Species Status Assessment Report
for the
Brook Floater (*Alasmidonta varicosa*)
Version 1.1.1

Molunkus Stream, Tributary of the Mattawamkeag River in Maine. Photo credit: Ethan Nedeau, Biodrawversity. Inset: Adult brook floaters. Photo credit: Jason Mays, USFWS.

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U.S. Fish and Wildlife Service

This document was prepared by Sandra Doran of the New York Ecological Services Field Office with assistance from the U.S. Fish and Wildlife Service Brook Floater Species Status Assessment (SSA) Team. The team members include Colleen Fahey, Project Manager (Species Assessment Team (SAT), Headquarters (HQ) and Rebecca Migala, Assistant Project Manager, (Region 1, Regional Office), Krishna Gifford (Region 5, Regional Office), Susan (Amanda) Bossie (Region 5 Solicitor's Office, Julie Devers (Region 5, Maryland Fish and Wildlife Conservation Office), Jason Mays (Region 4, Asheville Field Office), Rachel Mair (Region 5, Harrison Lake National Fish Hatchery), Robert Anderson and Brian Scofield (Region 5, Pennsylvania Field Office), Morgan Wolf (Region 4, Charleston, SC), Lindsay Stevenson (Region 5, Regional Office), Nicole Rankin (Region 4, Regional Office) and Sarah McRae (Region 4, Raleigh, NC Field Office). We also received assistance from David Smith of the U.S. Geological Survey, who served as our SSA Coach. Finally, we greatly appreciate our partners from Department of Fisheries and Oceans, Canada, the Brook Floater Working Group, and others working on brook floater conservation.

Version 1.0 (June 2018) of this report was available for selected peer and partner review and comment. Version 1.1 incorporated comments received on V 1.0 and was used for the Recommendation Team meeting. This final version, (1.1.1), incorporates additional comments in addition to other minor editorial changes including clarifications.

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Species Status Assessment Report
For
Brook Floater (*Alasmidonta varicosa*)

Prepared by the U.S. Fish and Wildlife Service

EXECUTIVE SUMMARY

This species status assessment reports the results of the comprehensive status review for the brook floater (*Alasmidonta varicosa* (Lamarck 1819)) and provides a thorough account of the species' overall viability and extinction risk.

The brook floater is an Atlantic slope freshwater mussel historically native to the District of Columbia, 16 states in the eastern United States (Connecticut, Delaware, Georgia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Vermont, Virginia, and West Virginia), and two Canadian provinces (New Brunswick and Nova Scotia). Brook floaters occur in creeks and rivers of varying size, with stable substrates, intact riparian buffers (which are vegetated areas comprised of forest, shrub, or herbaceous plants located adjacent to streams), excellent water quality and in areas with little to no anthropogenic influences. To evaluate the biological status of the brook floater both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). The brook floater needs multiple resilient populations distributed widely across its range to maintain its persistence into the future and to avoid extinction. Several factors influence whether brook floater populations will grow to maximize habitat occupancy, which increases the resiliency of a population to stochastic events. These factors are adequate water quality, temperature and flow; stability of substrate; food availability; chemistry of interstitial spaces; and presence of fish hosts.

As we consider the future viability of the species, more populations with high resiliency distributed across the known range of the species are associated with higher overall species viability. Brook floater populations are currently found in 14 of the 16 historically known states and are considered extirpated in the District of Columbia, Delaware, and Rhode Island. In addition, the brook floater appears to be extirpated from multiple rivers across the rest of the range.

We have assessed the brook floater's levels of resiliency, redundancy, and representation currently and into the future by ranking the condition of each population. Rankings are a

qualitative assessment of the relative condition of occupied streams based on the knowledge and expertise of Service staff as well as published reports. Our analysis of the past, current, and future influences on what the brook floater needs for long term viability revealed that there are several influences that pose the largest risk to future viability of the species. These risks are primarily related to disjunct populations facing habitat loss or fragmentation, changes in water flows, and degraded water quality from development, including urbanization, energy production (e.g., oil and gas extraction), and agricultural development. There are limited conservation programs that specifically target the brook floater or are significantly reducing any of the primary stressors. Development is a primary source of the major stressors (e.g., sedimentation, water quality impairment, habitat loss, and fragmentation) influencing population resilience and ultimately species viability. Thus, we structured future scenarios around levels of development. Other factors considered relate to climate variables.

If populations lose resiliency, they are more vulnerable to extirpation, with resulting losses in representation and redundancy. To assess the 3R's, we developed two scenarios using economic-based land use projections and predicted energy development: Scenario 1 has land-use change similar to trends from 2007-2012, which favors agriculture) and Scenario 2 has land-use change similar to trends from 1992-1997, which favors urbanization).

In both scenarios, agricultural and urban land use is projected to increase. However, Scenario 1 incorporates a 10% increase in crop prices every 5 years relative to Scenario 2. As a result, Scenario 1 has a higher rate of increase in conversion of land to agricultural use than does Scenario 2. Energy development models predicted the impact would be similar to impervious surface and translated the effect of energy development in combination with urbanization on stream quality. Although our analysis could not relate climate change quantitatively to population condition, regional climate summaries and down-scaled projections along with the land-use change scenarios and analyses were available to the core team when future condition was assessed. The effects of climate change were not expected to be uniformly negative across the species' range.

We examined the resiliency of brook floater under each of these plausible scenarios; at 15 years into the future and at 30 years into the future (Table ES-1). Resiliency of brook floater populations depends on future water quality, availability of flowing water, and substrate suitability. We expect the four extant brook floater representative areas to experience changes to these aspects of their habitat in different ways under the different scenarios. We projected the brook floater's expected future resiliency, representation, and redundancy based on the events that would occur under each scenario (Table ES-2).

Based on our analysis under Scenario 1, out of a total of 239 AUs in the U.S. and Canada, approximately 8 percent fewer AUs are expected to be in high condition and 13 percent more AUs are expected to be in very low condition within 30 years. The Southeast and Northeast Representative Areas are expected to experience some decrease in resilience. In the Northeast, 7 percent fewer AUs (34 to 31.5) are expected to be in high or medium condition. In the Southeast, approximately 2 percent fewer AUs (13 to 12.8) are expected to be in high or medium condition. The mid-Atlantic Representative Area is where the largest change in resilience and redundancy is expected. In the mid-Atlantic, the AUs currently in high or medium condition will be reduced by approximately 32 percent from 12 to 8.2 AUs, and the AUs in low or very low will be increased by approximately 6 percent from 69 to 72.8. While brook floater populations continue to occur in scattered populations across all representative areas under this scenario, redundancy will be reduced especially in the mid-Atlantic as the AUs experience decreased resilience.

Based on our analysis under Scenario 2, reductions in resilience and redundancy are expected to be greater than under Scenario 1. Out of a total of 239 AUs in the U.S. and Canada, approximately 21 percent fewer AUs are expected to be in high condition, and 21 percent more AUs are expected to be in very low condition within 30 years. In the Northeast, 18 percent fewer AUs (34 to 27.8) are expected to be in high or medium condition. In the Southeast, approximately 11 percent fewer AUs (13 to 11.6) are expected to be in high or medium condition. Among the representative areas, the mid-Atlantic is expected to experience the biggest decreases in resilience and redundancy. In the mid-Atlantic, the AUs in high or medium condition will be reduced by approximately 43 percent from 12 to 6.9 AUs and the AUs in low or very low condition will increase by 7 percent from 69 to 74.1. While brook floater populations continue to occur in scattered populations across all representative areas under this scenario, redundancy will be reduced especially in the mid-Atlantic as the AUs experience decreased resilience.

Table ES-1. Brook floater resiliency ratings under Current Condition and Future Scenarios, by number of Analytical Units in each Representative Area.

Representative Area	**Current Condition (AU)**	**Future Scenario 1a (land-use change similar to trends from 2007-2012 at 15 years) (AU)**	**Future Scenario 1b (land-use change similar to trends from 2007-2012 at 30 years)(AU)**	**Future Scenario 2a (land-use change similar to trends from 1992-1997 at 15 years)(AU)**	**Future Scenario 2b (land-use change similar to trends from 1992-1997 at 30 years)(AU)**
Canadian					
High	6	6	6	6	6
Medium	2	2	2	2	2
Low	2	2	2	2	2
Very low	5	5	5	5	5
Unknown	4	4	4	4	4
Northeast					
High	17	16.2	15.4	15	13
Medium	17	16.6	16.1	15.9	14.8
Low	11	10.9	10.9	11.8	12.7
Very low	20	21.3	22.6	22.3	24.7
Unknown	12	12	12	12	12

Representative Area	Current Condition (AU)	Future Scenario 1a (land-use change similar to trends from 2007-2012 at 15 years) (AU)	Future Scenario 1b (land-use change similar to trends from 2007-2012 at 30 years)(AU)	Future Scenario 2a (land-use change similar to trends from 1992-1997 at 15 years)(AU)	Future Scenario 2b (land-use change similar to trends from 1992-1997 at 30 years)(AU)
Mid Atlantic					
High	4	3.4	2.8	3	2.1
Medium	8	6.7	5.4	6.4	4.8
Low	15	13.3	11.6	12.7	10.4
Very low	54	57.6	61.2	58.8	63.7
Unknown	35	35	35	35	35
Southeast					
High	9	9	9	8.2	7.3
Medium	4	3.9	3.8	4.1	4.3
Low	6	5.7	5.4	5.8	5.5
Very low	0	0.4	0.8	0.9	1.9
Unknown	8	8	8	8	8

Table ES-2. Species Status Assessment Summary for the Brook Floater

3Rs	Needs	Current Condition	Future Condition (viability)
Resiliency: *large populations (AUs) able to withstand stochastic events*	Suitable substrate Sufficient water quality Flowing river ecosystems Sufficient occupied stream length	15% high 13% medium 14% low 33% very low 25% unknown	Projections based on future scenarios over 30 years. Scenario 1b: Drop in resiliency for 3 of 4 representative areas: moderate decrease for Mid Atlantic, light decline for Northeast, very slight decline for Southeast AUs. No change in Canadian AUs. Scenario 2b: Moderate decrease for mid-Atlantic and Northeast, slight decline for Southeast AUs. No change in resiliency of Canadian AUs. See Chapter 5 for other scenarios

3Rs	Needs	Current Condition	Future Condition (viability)
Representation: *genetic and ecological diversity to maintain adaptive potential*	Ecological variation between small spring-fed headwater streams and larger rivers to preserve the breadth of a species' adaptive diversity.	The brook floater has a wide distribution and shows variation in habitat use as well as host fish use.	Projections based on future scenarios over 30 years. Scenario 1b and 2b: AUs in all representative areas are likely to persist, however the US areas will have lower resiliency. The resiliency of Canadian AUs remains unchanged. See Chapter 5 for other scenarios
Redundancy: *number and distribution of populations (AUs) to help withstand catastrophic events*	Multiple AUs in each area of genetic representation	In Canada, the majority of AUs are in high condition. In the U.S., AUs in high condition occur in areas of relatively good habitat and water quality, but they vary in size and abundance. The Northeast and Southeast representative areas have the largest number of AUs in high condition.	Projections based on future scenarios over 30 years. Scenario 1b and 2b: AUs in all representative areas are likely to persist, however the US areas will have lower resiliency. The resiliency of the Canadian AUs remains unchanged. See Chapter 5 for other scenarios

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Appendix A: Similar Looking Species as Brook Floater

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CHAPTER 1. INTRODUCTION

The brook floater (*Alasmidonta varicosa* (Lamarck 1819)) is an Atlantic slope freshwater mussel historically native to the District of Columbia, 16 states in the eastern United States (Connecticut, Delaware, Georgia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Vermont, Virginia, and West Virginia), and two Canadian provinces (New Brunswick and Nova Scotia). This report provides a summary of the U.S. Fish and Wildlife Service's (Service) Species Status Assessment (SSA) for the brook floater. The SSA framework (Smith *et al.* 2018, entire) is intended to support an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for this SSA report to be easily updated as new information becomes available and to support all functions of the Endangered Species Program, such as listing, consultations, and recovery, as relevant. As such, the SSA report will be a living document upon which other documents, such as listing rules, recovery plans, and 5-year reviews, would be based if the species warrants listing under the Endangered Species Act of 1973, as amended (Act).

The Service conducted the SSA in response to a petition we received in 2010 to list the brook floater under the Act. The Service will issue a 12-month finding on the petition, which will address whether the brook floater warrants listing as a threatened or endangered species under the Act. This SSA will be the biological underpinning of the Service's forthcoming decision on whether the brook floater warrants protection under the Act and, if so, whether or not to propose a critical habitat designation. Importantly, the SSA report does not result in a decision by the Service on whether this species warrants listing as a threatened or endangered species under the Act. Instead, this SSA report provides a review of the best available information strictly related to the biological status of the brook floater. The decision about whether the species warrants listing will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of the decision will be announced in the *Federal Register*, with appropriate opportunities for public input.

For the purpose of this assessment, we generally define viability as the ability of the brook floater to sustain healthy populations in natural river systems within a biologically meaningful timeframe. Using the SSA framework (Figure 1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (collectively termed the "3Rs") (Smith *et al.* 2018, entire).

Resiliency describes the ability of populations to withstand stochastic events (arising from random factors). Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates and juvenile/adult survival (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.

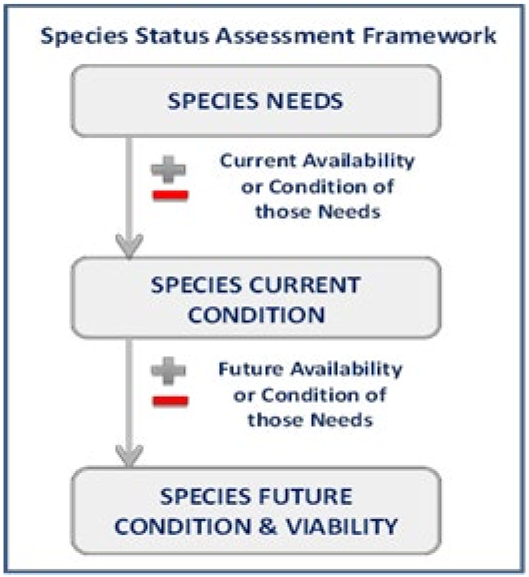

Figure 1. Species Status Assessment Framework.

Redundancy describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations).

Representation describes the ability of a species to adapt to near- and long-term changes in the environment. It can also be thought of as the evolutionary capacity or flexibility of a species. Representation is the range of variation found in a species and this variation—called adaptive diversity—is the source of a species' adaptive capabilities. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment.

This SSA report provides a thorough assessment of biology and natural history and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the species. This SSA report includes:

1. A description of the resource needs of individual brook floaters (Chapter 2);
2. The brook floater's historical and current distribution and a framework for determining the distribution of resilient populations across its range for species viability (Chapter 3);
3. A review of the likely factors influencing the current and future condition of the species and determining which of these factors affects the species' viability and to what degree (Chapter 4); and
4. A description of the viability in terms of resiliency, redundancy, and representation (Chapter 5).

This document is a compilation of the best available scientific and commercial information and a description of past, present, and likely future risk factors to and conservation efforts for the brook floater.

CHAPTER 2. INDIVIDUAL NEEDS, LIFE HISTORY AND BIOLOGY

In this chapter we provide basic biological information about the brook floater, including its taxonomic history, genetics, morphological description, and known life history traits. We then outline the resource needs of individual brook floaters. Here we report those aspects of the life history of the brook floater that are important to our analysis.

2.1 Taxonomy

The brook floater was first described by Lamarck (1819, pp. 78-79) as *Unio varicosa* from the Schuylkill River in Pennsylvania. The species was subsequently placed in the genus *Alasmidonta* described by Say (1818, p. 459). The genus *Alasmidonta* is comprised of the brook floater and 11 additional species, of which 3 species (*A. robusta*, *A. wrightiana*, and *A. mccordi*) are presumed extinct (Bogan 2000a and 2000b, entire; Cummings and Cordeiro 2011, entire) and 3 are federally listed as endangered species (*A. raveneliana*, *A. heterodon*, and *A. atropurpurea*). The remaining 5 species in the genus are considered in decline. For example, the wide ranging *A. marginata* and *A. undulata* have experienced significant declines in portions of their respective ranges.

The currently accepted classification is (Integrated Taxonomic Information System 2017):
Phylum: Mollusca
Class: Bivalvia
Order: Unionoida
Family: Unionidae
Subfamily: Unioninae
Tribe: Anodontini
Genus: Alasmidonta
Species: *Alasmidonta varicosa*

2.2 Genetic Diversity

To our knowledge, there are no comprehensive studies that address the rangewide genetic diversity of brook floater. The first genetic analysis for brook floater focused on characterizing phylogenetic (evolutionary history) relationships of *Alasmidonta* species within North Carolina (Bogan *et al.* 2008, entire). Using sequences from 2 mitochondrial genes, the CO1 (cytochrome c oxidase c subunit 1) and ND1 (NADH dehydrogenase subunit 1), the authors concluded that brook floaters collected from Patterson Creek in West Virginia, Savannah River basin in South Carolina/Georgia, Potomac River basin in Virginia, the upper Catawba River basin and the Cape Fear River basin in North Carolina cluster together and are similar, while mussels collected from the Uwharrie River (Yadkin/Pee Dee River Basin) in North Carolina form a separate clade (a group of organisms that evolved from a common ancestor) (Bogan *et al.* 2008, pp. 14, 28). According to Bogan *et al.* (2008, p. 14), individuals from the Uwharrie River share some shell characteristics with Carolina elktoe (*Alasmidonta robusta*), a species described from an adjacent river basin, which is presumed extinct.

