical), which might then increase the probability of predation (I can't speak on this empirically as we caged those nests)) (Knoerr 2021, pers. comm).
	Flooding: We have noticed an increase in the past 5–10 years of more intense storms (high rainfall within a short time period) impacting some of the bogs through erosion and sedimentation via overland flow, as well as worsening head-cuts and increased flooding of bogs from adjacent streams (Graeter 2021, pers. comm.).
	Temperature: We have observed that bog turtles have phenomenal plasticity in regards to incubation period, which is directly linked to incubation temperature. I've observed turtles hatch at 60 days, and at 100 (although I'd think there are some energetic/survival costs to either extremes). So I don't know what the effects of increased ambient temperature is on hatch rates, but extreme droughts could certainly fry eggs (which I've seen when *Juncus* spp. thatch density is high and nests have been placed atypically in the thatch itself when good nesting habitat is limited) (which then brings up the question of a shifting climate on plant growth rates and increasing rates of succession). Conversely, I have seen nest mortality associated with freeze events as well. At our higher elevation sites, our last turtles to hatch are hatching during the first freezes of the year (some of which I'm sure is a normal phenomena). Some of those hatchlings appear to survive the freeze, others do not. So, increased ambient temps may extend the incubation window, but shifting weather patterns might also produce more "early" freezes that kill emerging hatchlings before they can get under the water/muck (Knoerr 2021, pers. comm.).
	Temperature: A concern that I've had, but have no data on, is the effect of these warm spells in the winter on bog turtle physiology. They surface from their hibernacula to bask sometimes, and if they start metabolizing in any significant way, they are going to lose weight or start feeding, presuming they can find food. This in itself might be problematic if they need to go back into brumation because of fermentation, etc. (my understanding is that they need an empty gut when dormant, but I am not 100% on that) (Knoerr 2021, pers. comm.).
	Drought: I think one of the more compelling anecdotes was the massive die off we had at our largest population (~350 marked turtles). It's our only population in North Carolina modeled to be growing. We found over 50 dead turtles in 2019. There is still disagreement as to whether the primary mechanism was disease or predation (or both), but what is agreed is that the event coincided with a serious drought period that reduced area of inundation significantly—turtles were forced to congregate in a less than 0.5-acre wet area. As the turtles were at incredible densities (59 adult turtles/acre, but much higher density than that when considering 40% of raw encounters are juveniles), they were concentrated in the wet areas that remained, and were affected by something. I think the drought was the stressor that made either disease or mass predation possible (Knoerr 2021, pers. comm.).
	Drought: Also, that same 2019 drought period, I visited the highest elevation bog turtle site in the world, and it was almost completely dry, when normally it has multiple springs feeding it. There is one turtle known in that wetland, and he resides in water under a big rock. He was found under that rock which still had some saturated soil; thus, he did survive that event (Knoerr 2021, pers. comm.).

Changes in precipitation may alter bog turtle wetland hydrology, and because it is a primary factor in determining core habitat, any changes in hydrology can impact the species' habitat use and movements (Feaga 2010, pp. 8, 221). Drought conditions can lower water tables and reduce surface saturation and reduce mucky areas that turtles bury into or dry out hibernation areas. Conversely, flooding raises water tables and increases surface water saturation where nesting areas become inundated, as has been evidenced by Zappalorti *et al*. (2015, p. 581) and Knoerr *et al*. (2021, p. 299), as well as can inundate overwintering habitat and facilitate the expansion of invasive plant species (Sirois 2011, pp. 6, 11). Feaga (2012, p. 1020) suggests that because bog turtle wetlands are “hydrologically buffered,” assuming by the influence of groundwater recharge (although not specifically stated), that core habitats can overcome the effects of drought. However, repeated drought events make it difficult for water tables to rebound over time. Monitoring can help us better understand the persistence of wetland hydrology and long-term climate changes in bog turtle wetlands.

Further, increases in temperature can lead to heat stress which was attributed to failure of two nests at a southern range population (Knoerr *et al*. 2021, p. 299). Knoerr *et al*. (2021. pp. 299–300) also assumed that decreased temperatures during egg incubation leads to an extended incubation period, and may also lead to delayed time to maturity, reduced embryonic survival, and body size.

Evaluating the changes in body size and growth is a different approach to assessing the effects of climate change. Wood turtles (*Glyptemys insculpta*) are known to co-occur at bog turtle wetlands. Jones *et al*. (2019, entire) compared wood turtles from an 1850’s museum collection to present-day wild individuals in Massachusetts and found that present-day adults and juveniles are 20% larger and grow significantly faster, respectively, than the museum specimens. The authors attributed this difference to potential density-dependent, as well as temperature-related factors. The analysis of weather station data showed that the average summer temperature for the study area has increased over the past 100 years by 0.016 °C per year and has resulted in an increase in growing degree-days. A comparative study for bog turtles like Jones *et al*. (2019, entire) has not been done, but would be interesting to complete to see if similar conclusions are reached.

Lastly, five bog turtle wetlands near the coastal area of New Jersey may become affected by sea level rise and saltwater intrusion.