Recent additional genetic samples being evaluated at the Service's Conservation Genetics Laboratory in Warm Springs, Georgia, suggest that the brook floater from the Uwharrie River and Little River in North Carolina demonstrate divergence from other populations of the brook floater (Mays pers. comm. 2018). This information is only preliminary and we are treating individuals from these rivers as brook floaters at this time. Further, we have no evidence to suggest that the rest of the individuals within the range of the brook floater demonstrate this divergence. We (the Service) for the purposes of our assessment are accepting the taxonomy as is currently accepted in the literature.

2.3 Morphological Description

The brook floater is a small freshwater mussel usually less than 75 millimeters (mm) (2.95 inches [in]) in length (Nedeau 2008, p. 76); however, specimens from Maine and South Carolina have been observed over 75 mm (2.95 in) (Nedeau and Savidge pers. comm., respectively). The shell is yellowish-green in young animals to brownish-black in older specimens, often has broad dark green rays, and individuals have a distinctly orange-colored foot.

Molluscs are mostly aquatic, and are named from the Latin *molluscus*, meaning "soft". Their soft bodies are enclosed in a hard shell made of calcium carbonate ($CaCO_3$), which functions as an exoskeleton. This shell is secreted by a thin sheet of tissue, called the mantle, which lines the inside of the shell and encloses the internal organs like a glove. Brook floater shells are relatively thin (1 to 2 mm [0.04 to 0.08 in] at the center in adults) (COSEWIC 2009, p. 5).

The brook floater is sexually monomorphic, which means lacking visible differences between males and females. The shell shape is elliptical to trapezoidal with inflation near the dorsal (top) side with a pronounced posterior ridge (Figure 2 and Figure 3). The ventral margin (bottom of the shell) may be slightly rounded, giving it a kidney-like shape, but is usually straight or indented. The valves are moderately inflated, giving the mussel a swollen appearance. A series of distinctive ridges or corrugations can often be found along the dorso-posterior slope (Nedeau 2007, p. 1). From the beak, the posterior shell is elongate and curves gently to the ventral margin; the anterior shell curves abruptly from the beak to the ventral margin. The periostracum (shell exterior) is yellowish-green to yellowish-brown with green rays, which may be obscured by a deep brown-black periostracum in older adults (Wicklow *et al.* 2017, p. 13). The nacre (shell interior) is variable and ranges from bluish-white to pinkish-white to pale orange (Nedeau 2007, p. 1). One of the more interesting, and noted, behaviors of the brook floater is its propensity for its shell to "gape", or open slightly, when removed from water, which exposes its orange-colored foot and mantle cavity (Figure 4) (Nedeau 2008, p. 78). Internally, pseudocardinal teeth (interlocking triangular or ridge-like teeth structures located along the hinge, which serve to keep the two shell halves in alignment) are poorly developed and "knoblike," and lateral teeth are absent (Figure 2).

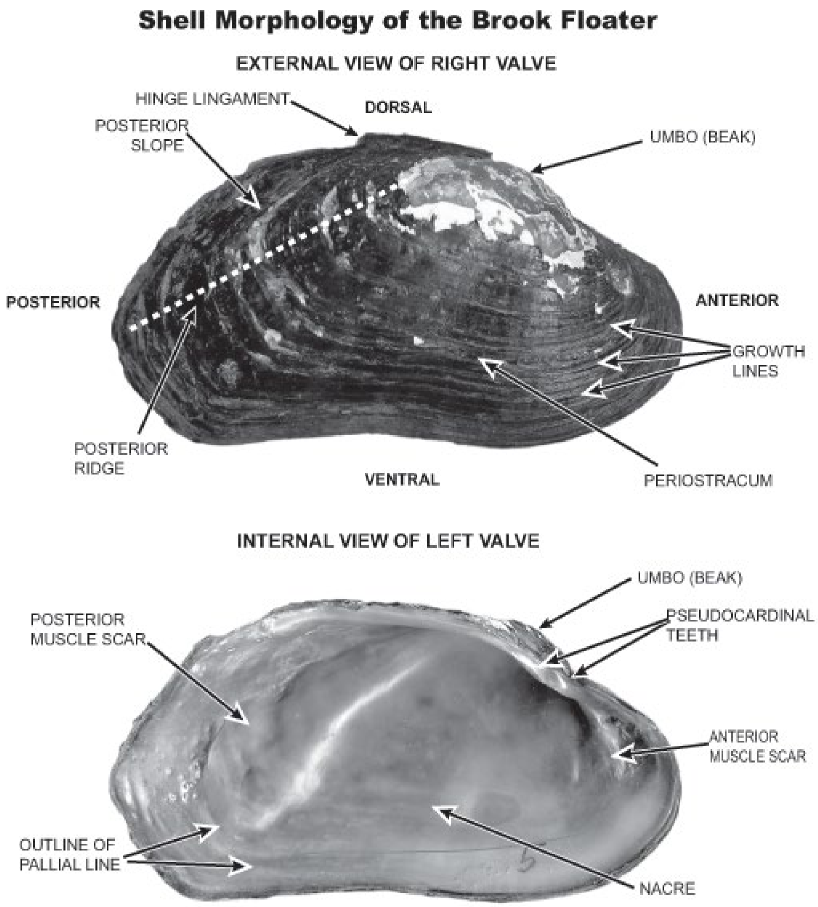

Figure 2. Shell morphology of the brook floater (COSEWIC 2009, p. 6).

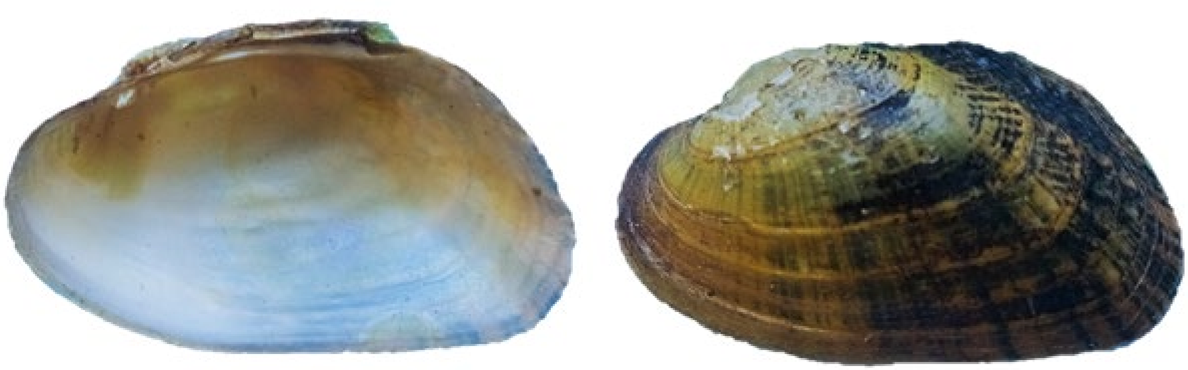

Figure 3. Internal shell right valve (left) and external shell left valve (right) of *Alasmidonta varicosa*, photo credit: Barry Wicklow (Wicklow *et al.* 2017, p. 14).

Figure 4. Photo showing orange-colored foot of brook floater (Nedeau 2008, p. 78).

Similar looking species that overlap in range with the brook floater can be found in Appendix A.

2.4 Life History

2.4.1 Reproduction, including host fish interaction

As is the case with most freshwater mussels, the brook floater has a complex life cycle that relies on fish hosts for successful reproduction (Figure 5).

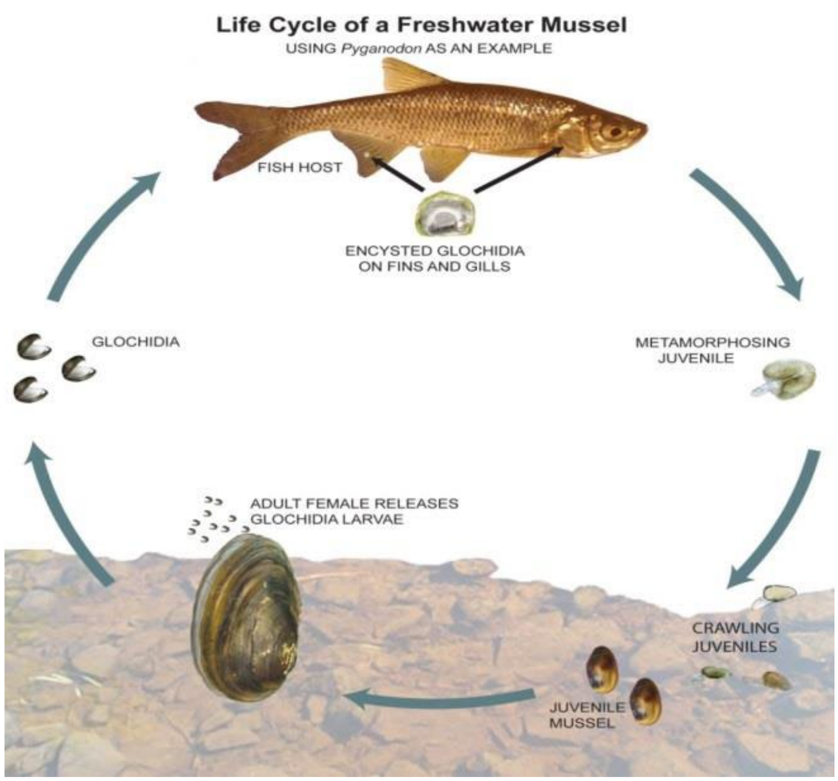

Figure 5. Freshwater mussel life cycle (Martel *et al.* 2010, p. 558).

In general, mussels are either male or female (gonochoristic) (Haag, 2012, p.54). Male brook floaters release sperm into the water column which flows downstream with the current and is taken in by the female through the incurrent aperture (see Figure 6 for general anatomy such as apertures), where water enters the mantle cavity.

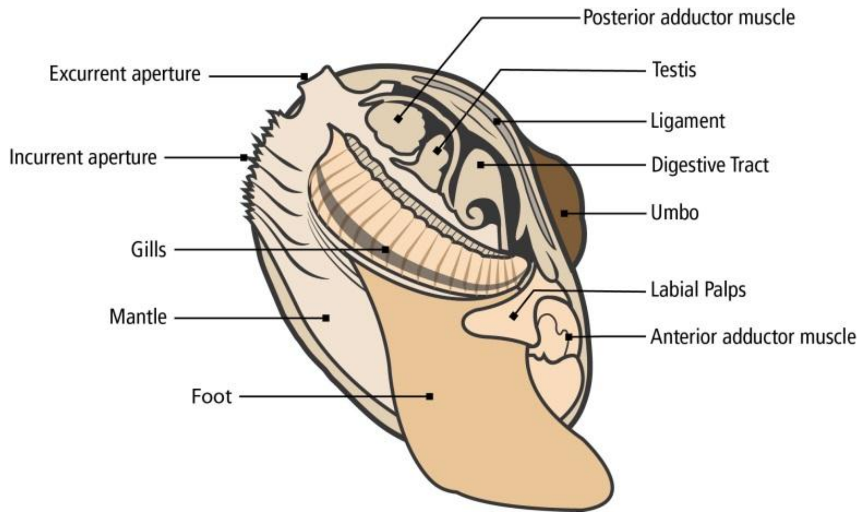

Figure 6. Illustration showing the internal anatomy of a male freshwater mussel. Credit: M. Patterson, USFWS.

The sperm fertilizes eggs that are held within the female's gills in the marsupial chamber. The developing larvae remain in the gill chamber until they mature (called glochidia) and are ready for release. Freshwater mussel species differ from each other regarding when spawning occurs and when the larvae are naturally released. The brook floater is presumed to be a long-term brooder (also called bradytictic), which means that it undergoes fertilization in the late summer-fall and the female retains larvae until the following spring before releasing them (Wicklow *et al*. 2017, p. 7). Other species can be short-term brooders (also called tachytictic) that spawn in spring and release glochidia later that spring or summer. The release of brook floater glochidia is highly temperature dependent, typically occurring when the water temperature reaches 14° C (57.2° F) (Wicklow 2008, p. 7).

Brook floater glochidia are parasites, which derive nutrition from a host fish to complete development from larvae to the juvenile life stage (Fritts et *al*. 2013, p. 165). Many species of mussel including brook floater cannot develop to the juvenile stage without a host fish. Glochidia are open when released into the water and snap shut when they attach to the gills, head, or fins of fishes (Vaughn and Taylor 1999, p. 913). For most mussels, the glochidia will die if they do not attach to a fish within a short period of time. Once on the fish, the glochidia are engulfed by tissue from the host fish that forms a cyst. The cyst protects the glochidia and aids in their maturation. After a few weeks to months after initial attachment, the larvae have developed enough internal organs to drop off or excysts from the fish as a juvenile mussel.

Many freshwater mussel species have strategies to attract host fish in order to complete their life cycle. In contrast, the brook floater, like other species of *Alasmidonta*, may use a passive entanglement strategy to ensure larvae come into contact with host fish (Haag 2012, p. 158).

The female discharges long mucus threads that have larvae attached. The brook floater also has hooked larvae that allow better attachment when fish swim through the mucus web; it is easier for the larvae to attach to the fins and body of the host fish (Figure 7). Passive entanglement is considered to be a nonselective strategy for mussels classified as 'host generalists' because many types of host fish can swim through the mucus web and a specific type of host fish is not being selected (Haag 2012, p. 156). Laboratory trials have confirmed that the brook floater is capable of using many different families of fish as hosts; however most of the fish species are only moderately suitable as hosts, due to the low numbers of mussels that drop off of the fish (see Appendix B for more information on host fish).

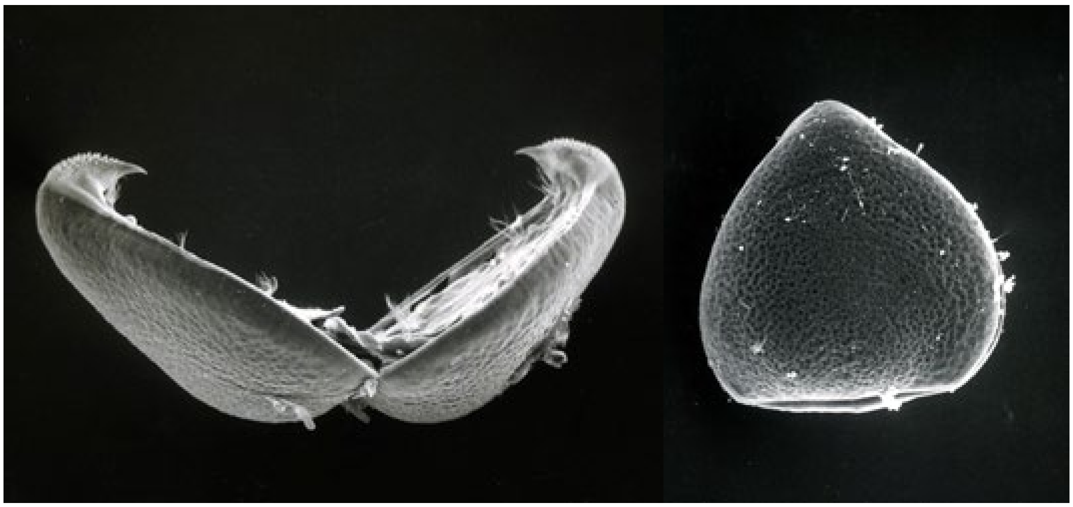

Figure 7. Scanning electron micrographs of *Alasmidonta varicosa* glochidia. Open glochidia (left) showing sensory hairs and hooks that have fine teeth and lateral view of glochidium (right), Photo credit: Barry Wicklow (Wicklow *et al.* 2017, p. 21).

2.4.2 Feeding

While we have no specific dietary studies of the brook floater, we surmise that, similar to all other unionids, the brook floater is an omnivore that presumably feeds on a wide variety of microscopic (less than 28 µm [0.0009 in] in diameter) particulate matter suspended in the water column, including phytoplankton, zooplankton, bacteria, detritus, and dissolved organic matter (Nichols and Garling 2000, p. 872; Haag 2012, p. 26). Juveniles use ciliary patches or hairlike structures on their foot to pedal feed. Pedal feeding is the use of these cilia to move food particles to the labial palps, which are soft tissue appendages where the food is sorted and either assimilated, meaning digested by the mussel, or bound by mucus and rejected in the form of pseudofeces (waste).

Adult freshwater mussels are suspension feeders, meaning they capture food material by pumping water through their incurrent apertures (Figure 6). They do not actively pedal feed, but are capable of accessing food through cilia-generated water currents while the foot is extended (Vaughn *et al.* 2008, p. 410). Adults are able to regulate the rate of feeding by closing their apertures.

2.4.3 Demographics

Little information is known about the demographics of brook floater populations. Overall, we find that brook floaters have low to moderate reproductive potential compared to many other mussel species as discussed below.

While we lack rangewide information on life span, in Canada, brook floaters have been found to live between 7-14 years, with an estimated average life span of 10 years (COSEWIC 2009, p. 31).

Similarly, little information is available for growth rate (proportional change in length per year) in brook floaters. In New Hampshire, Wicklow *et al.* (in prep) studied brook floaters and found that annual growth rate ranged from -0.18 to 0.38 mm/year (-0.007 in to 0.06 inches/year with a mean of 0.05 mm/year (0.002 in/year). However, in the southern part of the range growth rates of mussels (in general) appear to be faster (Bauer 1992, p. 429; Haag 2012, p. 184) and we presume this is the case for the brook floater.

Similar to most mussels (Haag 2012, p. 202), fecundity of brook floaters is directly related to mussel size, with larger individuals producing more young (Wicklow *et al.* 2017, p. 20; Figure 8). The genus *Alasmidonta*, which includes the brook floater, has a low-moderate annual fecundity, ranging from 1,800-68,000 larvae (Wicklow *et al.* 2017, p. 19; R. Mair pers. comm. 2018, T.R. Russ pers. comm. 2018). The brook floater is one of the more fecund *Alasmidonta*, however, with their fecundity in the upper end of the above range. Compared to other freshwater mussels with similar lifespans of 5-11 years and annual fecundity ranging from 7,213 to 9,586,987, brook floater and other *Alasmidonta sp.* lie on the lower end of the range (Haag 2012, p. 205). This is likely due to multiple factors. Reproduction does not occur for a few years. Wicklow *et al.* (2017, p. 8) reports the youngest gravid individuals observed in the wild were 3-4 years old (but it is unclear where in the range this finding is based on and whether this would be similar across the range). In addition, the larvae of *Alasmidonta* are generally much larger than in other genera of mussels, with a mean length of 368 μm (0.014 in) (Wicklow *et al.* 2017, p. 20). We recognize that fecundity may vary across the range and larger brook floaters (not shown in Figure 8) are anticipated to produce more larvae.

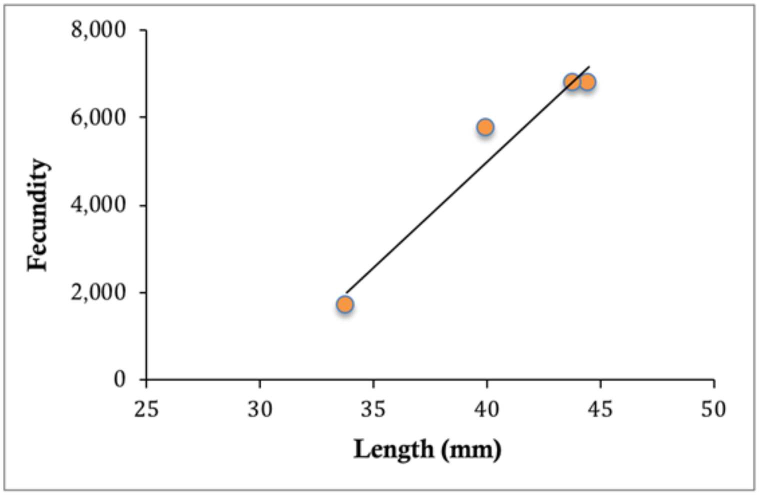

Figure 8. Direct relationship between brook floater annual fecundity and adult female length (mm) (Wicklow *et al.* 2017, p. 20).

2.5 Individual needs - Habitat

In general, the most robust populations of the brook floater historically occurred and currently occur in creeks and rivers of varying size, with stable substrates, intact riparian buffers (which are vegetated areas comprised of forest, shrub or herbaceous plants located adjacent to streams), excellent water quality and in areas with little to no anthropogenic influences (Haag 2012, p. 107; Massachusetts Division of Fisheries and Wildlife 2009).

Brook floaters need clean, low to moderately flowing water, with stable substrate (sand, gravel, and cobble), appropriate food levels, water temperatures above 14°C (57.2°F) for glochidia release (Strayer 1999, p. 468) and interstitial chemistry and presence of fish hosts for glochidia attachment and dispersal (Haag 2012, p. 42).

The following sections further describe our understanding of brook floater needs.

2.5.1 Low to Moderate Current

While brook floaters are generalists when it comes to habitat, they can be found in smaller rivers and streams or in large rivers as well (Ortmann 1919, p. 193; Clarke 1981a, p. 78), such as the Potomac River in Maryland, Virginia, District of Columbia, and West Virginia and the Delaware River located on the New York and Pennsylvania border.

Within these rivers and streams, this species is found in slow to medium currents in runs, pools, and glides or in areas with higher currents but protected behind large cobble, boulders, and woody debris (Wicklow 2008, p. 32). The currents bring a continuous supply of fresh water with oxygen and food to the brook floaters and facilitate the removal of waste products as water exits the shell (Vaughn *et al.* 2008, p. 410). Brook floaters are generally absent from high-velocity, high-gradient streams and scour-prone areas, or unstable sections of sand (Nedeau *et al.* 2000, p. 63; Wicklow 2008, p. 32). Scour is caused by swiftly moving water that causes erosion, channel instability, and scour holes tend to form, especially behind manmade structures such as bridge piers. However, in North Carolina, particularly in the upper Yadkin drainage, they can be found in flow refugia within high gradient, scour-prone streams, mid-riffle and well-buried in gravel/sand or cobble mixes) (B. Jones, pers. comm. 2018, T. Savidge, pers. comm. 2018).

In addition to these typical situations, in Nova Scotia and Massachusetts, the brook floater is occasionally found in lakes or ponds with no evident water flow (Davis 2007, p. 17; Massachusetts Division of Fisheries and Wildlife 2009). We are unaware of any similar situations throughout the rest of the species' range and would not generally consider this to be suitable habitat elsewhere because brook floaters and their host fish reside in cool water, well oxygenated protected areas. Adult mussels in the North may survive short periods of dewatered habitats, however these mussels would have no access to host fish to reproduce or to food suspended in the water column. Additionally, in New Hampshire, dewatering of streams have required massive relocation efforts to move mussels back into flowing water habitats (Wicklow 2008, p. 5).

2.5.2 Stable Substrate

Brook floaters are often found in areas with stable substrates predominantly composed of sand and gravel with small to large cobble (Strayer 1999, pp. 468, 472; Wicklow *et al.* 2017, p. 18). For example, in the Suncook River in New Hampshire, recruiting populations of the brook floater were found in very fine to very coarse gravel among small cobble in areas of moderate current velocities (Wicklow 2008, p. 32). Stable substrates and flow refuges are important for freshwater mussels like the brook floater because they are sessile animals with limited mobility and are at risk of being washed away during high water events (e.g., floods) (Strayer 1999, p. 468,472). Mussels bury in substrate to secure and protect themselves during droughts or high water events. Burying also protects mussels from the impacts of invasive mussel species which can attach to and smother them. If dislodged from the substrate, freshwater mussels can take up to 30 minutes to rebury (Haag 2012, p. 32).

In general, adult mussels bury themselves just below the surface with their posterior side up, which allows them to suction the water with their incurrent aperture and secrete waste with their excurrent aperture, and their anterior side in the substrate, which allows them to stabilize themselves using their foot. The depth to which they can bury themselves varies among species, but in general, mussels can bury as deep as 10-20 cm (3.4-7.8 in), but usually less than 6-10 cm (2.3-3.4 in) (Haag 2012, p. 31).

Most freshwater mussels, including the brook floater, are found in aggregations (e.g., mussel beds which are many mussels together in suitable habitat) or individually. For most species, mussel beds are patchy in distribution and have average densities of more than 10-20 individual mussels/m^2 but can exceed 100 mussels/m^2 (Haag 2012, p. 128). Mussel beds vary in size and are often separated by stream reaches in which mussels are absent or rare due to areas of fast flowing water (e.g., thalweg or deepest part of the channel) (Vaughn 2012, p. 983). Genetic exchange is expected to occur between and among mussel beds via sperm drift, host fish movement, and movement of mussels during high flow events and through the drift of glochidia before they attach to fish.

2.5.3 Unimpaired Water Quality

Freshwater mussels, as a group, are sensitive to changes in water quality parameters such as dissolved oxygen (DO), salinity, ammonia, and pollutants (see Chapter 4 for more information). Habitats with appropriate levels of these parameters are considered suitable, while those habitats with levels outside of the appropriate ranges are considered less suitable. Sublethal effects of environmental stress include gaping, changes in siphoning behavior, foot extension, changes in activity level, and increase in burrowing behavior (Sparks and Strayer 1999, p. 132).

As stated above, the release of glochidia is highly temperature dependent, typically occurring when the water temperature reaches 14° C (57.2° F) (Wicklow 2008, p. 7). Beyond that, there is limited information about ideal temperature requirements for brook floaters. The primary need is to have temperatures warm enough for glochidia release but not warm enough to result in mortality or sublethal effects. Pandolfo *et al.* (2010, p. 960) tested mortality of glochidia in 8 species of mussels (including brook floater) and mortality of juveniles aged 3-8 weeks in 7 species of mussels (including brook floater). Temperatures between approximately 28 and 31° C (82-88° F) caused 5 percent mortality of glochidia and juveniles and temperatures of approximately 35-38° C (95-100° F) caused 50 percent mortality (Pandolfo *et al.* 2010, p. 966). An additional experiment, Galbraith *et al*. (2012, pp. 85, 86), tested brook floaters and 2 other mussel species to assess the Critical Thermal Maximum (CTM), the temperature at which mussels begin demonstrating extreme gaping behavior (n=6). The experiment tested 2 acclimation temperatures and for a 47- to 92-minute duration. Results of this study showed the CTM for the brook floater under the above testing conditions was 39.5-41.1° C (103.1- 106.0° F).

Another study tested juveniles of three species (two in the *Lampsilis* genus and one species in the *Meglonaias* genus) for a longer, 28-day experimental duration and found that a lethal temperature affecting 50 percent of the population was 25.3-30.3° C (77.54-86.54° F) (Ganser *et al.* 2013, p. 1172). Lethal temperatures observed were considerably lower than those reported by Pandolfo *et al.* (2010) and Galbraith *et al*. (2012) likely due to the longer experimental duration of the test (28 days versus 48- and 96-hour, and 47-92 minute tests, respectively).

Dissolved oxygen requirements are poorly understood for most mussel species, including the brook floater. However, even for Eastern elliptio (*Elliptio complanata*), a common, habitat generalist, individuals exposed to low DO exhibit stress behaviors such as gaping and surfacing more often than individuals not exposed to low DO (Sparks and Strayer 1998, p. 132). Species such as the brook floater that are found in flowing waters are expected to be more sensitive to lower DO than mussels like Eastern elliptio that can be found in still water like ponds and lakes. Chen *et al.* (2001, p. 214) tested DO sensitivity of multiple mussel species in the lab and found that the rainbow mussel (*Villosa iris*) requires DO levels above 6 milligrams per liter (mg/L). A site in the Suncook River, New Hampshire, where brook floaters are known to occur, has DO readings of 8.9 mg/L (Wicklow 2008, p. 13). However, we recognize that this single reading is not conclusive given the hourly, daily, and seasonal fluctuations in DO. Based on the best available information, we currently conclude that brook floater likely requires DO levels above 6 mg/L.

Host fish of the brook floater tend to have similar DO requirements to the normal range for most mussels. Cool water host fish species require DO levels of 4-7 mg/L, while some fish species, including brook trout (*Salvelinus fontinalis*), require DO levels greater than 7 mg/L at temperatures between 9-15° C (48-59° F) (Raleigh 1982, p. 7; Hartline 2013, p. 25).

Appropriate interstitial chemistry includes adequate DO levels (greater than 6 mg/L) (Chen *et al.* 2001, p. 214, Sparks and Strayer 1998, p. 132), low salinity and low levels of contaminants including ammonia (less than 0.57 mg/L) (Augspurger *et al.* 2003, p. 2572), and potassium (less than 4 mg/L) (Imlay 1973, p. 97).

CHAPTER 3. POPULATION AND SPECIES NEEDS AND CURRENT CONDITION

In this chapter, we consider the brook floater's historical and current distribution, and its current condition. Current distribution for the purpose of this SSA was defined as any occurrence documented in field surveys from 1997 to 2017. Historical is defined as any occurrence documented before 1997. We first review the historical information on the range and distribution of the species. Next we evaluate the species' requisites to consider their relative influence on the brook floater 3Rs (resiliency, representation, and redundancy). Through the lens of the 3Rs, we then estimate the current condition of brook floater populations.

3.1 Historical Range and Distribution

Historically (prior to 1997), the brook floater was broadly distributed throughout streams and rivers draining into the Atlantic Ocean from Canada (New Brunswick and Nova Scotia) to Georgia, including rivers in the states of Connecticut, Delaware, Georgia, Massachusetts, Maine, Maryland, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Vermont, Virginia, and West Virginia (Johnson 1970, p. 355; Clarke 1981a, p. 79-81; Wicklow *et al.* 2017, p. 11) (Figure 9).

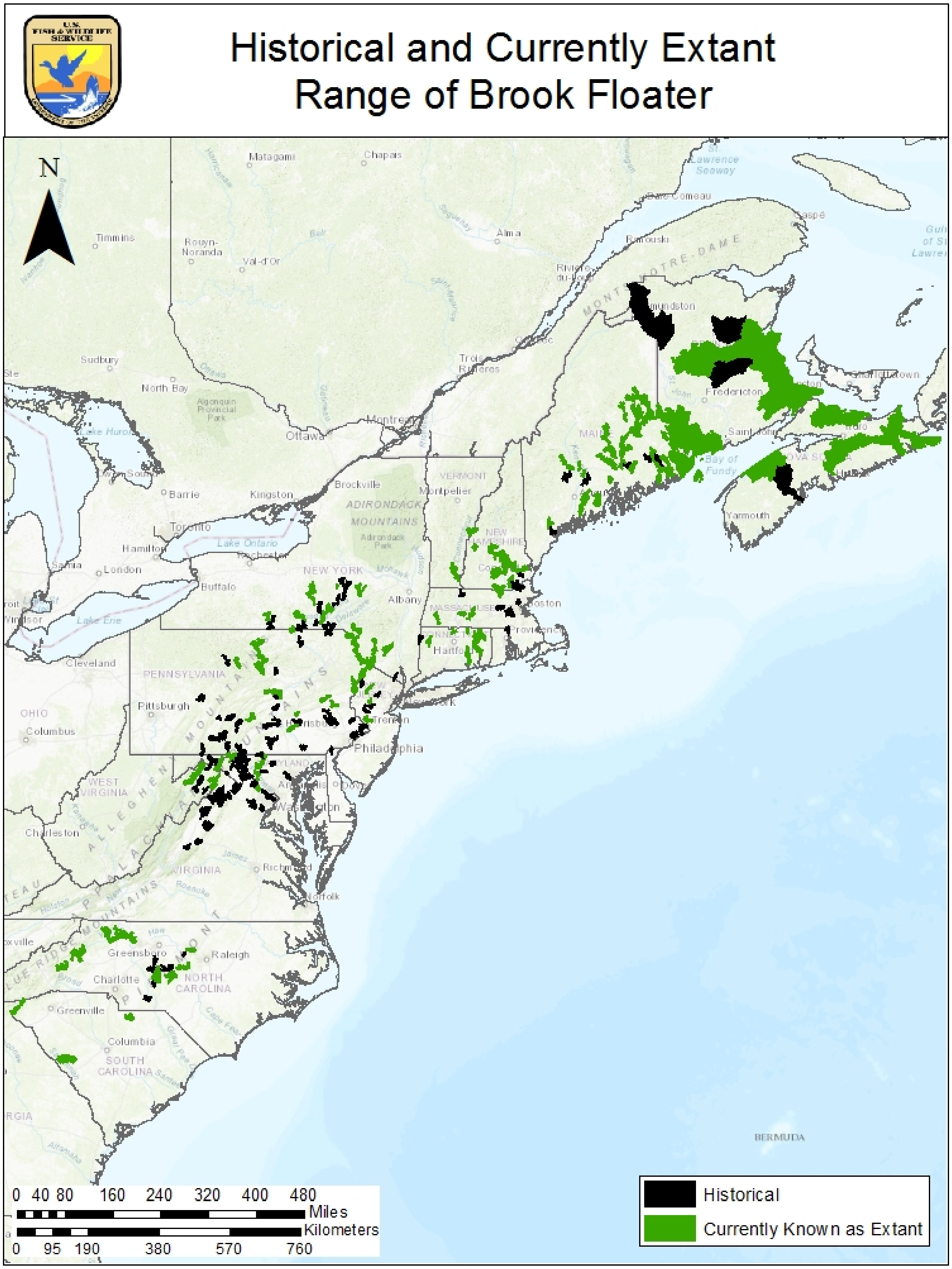

Figure 9. Historical and currently extant range of the brook floater, *Alasmidonta varicosa*, in the U.S and Canada.

3.2 Current Range and Distribution

Current range was determined using available data (*e.g.*, NatureServe (2017), which includes state Natural Heritage data and surveys conducted by partners, including state agencies, federal agencies, non-profit organizations and contractors. In some cases, surveys were conducted specifically for brook floater, while others targeted other mussel species (e.g., listed mussels). Data was provided in several formats including count data, catch per unit effort (CPUE), and presence/absence. If presence of the brook floater was noted between 1997 and 2017, we considered it extant (or current). If presence of the brook floater has not been detected since 1997 or no surveys have been conducted between 1997 and 2017, we considered it historical (but not necessarily extirpated). Condition of individual populations is further described later in the report (section 3.4).