Conservation Actions

Table B3 provides additional details regarding state endangered species laws, state amphibian and reptile laws that regulate the possession, import/export, sale, propagation and release of species, and state wetland laws that regulate direct disturbance to wetlands and their adjacent buffers in the northern range states.

Table B3. A summary of amphibian and reptile regulations and wetland regulations by state.

State		State Listing Status	State Amphibian and Reptile Regulations	State Wetland Regulation
CT		Endangered	Regulations of Connecticut State Agencies – Section 26-55-6 Importation, Possession or Liberation of Wild Birds, Mammals, Reptiles, Amphibians and Invertebrates. Considered a "Category Four Wild Animal" – no person shall import or possess any unless such person has been issued a permit	All inland wetlands are protected under The Connecticut Inland Wetlands and Watercourses Act. A permit is needed from a municipal inland wetlands agency and/or a permit from the Department of Energy and Environmental Protection is needed. Permits are needed for removal or deposition of material, or for any obstruction, construction, alteration or pollution of wetlands. Towns regulate the buffer areas around wetlands. A permit is needed for Federal wetlands through the Army Corps of Engineers (Corps).
DE		Endangered	Title 7 Natural Resources and Environmental Control Delaware Administrative Code – Section 15.1 Commercial Collection, 15.2 Collection and Possession, 16.1 Importation, Transportation and Possession – illegal for all without a permit	All tidal and non-tidal wetlands are state regulated under the Delaware Wetlands Act (7 Del. Code, Chapter 66) and the Wetlands Regulations (7 DE Admin. Code 7502). Permits are required for dredging, draining, filling, construction of any kind, bulkheading, mining, drilling and excavation. A permit is needed for Federal wetlands through the Corps.
MA		Endangered	321 CMR 9.01 Exemption List. Considered a "Categorical Non-Exemption" species and may not be imported, possessed, maintained, propagated, bought, sold, exchanged, or offered for sale or exchange except by a person holding a current and valid license or permit.	Wetlands are protected under Massachusetts General Law Chapter 131, Section 40 – The Wetlands Protection Act. Permits are needed for wetland and 100-ft buffer zone disturbance for vegetation removal, regrading, construction of houses, decks, driveways, and commercial or industrial buildings. A permit is needed for Federal wetlands through the Corps.
MD		Threatened	Title 8 Department of Natural Resources Subtitle 3 Wildlife, Section 08.03.11.03 – except under the authority of a permit, bog turtle may not be possessed, bred or commercially traded.	Non-tidal wetlands are protected under the Maryland Non-tidal Wetlands Protection Act and need a permit or letter of authorization for disturbance activities in a non-tidal wetland or within a 25-foot buffer or 100-foot extended buffer around a non-tidal wetland. A permit is needed for Federal wetlands through the Corps.
NJ		Endangered	Section 7:25-4.2 (a) no person shall possess any nongame species or exotic species of any mammal, bird, reptile or amphibian unless such person has first received both the appropriate permit from the	Authorization is needed under the N.J.A.C. 7:7A Freshwater Wetland Protection Act for removal, excavation, disturbance or dredging of soil, sand, gravel or aggregate material, draining or disturbance of water levels or water table, dumping, discharging or filling with any materials, pile driving, placing

			Department as listed in N.J.A.C. 7:25-4.6(a) as well as any other state, municipal or Federal permits or licenses which may be required to possess such species, (b)no liberation without a permit	of obstructions that affect the wetlands functions and values, and destruction of plant life that would alter the character of the wetland. "Transition Areas" (buffers) are also regulated for removal, excavation or disturbance of soil, dumping or filling with any materials, erection of structures, placement of pavement, and destruction of plant life. A permit may be needed for Federal wetlands through the Corps.
NY		Endangered	Environmental Conservation Law 11-0515 and 6 NYCRR Part 175 - all native reptiles in state are considered "small game", with most species having no open season. No possession, collection, propagation, sale, scientific or exhibition purposes can take place without a permit.	Freshwater wetlands are protected under The Freshwater Wetlands Act for wetlands that are ≥ 12.4 acres (5 ha); smaller wetlands may be protected if they are considered of unusual importance. A 100-ft buffer area surround wetlands are also regulated. Permits are needed for both the wetland and buffer area for construction of buildings, roadways, septic systems, bulkheads, dikes or dams, placement of fill, excavation or grading, modification, expansion, or extensive restoration of existing structures, drainage (except for agriculture), and application of pesticides. A permit is needed for Federal wetlands through the Corps.
PA		Endangered	30 Pa C.S. 2305 - species listed as endangered or threatened are protected from collection, possession, import, export, sale, trade purchase or barter, unless permitted. 58 Pa Code Section 75.4 (special permits) states that permits are needed for educational, consulting and research purposes.	Wetlands are regulated by the Department of Environmental Protection (DEP) under the Dam Safety and Encroachments Act and Dam Safety and Waterway Management Rules and Regulations (Title 25, PA Code, Chapter 105). Wetlands and waterways permitting in PA is based on Clean Streams Law and Dam Safety and Encroachments Act. Section 404 of the Clean Water Act review and permitting by the Corps is not needed as a programmatic general permit is in place allowing the DEP to review and process permits. Permits are needed for dredging, filling, water obstruction and encroachments.