Brook floaters are currently found in 14 of the 16 historically known states and considered extirpated in Delaware and Rhode Island (Wicklow *et al.* 2017, p. 11) and in the District of Columbia (Figure 9). In addition, the brook floater appears to be extirpated from multiple rivers across the rest of the range. NatureServe (2017) identified approximately 70-90 site extirpations (of 150 or more known historically) that have occurred across the range. In many instances, no specific cause for extirpation can be identified, but suggested causes include acid mine drainage (which is the outflow of acidic water from metal or coal mines) (Wicklow *et al.* 2017, p. 128), extreme flood events (Wicklow *et al.* 2017, p. 42), and impaired water quality due to pollution and land use changes (Wicklow *et al.* 2017, p. 104). For example, freshwater mussels have been extirpated from the West Branch of the Susquehanna River due to acid-mine drainage (A. Bogan pers. comm.).

Currently, the brook floater occurs in 15 watersheds in New Brunswick and Nova Scotia. With recent focused surveys (since 2001 in New Brunswick and between 1998 and 2007 in Nova Scotia) (Figure 10), brook floaters have been found at six new locations in New Brunswick and four new locations in Nova Scotia (COSEWIC 2009, p. 12; Fisheries and Oceans Canada 2018).

Brook floaters surveys have found new populations in some locations revealing that additional areas need to be surveyed, particularly in Canada and Maine.

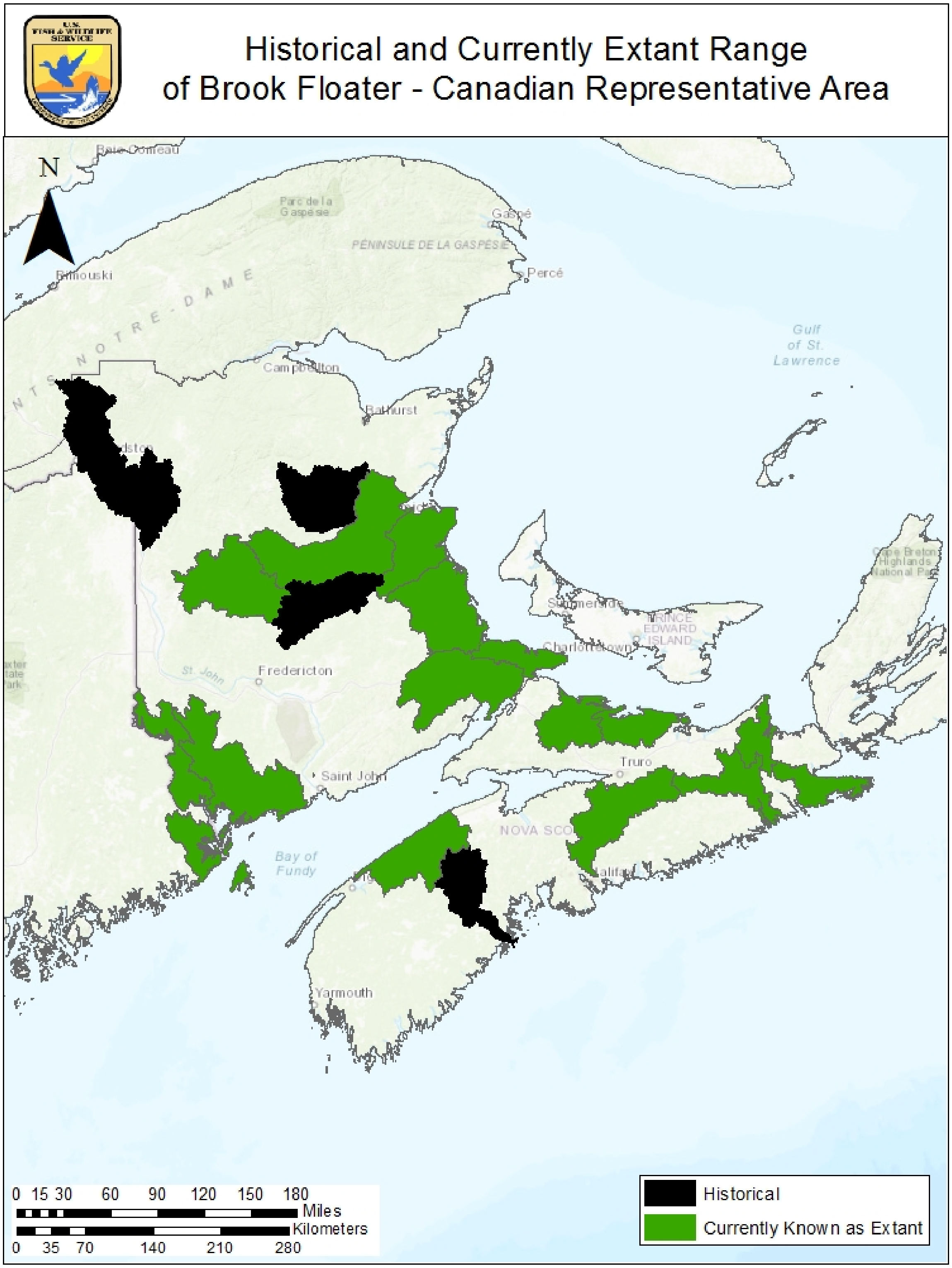

Figure 10. Historical and currently extant range of the Brook Floater in Canada.

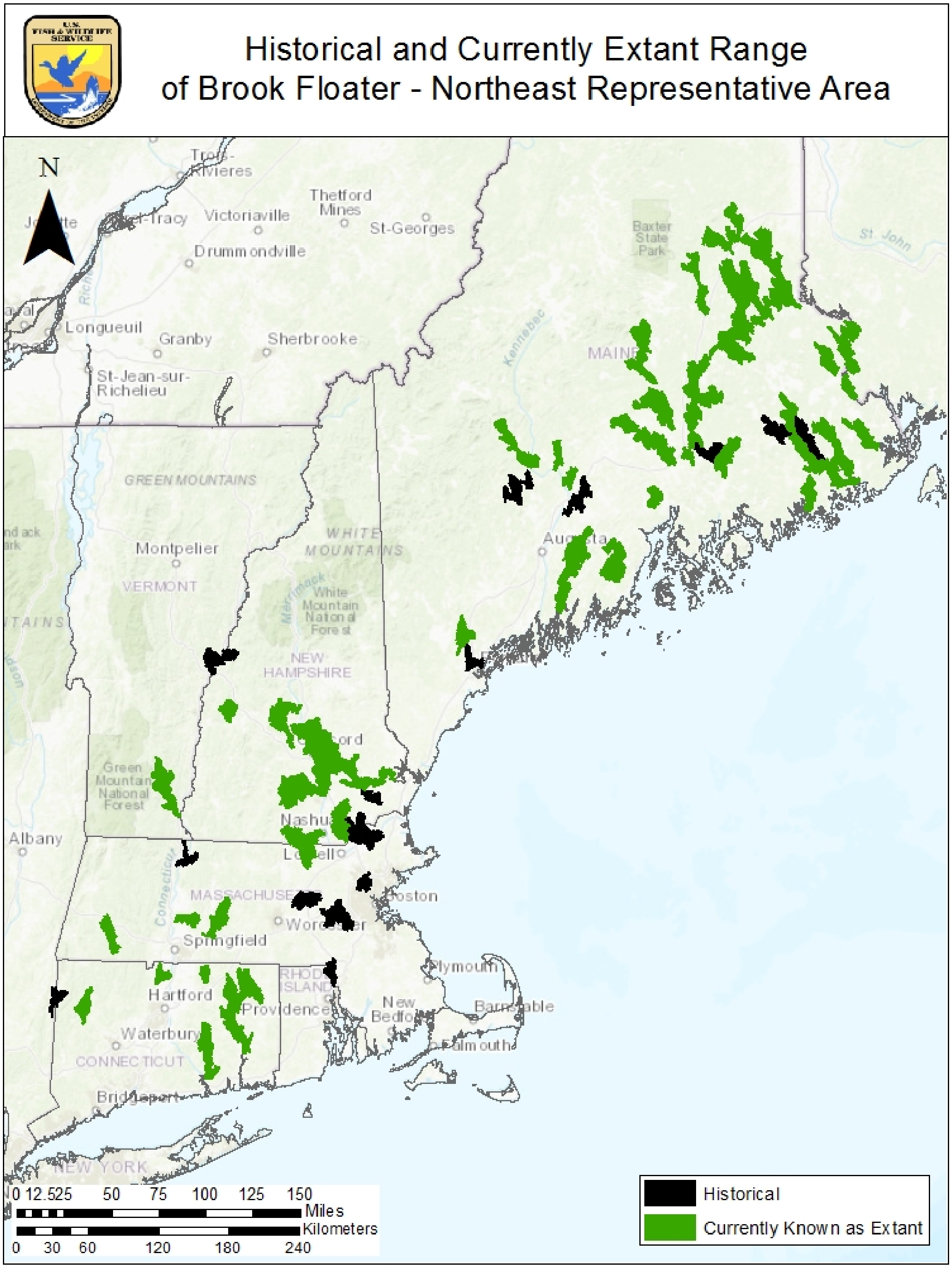

Figure 11. Historical and currently extant range of the brook floater in the Northeast.

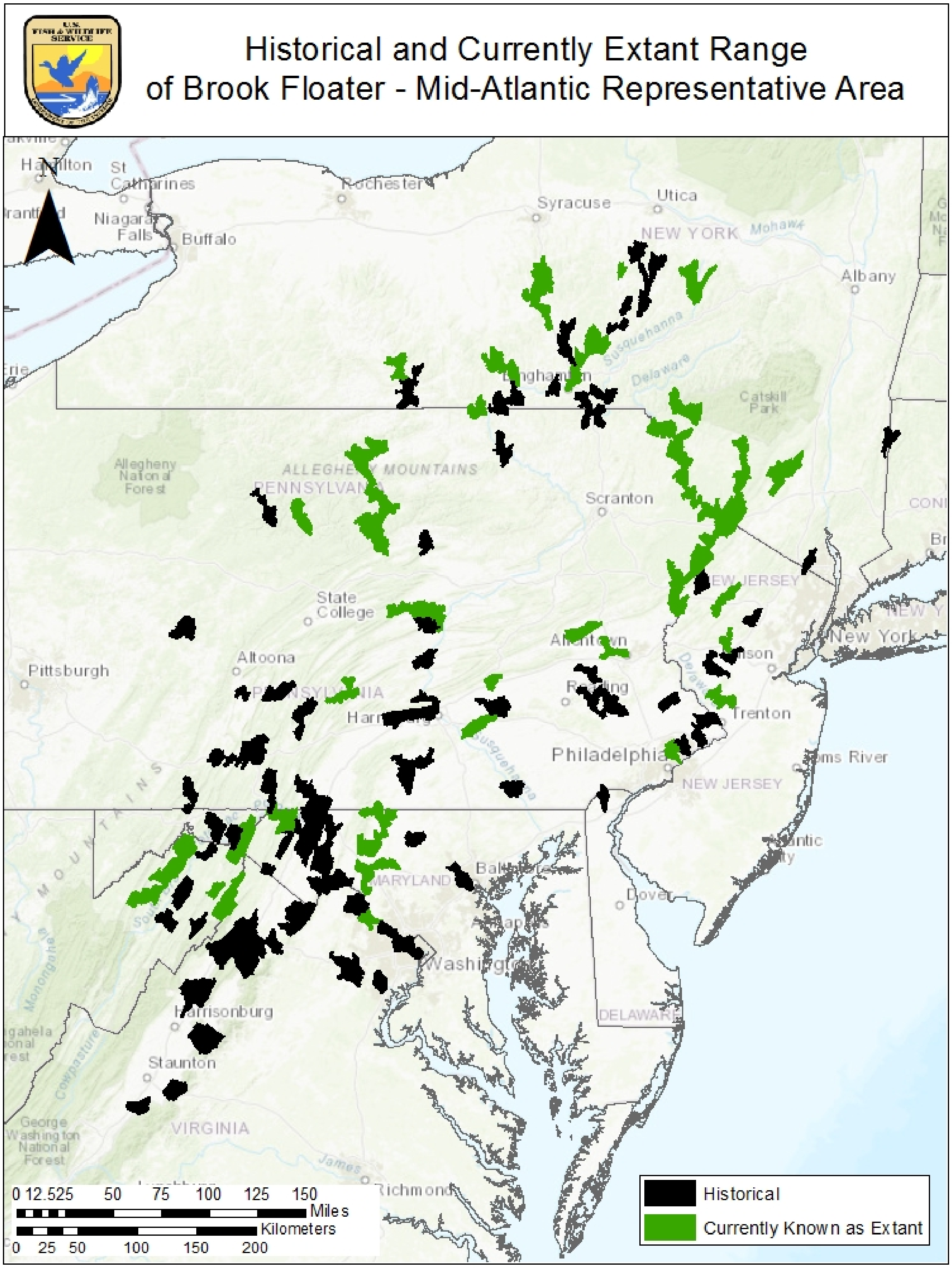

Figure 12. Historical and currently extant range of the brook floater in the mid-Atlantic.

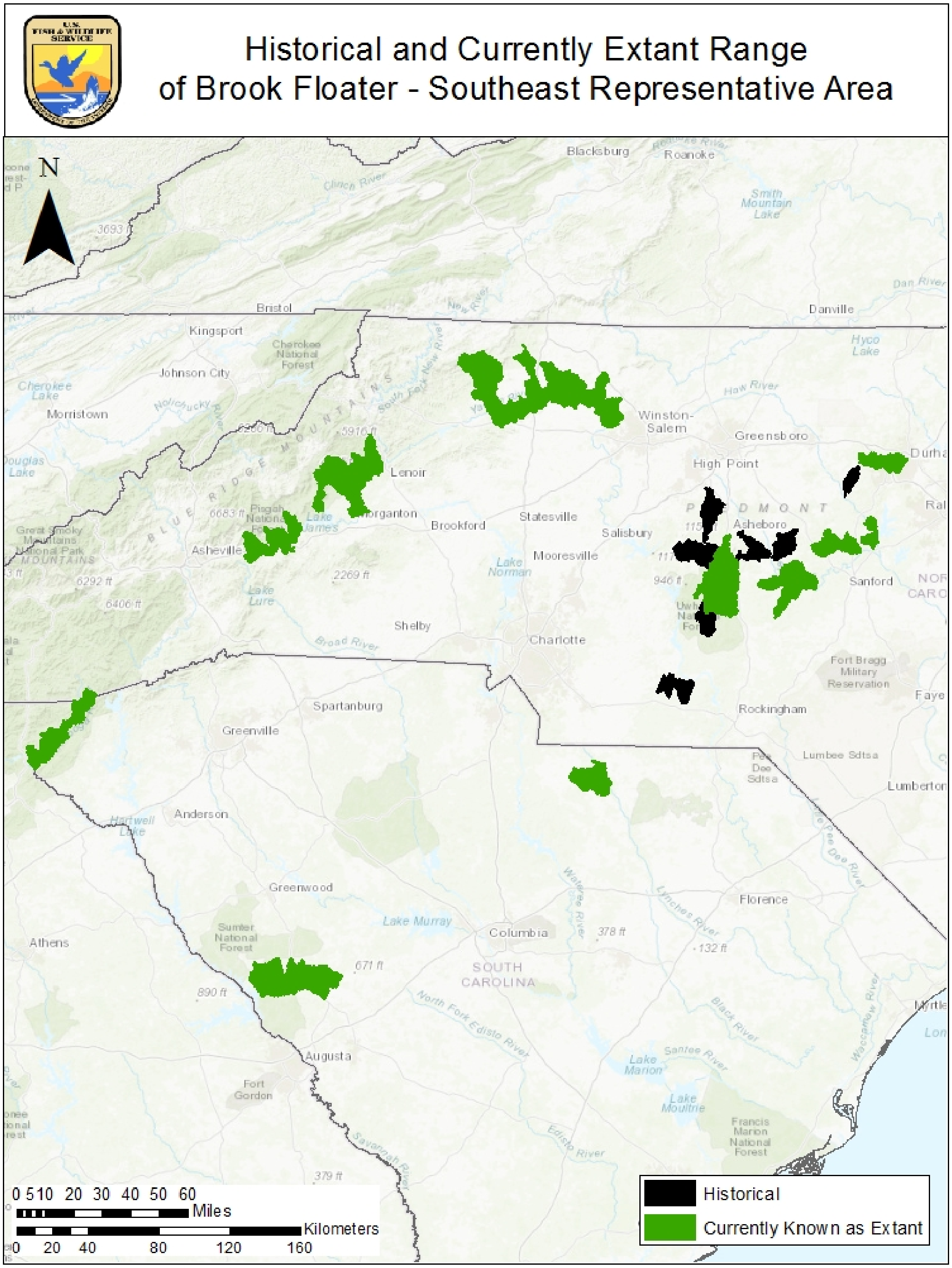

Figure 13. Historical and currently extant range of the brook floater in the Southeast.

3.3 Needs of Brook Floater

As discussed in Chapter 1, for the purpose of this assessment, we define viability as the ability of the species to sustain healthy populations in natural river systems within a biologically meaningful timeframe. Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its **resiliency**, **redundancy**, and **representation** (the 3Rs).

3.3.1 Population Resiliency

To assess the resiliency or "condition" of brook floater populations, we compiled data from survey records and spatial data from U.S. federal agencies, Canadian provinces, state natural resource agencies, and non-governmental organizations (i.e., NatureServe). In addition to survey records provided by those organizations, we used the National Hydrography Dataset (NHD), the Watershed Boundary Dataset which further divides watershed boundaries into Hydrologic Unit Codes (HUC), and the 12 element occurrence ranks and descriptive information about surveys recently compiled by Wicklow *et al.* (2017, entire).

HUCs define a hydrological feature like a river, lake or drainage basin (also called watersheds) and are divided into smaller units (e.g., HUC 8, 10 or 12 units). For this SSA, we used HUC 12 units (HUC 12s) because the brook floater is such a wide ranging species. Similar information was gathered for brook floater occurrences in Canada from Fisheries and Oceans Canada's (DFO) 2018 Management Plan for the Brook Floater (*Alasmidonta varicosa*) (DFO 2018, entire), the 2009 Committee on the Status of Endangered Wildlife in Canada, Assessment and Status Report on the Brook Floater in Canada (COSEWIC 2009, entire), the Preliminary Assessment of the Recovery Potential of the Brook Floater (*Alasmidonta varicosa*) Canadian Population (Whitford Stantec Limited 2012, p. 7), the Freshwater Mussel Survey for the Miramichi River Watershed 2010 (Baisley 2010 p. 12), and Freshwater Mussels of Nova Scotia (Davis 2007, pp. 15-17). The National Hydro Network (NHN) GeoBase/Geodatabase (similar to the NHD in the U.S.) was used to download data for Canada. Using information about these metrics, we determined condition for all populations.

For the purpose of this SSA, we defined "populations" as "analysis units" (AUs) as geographically-defined watersheds that encompass historical and currently documented occupied habitat and covers diverse geographic areas throughout the range of the brook floater. Each AU is comprised of 1 or more HUC 12s, and is typically defined by a confluence with another water body or by blockages such as dams. AUs in Canada are defined by the boundaries of the NHN units.

For the brook floater to maintain viability, its populations or a sufficient portion thereof must be resilient and must be able to sustain itself over multiple generations. Stochastic events that have the potential to affect brook floater populations include high flow events, drought, pollutant discharge, and accumulation of fine sediment.

Population Condition Metrics

A number of factors influence the condition of populations, including occupied stream length, abundance, and reproduction/growth rate. While habitat condition also influences brook floater population condition, we had no reliable way to assess habitat metrics across the range.

Occupied Stream Length – Occupied stream length was defined as "the distance in kilometers from the most upstream documented brook floater to the most downstream documented brook floater in a continuous stretch of stream without a major confluence." We determined occupied stream length by measuring the distance within a waterbody in each AU that was occupied according to available survey data. If the AU was documented over 20 years ago or only one survey location was available, occupied length was assessed as "unknown." We assume that longer occupied stream lengths are associated with healthier brook floater populations.

Abundance – A vast majority of surveys for brook floater were conducted through visual searches of the surface of the stream bed. Because patterns of vertical movement in the stream bed vary seasonally, obscuring mussels from sight at different times of year (Amyot *et al.* 1997, p. 351), estimating abundance with accuracy can be difficult. Abundance was assessed based on available data. In many cases minimal data was provided and abundance was determined to the magnitude of count data provided.

In cases where CPUE (number of mussels found per hour) was available from recent survey efforts, we attempted to estimate the population to order of magnitude. Occupied length was determined using data provided (measuring the length from most upstream to most downstream occurrence) or by inspecting the watershed via satellite imagery and, in some cases, using a maxent model to estimate an approximate length of the occupied reach. Measurements of average stream width were used to calculate an area of stream bed that is likely to be occupied. In order to estimate a reasonable density for the stream, it is assumed that a typical mussel surveyor would be able to search approximately 100m^2 per hour.

It is unlikely that a surveyor would find 100 percent of brook floater in the survey reach due to individuals that were below the surface and not available for detection, and some that were missed by chance. We estimated that an average searcher could find around 1/4 of the brook floaters within the survey reach, and that the average catch per hour was reflective of 1/4 of the number of individual brook floaters in each 100m^2 surveyed. This density was applied to the whole occupied area of the river, estimated using the previous method to arrive at a total population in a river with uniform habitat distribution.

We acknowledged that due to heterogeneous habitat within any river that this method would likely overestimate the population size. To correct for this discrepancy, we assumed that on average 1/3 of the habitat in a river was suitable for the brook floater and divided the homogeneous estimate by 3 to arrive at a rough population estimate. We also acknowledge that this method is imperfect and in some cases is likely to overestimate the true population. To address this issue, we chose to use this estimate to place a population within a range of order of magnitude to be conservative. For example, if the estimate returned a number of 1,667 individuals based on a reported CPUE, we would assume that this population was likely to contain numbers in the 100s to 1000s magnitude. These orders of magnitude were then used, along with other supporting information, to assign a status of “high”, “medium”, “low” or “very low” to the population. Because this method was only applied to populations with recent positive occurrence, errors of assumption that led to an overestimation of the population only led to errors in assigning inappropriate status, but should not have led to errors in determining current range. Due to uncertainty in local abundance, we rely heavily on present occupied status in the assessment.

This simple model was used to estimate population size:

Population size = (((width*1000m)/unit area)*CPUE*occupied length)/percent efficiency)*average patch correction[1]

Reproduction – Resilient brook floater populations must also be reproducing and recruiting young individuals into the population. Population size and abundance reflects previous influences on the population and habitat, while reproduction and recruitment reflect population trends that may be stable, increasing (observing more adults and juveniles) or decreasing (observing less adults and juveniles). For example, a dense population of brook floaters that contains mostly old individuals is not likely to remain dense into the future, as there are few young individuals to sustain the population over time. Conversely, a population that is less dense but has many young and/or gravid individuals may be likely to become denser in the future. However, detection of very young juvenile mussels during routine abundance and distribution surveys are uncommon and juvenile detection surveys are lacking. Therefore, the vast majorities of brook floater surveys were lacking length or age information and mainly focused on obtaining presence/absence information on adults.

In AUs where a time series of surveys was available, we assessed reproduction or population growth as increasing or declining where a trend was sustained over multiple surveys at the same site over time. If multiple surveys over time were not available, reproduction/growth was assessed as unknown or stable based on expert opinion which included the frequency and results of known conducted surveys, survey trends, known watershed threats, and known conservation activities.

3.3.2 Species Representation

The intent of defining representation for a species within a SSA is to capture a species’ ability to adapt to environmental change (i.e., its adaptive capacity). Adaptive capacity is a function of adaptive diversity formed in response to living in its local environment. Thus, when considering representation, isolation within a species’ range and exposure to variation in geographic and environmental settings are taken into consideration.

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[1] Terms are defined as:
width = average stream width in meters
unit area = 100 m^2
CPUE = the number of mussels found per hour
occupied length = the distance in kilometers from the most upstream documented brook floater to the most downstream documented brook floater in a continuous stretch of stream without a major confluence.
Percent efficiency = the percent of mussels assumed to be found in a survey area, 0.25, and average patch correction of 0.3 was included to account for the percent of the area assumed to be suitable habitat.

Since there is limited genetic information available range wide for the brook floater, we considered other factors when defining representation. First, we considered broad geographic delineations as surrogates for genetic and possible morphological variation and proxies for potential local adaptation and adaptive capacity. Second, we considered discontinuities in the species' distribution and concentrations in sources of stressors throughout the range. We also considered the significant climatic variation, from the Canadian Maritime provinces to the Southeastern Piedmont. Threats to brook floater also vary by region. For example, economic development, which includes urbanization, agriculture and energy development (e.g., extraction of oil and gas) is higher in the mid-Atlantic Representative Area and is projected to become more concentrated. Finally, we used hydrographic units to define representation because watershed boundaries constrain ecological processes such as genetic exchange and ultimately adaptive capacity for aquatic species.

We applied NHD zones to four representative areas in the U.S., and NHN areas in Canada which are located within the defined boundaries of the Atlantic slope drainage, to represent the potential adaptive capacity for the brook floater. They are delineated coincident with discontinuities in the species' distribution. This suggests the potential for regional isolation.

- Canadian Representative Area: Province of New Brunswick and Province of Nova Scotia. The area in New Brunswick is comprised of the following waters; Kouchibouguacis River, St. Croix, Magaguadavic River, Petitcodiac River, Miramichi River, Shediac River, Scoudouc River, and the Bouctouche River and associated watersheds. The area in Nova Scotia is comprised of the following waters; Annapolis River, LeHave River, Gays River, Wallace River, French Mattail Lake, Saint Mary's River, and the Salmon River and associated watersheds in Nova Scotia.

- New England Representative Area: This area is comprised of down east rivers (coastal areas from northeastern New England into Canada's Maritime Provinces, which includes Maine): Merrimack River, Great Bay watershed, Connecticut River, and associated watersheds.

- Mid-Atlantic Representative Area: Chesapeake Bay watershed including Susquehanna and Potomac River watersheds and the Delaware River watersheds.

- Southeast Representative Area: watersheds in North Carolina, South Carolina, southwest Virginia, northeast Georgia.

The four representative areas shown below are defined to coincide with large hydrographic zones and represent the adaptive capacity within the brook floater's current range, given the best available information (Figure 14).

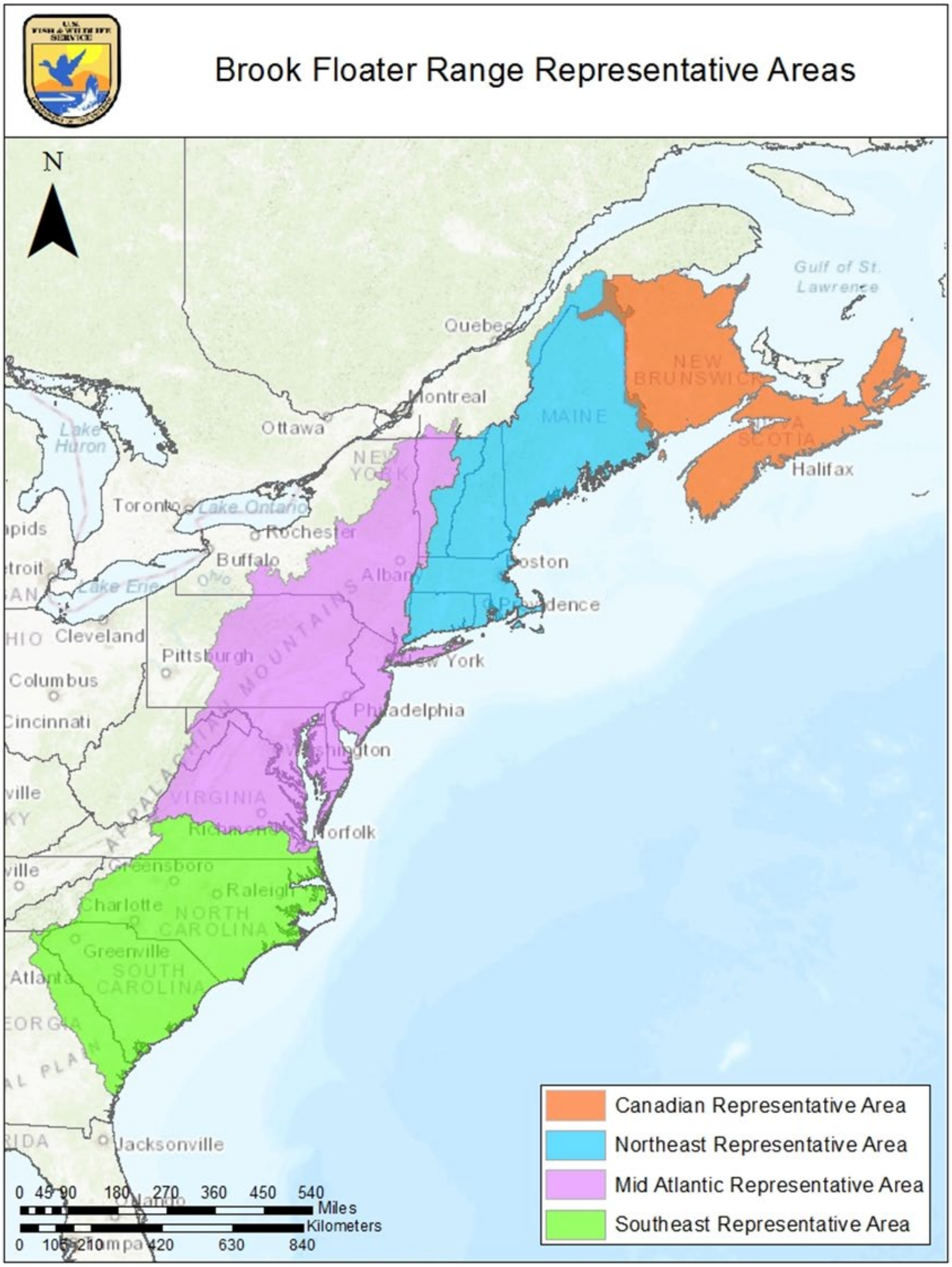

Figure 14. Map showing the four representative areas using National Hydrography Dataset (NHD) for U.S. and the National Hydro Network (NHN) for two Canadian provinces located within the Atlantic slope drainage.

3.3.3 Species Redundancy

The more populations, and the wider the distribution of those populations, the more redundancy the species will have. Redundancy reduces the risk that a species as a whole will be negatively impacted if an area of the species' range is negatively affected by a catastrophic natural or anthropogenic event at a given point in time, 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.

Redundancy for the brook floater is best achieved by having multiple resilient populations widely distributed across the species' range, which reduces the likelihood that all populations are adversely affected simultaneously. Also, having widely distributed populations reduces the likelihood of populations possessing similar vulnerabilities to a catastrophic event, thereby retaining their breadth of adaptive diversity. Furthermore, diverse and widespread populations of brook floaters may contribute to the increasing breadth of adaptive diversity (representation) within the species if redundant populations are adapting to different conditions.

3.4 Current Condition

3.4.1 Methodology

To assess the overall current condition of the brook floater, we evaluated the condition (using metrics from Table 1, below) of each AU within each of the four representative areas (Canadian Provinces, Northeast, Mid-Atlantic, and Southeast) shown above (Figure 14). As a reminder, we identified the needs of the brook floater as having multiple (redundancy), healthy (resiliency) populations with suitable habitat in each of the four representative areas to represent adaptive capacity within the brook floater's current range (representation).

Condition was assessed by combining information on brook floater abundance, reproduction, and occupied stream length (as described above). We were unable to use habitat metrics to help inform AU condition. Because population size is based on multiple assumptions and can have a large and/or undefined variance, we assigned a more general magnitude (<10, 10s, 100s, or 1000s) of brook floater abundance to each AU. Based on knowledge and experience, the core team determined these magnitudes to be representative of resilience. Where CPUE, occupied length, and width data were not available, we used available data and expert opinion to estimate abundance of populations to the closest magnitude. Overall condition was assigned as "high", "medium", "low", "very low" or "unknown" as defined in Table 1. "Unknown" condition is any occurrence documented prior to 1997, but for which no surveys have been done in the past 20 years. There are a number of circumstances under which an AU could be assigned as "Unknown", including the following:

1. The AU has not been surveyed in the past 20 years and is presumed historical/extirpated;

2. The AU was not identified as a priority by agencies/organizations and therefore no surveys were conducted;

3. Agencies/organizations did identify the AU as a priority but they lacked funding to conduct a survey;

4. The AU is presumed extirpated because of habitat conditions (not suitable or have not improved); or

5. The AU was surveyed more than 20 years ago, and the agency or organization assumed the AU is stable and recruiting (e.g., high/medium condition) and therefore did not deem it a priority to go back and survey.

Table 1. Matrix defining condition of brook floater using abundance, reproduction and occupied length within an AU.

High	Abundance is in 1000s and reproduction is increasing or stable, regardless of occupied length
	Abundance is in 100s and reproduction is increasing regardless of occupied length
	Abundance is in 100s and reproduction is stable and occupied length >10km
Medium	Abundance is 1000s and reproduction is declining and occupied length >1km
	Abundance is in 100s and reproduction is stable and occupied length <10 km
	Abundance is in 100s and reproduction is declining and occupied length >10km
Low	Abundance is in the 1000s and reproduction is declining and occupied length <1km
	Abundance is in the 100s and reproduction is declining and occupied length <10km
	Abundance is in the 10s and reproduction is increasing or stable
Very low	Abundance is in the 10s and reproduction is declining
	Abundance is less than 10 (including known or likely extirpated)
Unknown	Occurrences documented over 20 years ago; no survey data more recent than 1997.

We recognize that agencies and organizations treat survey schedules differently. Most states in the range prioritize surveys around state and federally -listed species and record non-listed species during survey efforts. In addition, the sites may only be visited every 5 to 10 years or not at all. The Service shared draft results of the designated condition of AUs with experts from each state and Canadian provinces for review. Experts provided their opinion, additional brook floater data, and information about the habitat to help finalize the condition for each AU.

We identified HUC 12s from the NHD Watershed Boundary Dataset (WBD) spatial layer to represent and map each of the AUs in the U.S. To determine which HUC 12s to include in an AU, we relied on expert review, the location(s) of element occurrences within a HUC 12, and occurrences in hydrologically connected HUC 12s.

Once HUC 12s were grouped into AUs, identification numbers were assigned to each AU so they could be identified spatially. AU identification numbers in the U.S. consist of the state name abbreviation followed by a number starting at 01 (e.g., PA_01, PA_02 etc.). We joined the information about condition to the spatial layer of occupied HUC 12s. This spatial layer displays the current condition of each AU across the range of the brook floater. For the occupied areas in Canada, a similar approach was used. Since the WBD does not extend into Canada, occupied hydrologic units were identified from the Canadian National Hydro Network (NHN) database. These hydrologic units were the only equivalent spatial unit found in Canadian spatial databases, and are larger than the HUC 12s used in the U.S. analysis.

3.4.2 Results

Current condition reflects the number and distribution (redundancy) of healthy (resiliency) brook floater AUs across the 4 representative areas (representation). Based on our analysis, we found that out of a total of 239 AUs rangewide, 36 (15 percent) were designated as having "high" condition, 31 (13 percent) were designated as having "medium" condition, 34 (14 percent) were designated as having "low" condition, 79 (33 percent) were designated as having "very low" condition, and 59 (25 percent) were designated as "unknown" (Figure 15 and Figure 16).

In order to address the AUs categorized as "Unknowns," we assume that the AUs without recent survey data are a random sample of all AUs. We then used the empirical relationship between region, land use, and population condition, which is presented in Appendix D, to predict the condition of the AUs where there is no recent survey data. This approach works only for the U.S. portion of the range because of the availability of land use data from the NLCD. A summary of results from this approach is as follows:

- Of the 12 (15 percent) of the AUs in Northeast region assigned the "Unknown" condition, 42 percent (5) were be predicted to be in "Low" condition, 42 percent (5) were be predicted to be in "Very Low" condition, 8 percent (1) were be predicted to be in "Medium" condition, and 1 could not be resolved.

- Of the 35 AUs in Mid-Atlantic region assigned the "Unknown" condition, 40 percent (14) were be predicted to be in "Low" condition, 51 percent (18) were be predicted to be in "Very Low" condition, and 3 could not be resolved.

- Of the 8 AUs in Southeast region assigned the "Unknown" condition, 100 percent (8) were predicted to be in "Medium" condition.

Based on comments received by reviewers and additional review by core team members, there are 15 AUs for which we think current condition should be different from what is reported in Appendix D, Table D1. Those revisions can be found in Appendix D, Table D3. Of the 15 changes in AU current condition, most (7) are changes from unknown to very low where additional information was received about more recent surveys conducted in AUs that were not previously noted. Five AUs should be changed from low to unknown where there is no recent survey data. One AU should be changed from low to very low where the partner reviewer suggested that change. Finally, two AUs in NH should be changed from high to unknown because surveys were conducted before 1997 (in 1996 and 1993).

A current condition table by state and province can be found in Appendix D.

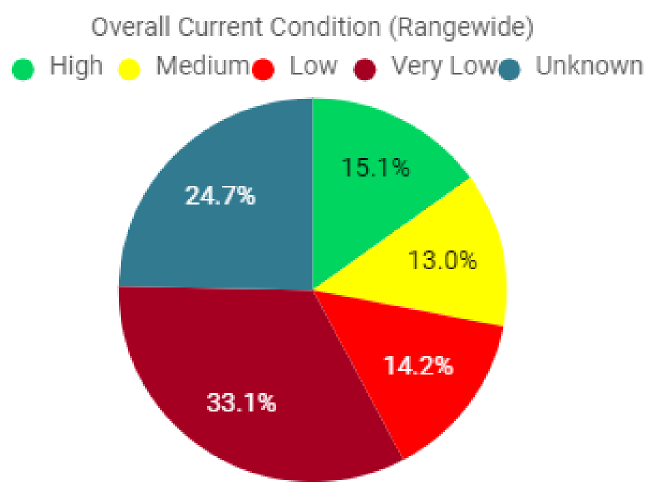

Figure 15. Pie chart showing overall current condition of brook floater (*Alasmidonta varicosa*) rangewide.

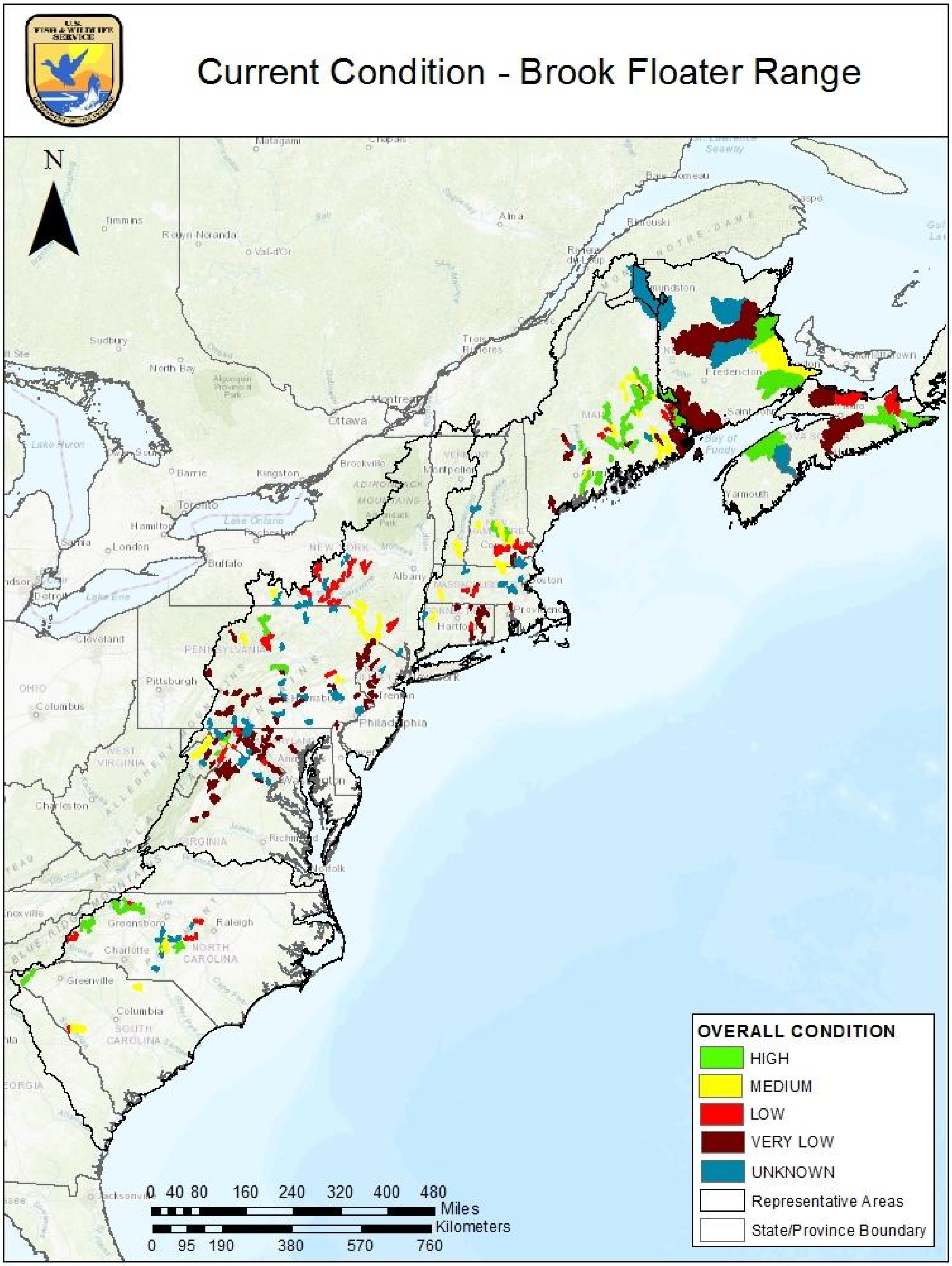

Figure 16. Current condition of brook floater (*Alasmidonta varicosa*) populations across its range.

The brook floater has a wide distribution and shows variation in habitat use as well as host fish use. However, there has been range contraction. Brook floater populations are considered entirely extirpated in Delaware and Rhode Island and in the District of Columbia. While brook floater populations are represented across all four representative areas, the proportion of AUs in "medium" to "high" condition varies across these areas (Table 2, Figures 17-20).

Table 2. Summary of current condition table by representative area.

Current Condition of AUs in each Representative Area						
Representative Area	HIGH	MED	LOW	VERY LOW	UNKNOWN	**TOTAL**
Canadian Provinces	6	2	2	5	4	19
Northeast	17	17	11	20	12	77
Mid-Atlantic	4	8	15	54	35	116
Southeast	9	4	6	0	8	27
TOTAL	**36**	**31**	**34**	**79**	**59**	**239**

The pie chart above (Figure 15) and the maps below (Figures 17-20) show current condition of brook floater (by AU) for each representative area.

In the U.S., the AUs in "high" condition occur in areas of relatively good habitat and water quality, but they vary in size and abundance. The Northeast and Southeast representative areas have the largest number of AUs in "high" condition. We consider the Penobscot AUs in Maine to be the largest "high" condition brook floater AUs in all the range. Several other AUs in the Northeast are also in "high" condition but occupy smaller geographic areas with lower condition AUs interspersed. In the mid-Atlantic, only small portions of Pine Creek, Penns Creek and the Cacapon River are considered in "high" condition and are geographically distant from one another. In the Southeast the Santee, Yadkin, Upper Pee Dee and Chattooga Rivers are all AUs in "high" condition. In Canada, brook floater AUs in the St. Mary's River in Nova Scotia, and the Petitcodiac, and Miramichi Rivers in New Brunswick are in "high" condition.

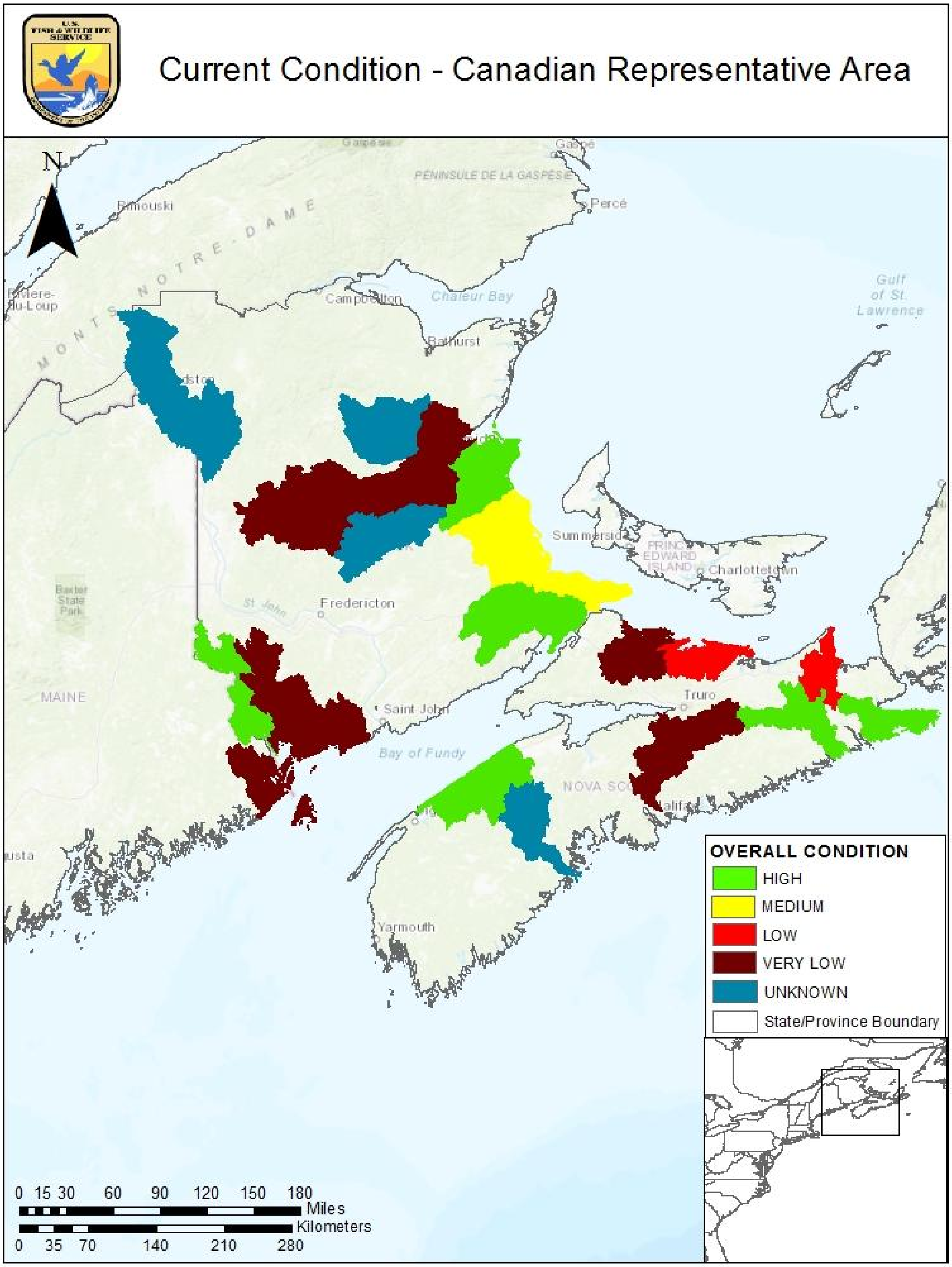

Figure 17. Current condition of brook floater (*Alasmidonta varicosa*) populations in the Canadian Provinces Representative Area.

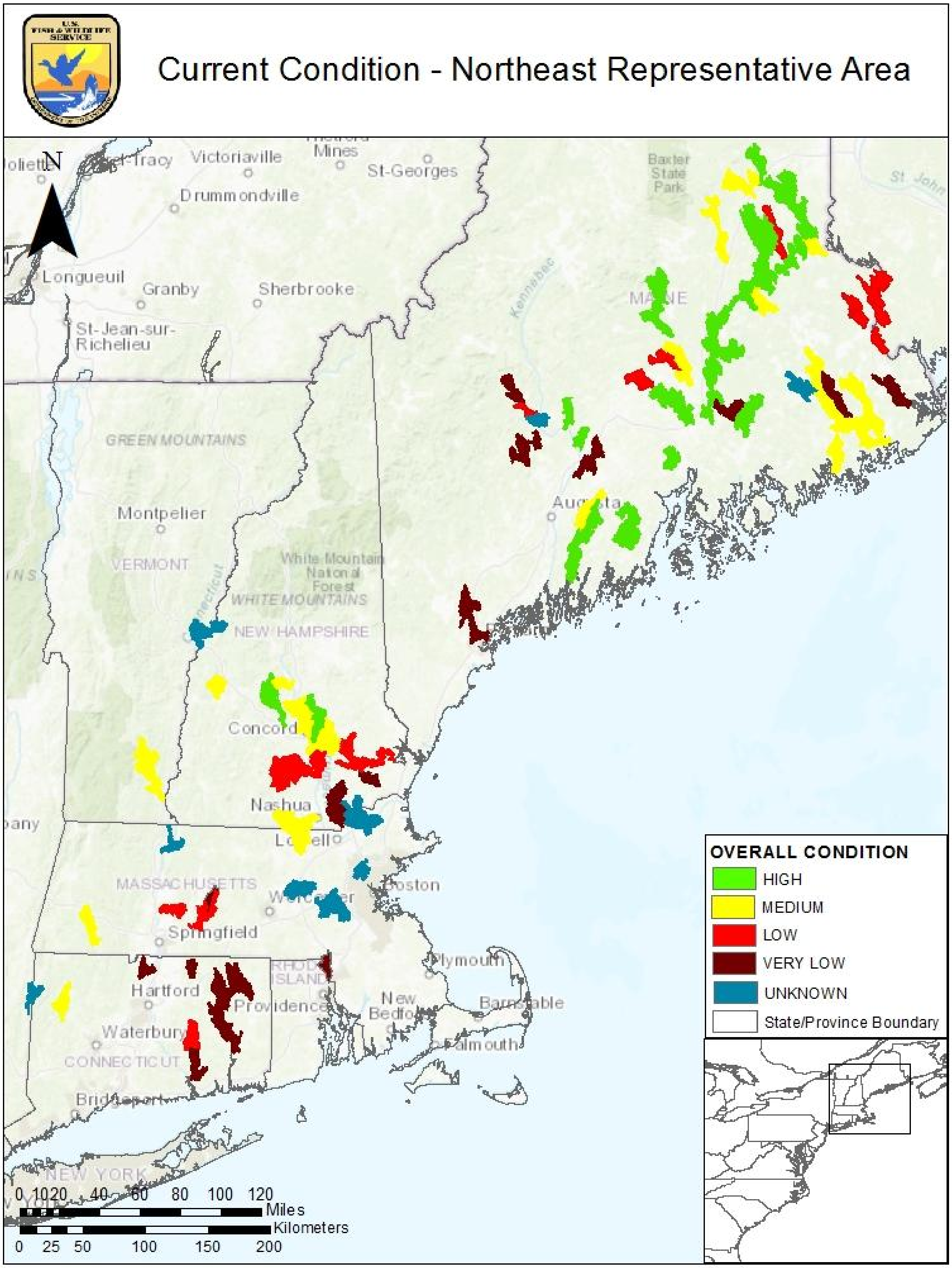

Figure 18. Current condition of brook floater (*Alasmidonta varicosa*) populations in the Northeast Representative Area.

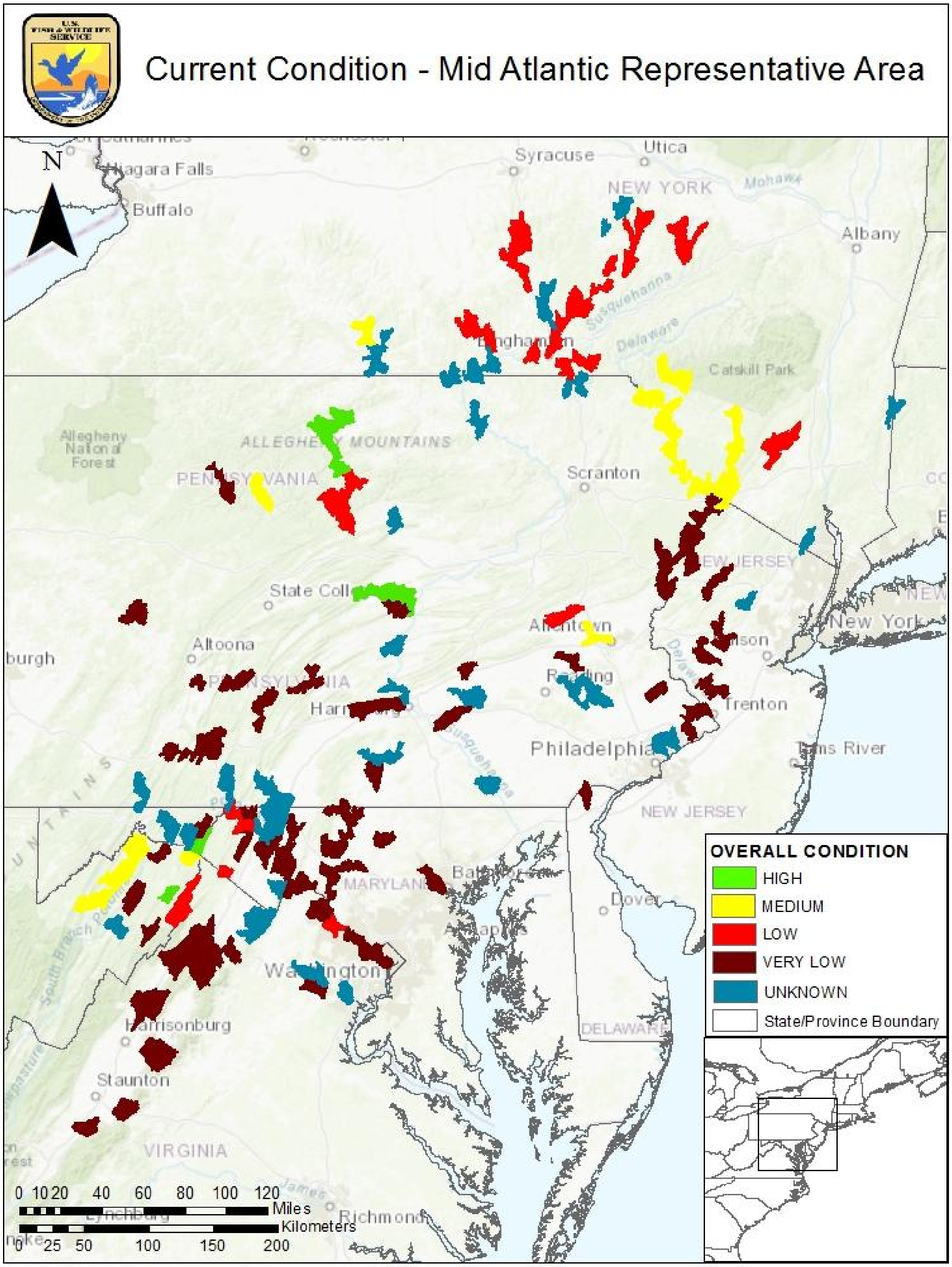

Figure 19. Current condition of brook floater (*Alasmidonta varicosa*) populations in the mid-Atlantic Representative Area.

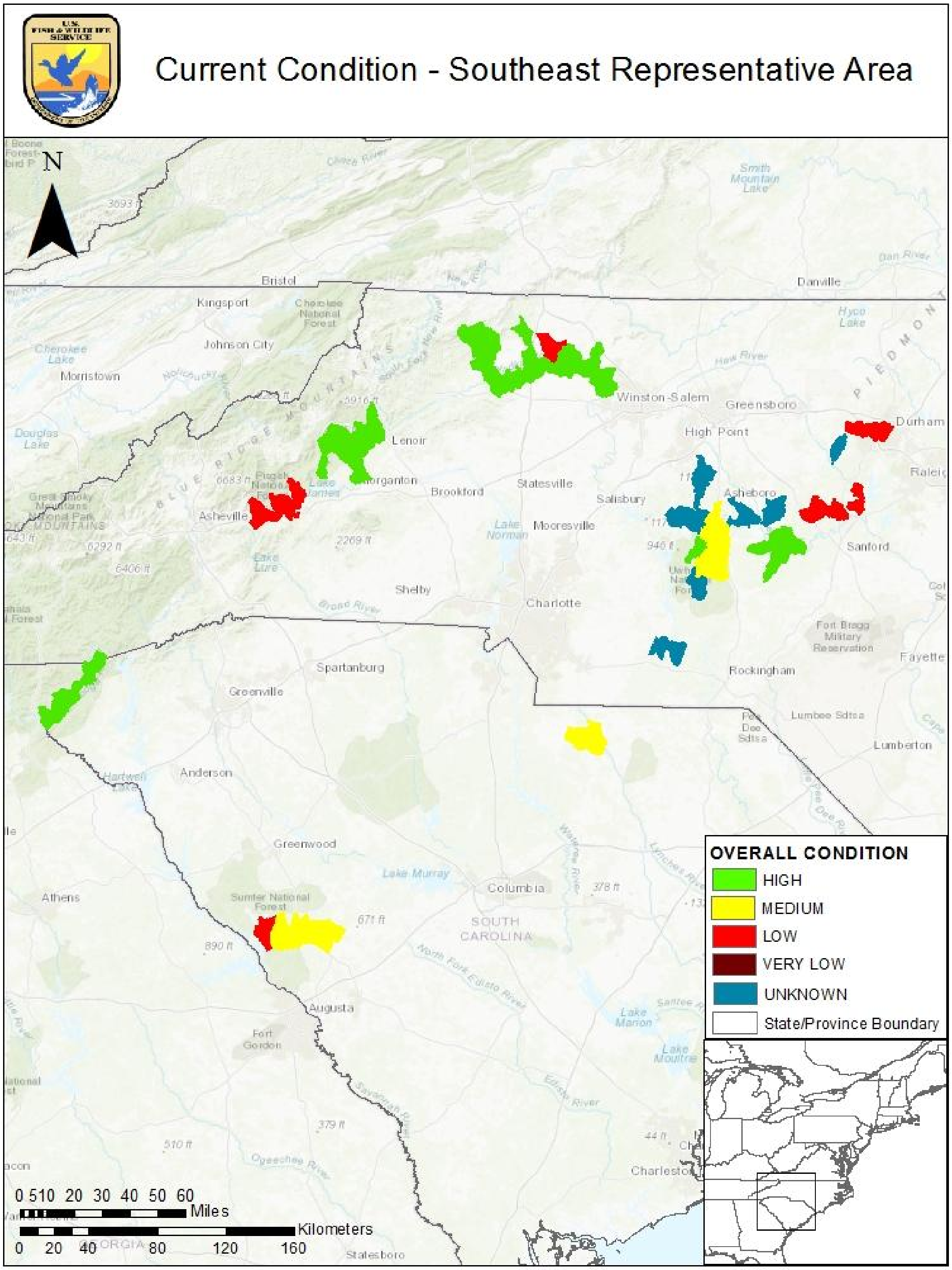

Figure 20. Current condition of brook floater (*Alasmidonta varicosa*) populations in the Southeast Representative Area.

CHAPTER 4. INFLUENCES ON VIABILITY

In this chapter, we evaluate the past, current, and future influences that are affecting the brook floater's long term viability. We evaluated the impacts of the negative influences (stressors) at the individual, population, and species level. We also discuss the primary sources of those stressors, such as development and climate change, within the stressor subsections. We also discuss conservation actions that could beneficially influence viability.

In response to our request for information from state natural resource agencies and other brook floater experts, we determined which stressors have the potential to impact multiple populations. Stressors that are not known to have effects on brook floater populations, such as disease and overutilization for commercial and scientific purposes, are not discussed in this SSA report. Table 3 summarizes the stressors that we analyzed, and is followed by a more detailed discussion of each factor in sections 4.1 to 4.6.

Table 3. Stressors influencing brook floater viability at the individual, population, and species levels.

Stressors	**Individual**	**Population**	**Species (multiple populations)**
Inherent factors	X	X	X
Increased fine sediments	X	X	X
Water quality impairment	X	X	X
Changes in water flows	X	X	X
Habitat Loss/Fragmentation	X	X	X
Invasive species	X	X	
Predation	X	X	

4.1 Inherent Factors

Brook floaters exhibit several inherent traits that influence population viability, including relatively small population size at many sites, and low fecundity compared to some other mussel species. It is important to note that average fecundity can and does differ throughout the range, with some populations exhibiting higher fecundity, and potential enhanced viability than others. Brook floaters are generally found at sites with clean, flowing water and stable substrates and are not often abundant within their occupied habitats. Smaller population size puts sites at greater risk of extirpation from stochastic events (e.g., drought) or anthropogenic changes and management activities that affect habitat. In addition, smaller populations may have reduced genetic diversity, are less genetically fit and thus are more susceptible to disease and extreme environmental conditions. Genetic drift[2] occurs in all species, but is more likely to negatively affect populations that have a smaller effective population size[3] and populations that are geographically spread out and isolated from one another. These stressors are expected play out mostly in parts of the range, like the mid-Atlantic, where population declines have exacerbated demographic issues. Interestingly, some small brook floater populations (North Carolina) have been able to retain their genetic diversity (B. Jones pers. comm.).

4.2 Increased Fine Sediment

Sedimentation, or the tendency of particles to settle out of a fluid, has the potential to increase through both instream and upland activities. Sedimentation from upland sources affects baseline water quality and increases the amount of silt, sand, gravel, and/or cobble present in the river. Aquatic community impacts may include abrasion of mussels by suspended particles, burial by sediment, increased mortality of fish eggs, and clogging of gills and respiratory systems in aquatic species (Wood and Armitage 1997, p. 211; Burkhead and Jelks 2001, p. 965). Additional adverse effects include alteration of physical habitat (e.g., change in amount and distribution of particle sizes) and changes in primary productivity that can limit the suitability of stream habitats for aquatic biota including fish, crayfish, mussels, snails, insects, and plants (Bogan 1993, p. 604; Wood and Armitage 1997, pp. 209-210; Taylor *et al.* 2007, p. 374).

Increased silt directly impacts mussels as well. Mussels must have their valves open to feed; however, in heavily silted water, they are forced to close their valves and wait for better water conditions. Mussels in turbid water have been observed to close their valves up to 90 percent of the time, as opposed to 50 percent for individuals living in silt-free environments (Ellis 1936, p. 40). Extended valve closure can result in starvation or a state of semi-starvation. Extensive exposure to suspended sediments in the water column also affects individuals by clogging gill filaments, which significantly impacts feeding efficiency and filtering clearance rates which can result in mortality (Aldridge *et al.* 1987, p. 25; Brim Box and Mossa 1999, pp. 100-101). Additionally, a recent study has shown that increased TSS (total dissolved solids) can reduce mussels' reproduction and their ability to become gravid (Landis *et al.* 2013, p. 74). Mussels in the highest TSS experimental pond did not become gravid at all and mussel gravidity declined sharply with an increase in TSS (Landis *et al.* 2013, p. 74).

Interstitial spaces (small openings between rocks and gravels) in the substrate provide essential habitat for adults and juvenile mussels. Adults bury themselves during the winter (A. Bogan, pers. comm.). Juvenile freshwater mussels burrow into interstitial substrates, making them particularly susceptible to degradation of this habitat feature. When clogged with sand or silt, interstitial flow rates and spaces may become reduced (Brim Box and Mossa 1999, p. 100), thus reducing juvenile habitat availability. In addition, increased fine sediment deposition on stream substrates and interstitial spaces increases their bioavailability, as well as the potential exposure of mussels to pollutants bound to those sediments. The degree of bioavailability of pollutants that have bound to sediments is affected by environmental characteristics. For example, when

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

[3] The number of individuals in a population who contribute offspring to the next generation.

determining the potential exposure and toxicity of metals found in stream sediments, water characteristics such hardness (Ca), alkalinity, dissolved organic carbon, chloride, and pH are measured (Farris and Van Hassel 2006, p. 206)

In the range of the brook floater, sources of sediment include development (urbanization, agriculture and energy), streambank erosion from poorly planned/managed land use such as commercial, residential and agricultural activities (e.g., livestock grazing, channelization, dredging, upland drainage piped through tile drains that eventually flow to streams), forestry practices, energy development and infrastructure such as roads and utilities, among others. We use the term "development" to refer to urbanization of the landscape, including, but not necessarily limited to, land conversion for urban and commercial use, infrastructure (roads, bridges, utilities), and urban water uses (water supply reservoirs, wastewater treatment, etc.). Urbanization is a source of stressors, such as, fragmentation, decreased water quality and physical habitat, altered hydrography. The impervious cover model (ICM) has been used to indicate current stream quality and forecast future stream quality since the 1990's (Schueler *et al.* 2009, entire).

The ICM model describes a 'wedge-shaped' relationship between stream quality and watershed impervious cover, where stream quality ranges widely at low level of impervious cover but is restricted to fair and then poor stream quality as impervious cover increased. Schueler *et al.* (2009, entire) reviewed studies relating biotic endpoints to impervious cover to assess support for the ICM and found that in freshwater systems 9 out of 10 studies with benthic macroinvertebrate endpoints either confirm or reinforce the ICM. Schueler *et al.* (2009, p. 313) reformulated the ICM to include transition zones between major categories of impact (Figure 21).

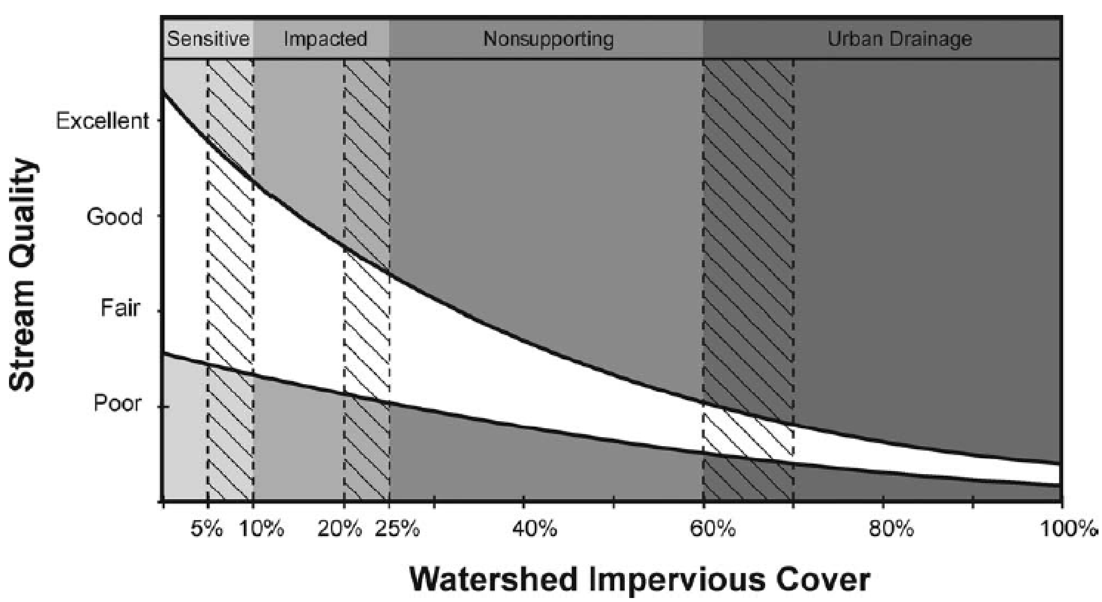

Figure 21. Reformulated impervious cover model from Schueler *et al.* (2009, p. 310).

4.3 Water Quality Impairment

Water quality can be impaired through contamination or alteration of water chemistry. Chemical contaminants are ubiquitous throughout the environment and are a major reason for the current declining status of freshwater mussel species nationwide (Augspurger *et al.* 2007, p. 2025). Chemicals enter the environment through both point and nonpoint discharges, including spills, industrial sources, municipal effluents, and agricultural runoff. These sources contribute organic compounds, heavy metals, pesticides, herbicides, and a wide variety of newly emerging contaminants (*e.g.*, untreated antibiotics and hormones from wastewater treatment facilities) to the aquatic environment. Ammonia is of particular concern because freshwater mussels have been shown to be particularly sensitive to increased ammonia levels (Augspurger *et al.* 2003, p. 2569). One of the main sources of ammonia is wastewater treatment facilities.

4.3.1 Sensitivity to Impairments

Wicklow *et al.* (2017, p. 130) suggest that brook floaters may be particularly sensitive to eutrophication and nitrogen loading. Eutrophication is the over-enrichment of water by nutrients (often from land runoff) that causes algal blooms and depletes the water of oxygen. In the range of the brook floater, sources of water quality impairment include agricultural activities (e.g., livestock grazing roads, natural gas extraction including construction of well pads, access roads, and storage ponds, water withdraw, removal of contaminated water, and climate change, among others.

A multitude of bioassays conducted on 16 mussel species (summarized by Augspurger *et al.* 2007, pp. 2025–2028) show that freshwater mollusks are more sensitive than previously known to some chemical pollutants, including chlorine, ammonia, copper, fungicides, and herbicide surfactants (Augspurger *et al.* 2003, p. 2574; Newton 2003, p. 2543), especially to juveniles (Mummert *et al.* 2003, p. 2548; Newton and Bartsch 2007, p. 2061; Wang *et al.* 2007, p. 2051; Wang *et al.* 2008, p. 1144-1145).

Mussels in the *Lasmigona* genus are closely related to *Alasmidonta* species as both belong to the Anodontini tribe (Augspurger *et al.* 2003, p. 2573). Of 8 mussel genera tested for toxicity to ammonia, all life stages of *Lasmigona* were the second most sensitive. Another study found that nickel and chlorine were toxic to three species (*Villosa nebulosa*, *V. umbrans*, and *Hamiota perovalis*) at levels below the current U.S. Environmental Protection Agency (USEPA) Water Quality criteria[4] (Gibson 2015, pp. 90–91). The study also found mussels (*Hamiota perovalis* and *V. nebulosa)* are sensitive to sodium dodecyl sulfate, a surfactant commonly used in household detergents, for which water quality criteria do not currently exist (Gibson *et al.* 2016 p. 33). We expect similar impacts to the brook floater.

[4] Water quality criteria are developed to implement requirements from the Clean Water Act which requires USEPA to develop criteria for water quality that accurately reflect the latest scientific knowledge on the impacts of pollutants on human health and the environment.

4.3.2 Types of Impairment

Water quality impairment is alteration of water quality parameters such as dissolved oxygen (DO), temperature, and salinity levels. DO levels may be reduced from increased nutrients in the water column from runoff or wastewater effluent, and juveniles seem to be particularly sensitive to low DO (Sparks and Strayer 1998, pp. 132–133). Increased water temperature from climate change and from low flows during drought can exacerbate low DO levels as well as have its own effects on both juvenile and adult mussels. Higher water temperatures increase metabolic processes in freshwater mussels, and can outstrip energy reserves if they remain above the natural thermal tolerance of a mussel for extended periods of time.

Natural gas extraction in the Marcellus Shale (the largest natural gas field in the U.S. that runs through northern Appalachia) region has negatively affected groundwater and surface water quality through accidental spills and discharges, as well as increased sedimentation due to increases in impervious surface and tree removal for construction of drill pads and pipelines (Vidic *et al.* 2013, p. 1235009-6; Olmstead *et al.* 2013, p. 4966). Disposal of insufficiently treated brine wastewater, which is more saline than seawater, has specifically been found to adversely affect freshwater mussels (Patnode *et al.* 2015, pp. 62-66). Contaminant spills are also a concern and threaten water quality in streams and rivers. Major spills can result in killing fish, mussels, crayfish and other aquatic species.

4.3.3 Climate Change

As mentioned in the Poff *et al.* 2002 (pp. ii-v) report on Aquatic Ecosystems and Global Climate Change, likely impacts of climate change on aquatic systems include:

- Increases in water temperatures that may alter fundamental ecological processes, thermal suitability of aquatic habitats for resident species, as well as the geographic distribution of species. Adaptation by migration to suitable habitat might be possible; however human alteration of dispersal corridors may limit the ability of species to relocate, thus increasing the likelihood of species extinction and loss of biodiversity.

- Changes and shifts in seasonal patterns of precipitation and runoff will alter the hydrology of stream systems, affecting species composition and ecosystem productivity.

- Aquatic organisms are sensitive to changes in frequency, duration, and timing of extreme precipitation events such as floods or droughts, potentially resulting in interference of reproduction. Further, increased water temperatures and seasonally reduced stream flows will alter many ecosystem processes.

- Since sedentary freshwater mussels have limited refugia from disturbances such as droughts and floods, and since they are thermo-conformers whose physiological processes are constrained by water temperature within species-specific thermal preferences, climate-induced changes in water temperature can lead to shifts in mussel community structure (Galbraith *et al.* 2010, p. 1176).

- Extreme events (both floods and droughts) can also affect water quality parameters, including DO. Drought is a large-scale effect likely to operate at the regional level.

4.4 Alteration of Water Flows

Brook floater populations need flowing water in order to survive. Mussels typically experience low flow and high flow periods and are adapted to deal with seasonal variability. However, extreme drought and extreme flooding can adversely affect mussel populations that are already stressed (Galladay *et al*. 2004, p. 504; Hastie *et al*. 2001, p. 114). More frequent occurrence of drought and flooding could be attributed to climate change in some parts of the brook floater's range.

Low flow events (including stream drying) as well as habitat inundation can eliminate appropriate habitat for brook floaters, and while the species can survive these events if the duration is short (in the case of stream drying), populations that experience these events regularly may be at risk. Inundation, or the transition from shallow, flowing water to deeper, still waters, has primarily occurred upstream of dams or other barriers such as culverts. Dams and other manmade blockages can affect flow upstream and downstream of the blockage. Impoundment and inundation of riffle habitats in central and eastern U.S. contributed to the extinction/extirpation of a number of North American freshwater mussels (Bogan 1993, p. 605). Humans have constructed dams for a variety of reasons: flood prevention, water storage, electricity generation, irrigation, recreation, and navigation (Eissa and Zaki 2011, p. 253). Reductions in the diversity and abundance of mussels in impoundments are primarily attributed to habitat shifts caused by impoundment (Neves *et al.* 1997, p. 63). Dimaio and Corkum (1995, p. 670) compared hydrologically flashy and hydrologically stable river types and found different mussel communities in each of the systems. They concluded that mussel species have preferences for a particular hydrologic regime and can be negatively impacted when the flow is altered by dams.

Upstream of dams, the change from flowing to impounded water, increased depths, and increased buildup of sediments, and decreased DO. The drastic alteration in resident fish populations inevitably can threaten the survival of mussels and their overall reproductive success (Haag 2009, pp. 117-118). While there are some cases of mussels thriving in stable conditions downstream of small dams (Gangloff 2013, p. 476 and references therein), it is common for mussels to experience fluctuations in flow regimes, minimal releases and scouring flows, seasonal DO depletion, reduced or increased water temperatures, and changes in fish assemblages. Downstream, the instability of sediment from scour, flushing, and deposition of eroded bank material can result in juveniles failing to settle and stay in interstitial spaces, and may prevent attachment to substrates using byssal threads (Hastie *et al.* 2001, p. 114). Rapid dewatering can also occur during times of water storage, which can lead to increased stress and mortality especially in more sensitive species like brook floater (Galbraith *et al.* 2015, p. 50) as well as preventing dispersal throughout the system. Water storage in reservoirs, usually taking place during dry summer months in order to recharge lake levels, is accomplished by decreasing

the amount and/or frequency of water released from the dam. In turn, the water available to mussel populations downstream is also reduced.
Inundation causes an increase in sediment deposition, eliminating the crevices in the substrate that this species inhabits. In large reservoirs, deep water is very cold and often devoid of oxygen and necessary nutrients. In smaller reservoirs, excess nutrient accumulation and higher temperatures than adjacent stream reaches are often the norm. Importantly, the frequency, duration, timing, and location of water release impacts downstream habitat suitability.

Very low water levels are detrimental to brook floater populations, as well. While brook floaters may survive short periods of low flow, as low flows persist, mussels face oxygen deprivation, increased water temperature and, ultimately, stranding (which means the inability to move or relocate to find flows), reducing survivorship, reproduction, and recruitment in the population. During low water flow periods, mussel mortality often occurs due to dehydration, thermal stress, and exposure to predation (Galladay *et al.* 2004, p. 504; Pandolfo *et al.* 2010, p. 965; Galbraith *et al.* 2015, pp. 49-50). More frequent and extended droughts are exacerbated by increased water withdrawals, for municipal water, sewage treatment, cooling towers at power plants, irrigation and natural gas extraction (Neff *et al.* 2000, p. 207), as evident in the Mid-Atlantic states.

High flows can result in dislodgement or displacement of mussels and habitat destabilization. More commonly, flooding causes mussels to become covered in silt, crushed by large substrate, dislodged, and moved to downstream habitat (which may be more or less suitable) and/or displaced to a riverbank that soon dries and results in desiccation of the mussels (Hastie *et al.* 2001, pp. 113-114). For example, remnants of several hurricanes scoured the streambanks and channel in several areas in the Upper Nolichucky watershed, temporarily reducing numbers and distribution of the Appalachian elktoe (*Alasmidonta raveneliana*) (USFWS 2017 p. 8; Fraley and Simmons 2006, p. 11).

4.5 Loss/Fragmentation of Suitable Habitat

Fragmentation and isolation contribute to the extinction risk that mussel populations face from stochastic events (see Haag 2012, pp. 336-338). Streams are naturally dynamic, frequently creating, destroying, or shifting areas of quality habitat over a particular timeframe. Habitat fragmentation (natural and human-induced) in stream systems is brought about by a number of factors, most of which interact to create patches of suitable and unsuitable mussel habitat.

The definition of fragmentation is the breaking apart of habitat, independent of habitat loss (Fahrig 2003, p. 487). Some sources, like barriers, directly and permanently fragment habitat. Other factors, like drought, water quality, host fish movement, substrate stability, adjacent land use, etc., lead to fragmentation in subtler and interdependent ways. In dendritic landscapes, like streams and rivers, increasing fragmentation can lead to systems featuring several small and one or a few larger fragments (Fagan 2002, p. 3247). In contrast to landscapes where multiple routes of movement among patches are possible, pollution or other habitat degradation at specific points in dendritic landscapes can completely separate portions of the system (Fagan 2002, p. 3246). Connectivity between patches (mussel beds or occupied habitat) is important in landscapes where the patches of suitable habitat are created and destroyed frequently. Where populations are small, local extinction caused by demographic stochasticity (e.g., changes in the proportion of males and females, the reproductive potential of females, and survival of individuals) happens often and populations must be reestablished by colonization from other patches.

Some dams have been identified as causing genetic isolation in river systems for fish which could have the same effect on mussel population genetics as well. In addition, the host fish could be negatively affected by extreme changes in habitat and temperature. Dams can negatively affect mussel reproduction by altering temperature regimes, flows, and habitats. Some dams, especially small low head dams or larger dams with established minimum flows have been found to have larger mussels and healthy mussel populations. Improperly designed or installed road culverts at stream crossings can also act as significant barriers and have similar effects as dams on stream ecology. Fluctuating flows through a culvert can differ significantly from the rest of the stream, preventing fish passage and scouring downstream habitats. If a culvert is installed incorrectly, over time the culvert becomes perched above the stream bed, preventing connectivity as aquatic organisms are unable to pass through them.

4.6 Other Factors

We examined a number of other factors, as described below, which did not rise to such a level that impacted populations or the species as a whole.

4.6.1 Predation

We identified three potential sources of predation risk for the brook floater: 1) rusty crayfish (*Orconectes rusticus*); 2) flatworms; and 3) changes in water levels which increase mussel exposure. Klocker and Strayer (2004, entire) investigated potential impacts of the introduction of the rusty crayfish on native mussels by assessing their ability to eat various sizes of fingernail clams and Eastern elliptio. With a few exceptions, crayfish ate fingernail clams only if the clams were less than 7 mm (0.3 in) long and clams were less likely to be eaten if they were buried than if they were exposed (Klocker and Strayer 2004, p. 174). Crayfish ate 75 percent of the unionid mussels less than 8.9 mm (0.4 in) long, whether they were buried or exposed. No mussels greater than 8.9 mm (0.4 in) long were eaten, but 30 percent received extensive damage to the outer margin of their shells (Klocker and Strayer 2004, p. 174). The authors suggest that the introduction of the rusty crayfish poses a potential danger to native bivalve populations. It should also be noted that throughout the range of the brook floater, other species of crayfish are expected to be at high enough densities and utilizing the same foraging behavior as the rusty crayfish, that they can be expected to predate on mussels in a similar fashion.

Predation of mussels from raccoons, muskrats and otters is known to occur. Low water flows (e.g., following a prolonged summer drought) may expose mussels to intense opportunistic predation and this has been observed for brook floaters at several locations (Wicklow *et al.* 2017, pp. 45, 47, 55, 137). Muskrat predation can be harmful to small populations of mussels (Neves and Odom 1989, p. 935). In addition, flatworms in the genus *Macrostomum* are known predators of juvenile mussels (Zimmerman *et al.* 2003, p. 28), but it is unclear whether this is a significant risk to brook floaters.

4.6.2 Invasive Species

When an invasive species is introduced to a natural system, it may have many advantages over native species, such as easy adaptation to varying environments and a high tolerance of living conditions that allows it to thrive in its non-native range. There may not be natural predators to keep the invasive species in check; therefore, it can potentially live longer and reproduce more often, further reducing the biodiversity in the system. The native species may become an easy food source for invasive species, or the invasive species may carry diseases that could potentially wipe out populations of native species.

Besides the rusty crayfish identified above (predation), examples of invasive species that affect freshwater mussels like the brook floater are: the Asiatic clam (*Corbicula fluminea*) which alters benthic substrates, competes with native species for limited resources, and causes ammonia spikes in surrounding water when they die off en masse (Scheller 1997, p. 2); Dreisseneid mussels; and invasive plants can also alter stream habitat, decrease flows, and contribute to sediment buildup in streams (North Carolina Aquatic Nuisance Species Management Plan Committee 2015, p. 61).

The Asiatic clam is hermaphroditic, enabling fast colonization and is believed to practice self-fertilization, enabling rapid colony regeneration when populations are low (Sousa *et al.* 2008 p. 85, Cherry *et al.* 2005, p. 369). Asiatic clams are prone to have die offs that reduce available DO and increase ammonia which can cause stress and mortality to the brook floater (Cherry *et al* 2005, p. 377). The relationship between Asiatic clam densities and viability of native freshwater mussel populations is complicated and the topic has produced conflicting results in the literature.

As suggested by Vaughn and Spooner (2006, p. 331), this may be because interactions between Asiatic clams and native freshwater mussels are different depending on the spatial scale analyzed. They used a hierarchical sampling strategy of quadrats (patches) nested within sites (mussel beds) to allow comparison of information across spatial scales. At the quadrat (patch) scale, their results showed that corbicula densities were higher in quadrats without mussels (Vaughn and Spooner 2006, p. 334). However, when patch-scale density and biomass information was pooled to represent entire stream reaches, the negative relationship between native mussels and *Corbicula* was no longer as apparent, and there was not a significant relationship between native mussels and *Corbicula* (Vaughn and Spooner 2006, p. 331).

The DFO (2018, p. 20) identified the introduction of Dreissenid molluscs, such as zebra mussel (*Dreissena polymorpha*) and quagga mussels (*D. bugenis*), as a potential threat to freshwater mussels. They are known to occur throughout the Great Lakes and the St. Lawrence River, but there is no indication that they are currently found in Nova Scotia or New Brunswick (DFO 2018, p. 20). Since its introduction in the Great Lakes in 1986, zebra mussel colonization has resulted in the decline and regional extirpation of freshwater mussel populations in lakes and river systems across North America (Schloesser *et al.* 1996, p. 302). One of the direct consequences of the invasion of these two species is the local extirpation of native freshwater mussel populations from 1) attachment to the shells of native mussels, which can kill them, 2) outcompeting native mussels and other filter feeding invertebrates for food, and 3) reduction of suitable habitat (clean substrates). This problem has been particularly acute in some areas of the U.S., such as the upper Ohio River Basin, which has a very rich diversity of native freshwater mussel species.

There is little evidence, however, that *Dreissenia* pose much of a threat to the brook floater. Maps of *Dreissenia* occurrences do not overlap much with the range of the brook floater (Whittier *et al.* 2008, p. 5). Whittier *et al.* (2008, p. 6) defined *Dreissenia* invasion risk based on calcium concentrations in surface water. They noted that for all mussels, but particularly for *Dreissenia*, calcium is considered a key limiting factor, required for basic metabolic function as well as shell building. Therefore, they hypothesized that low-alkalinity/low-calcium regions would resist invasion. They evaluated the hypothesis by plotting zebra mussel occurrences (through 2006), against relative risk zones defined by surface water alkalinity. This study classified New England, most of the southeast as very low risk or low risk of invasion. Their calcium classifications are consistent with the fact that most of New England, the Piedmont, and Coastal Plain ecoregions along the Atlantic, and much of the southeast have not been invaded by zebra mussels, despite nearby source populations.

Didymo (*Didymosphenia geminata*), also known as "rock snot", is a non-native algae (diatom) that can alter the habitat and change the flow dynamics of a site by forming dense mats that redirect flow within the channel. Clear, high-energy riffles can see reduced flows if growths are sufficient enough to occlude water movement, especially during low flow and base flow periods. Invasive plants grow uncontrolled and can cause the habitat to fill in, they can affect flow dynamics, and cause the water to become warmer, and can even dry out completely, especially in drought situations.

4.6.3 Hybridization

Strayer and Fetterman (1999, p. 337) suggest the potential for hybridization between brook floaters and the elktoe based on morphology; however, genetic studies are needed to confirm this hypothesis. In response to our request for information from state natural resource agencies and other brook floater experts, hybridization was not identified as a concern (Service unpublished data). At this time there is not sufficient information to suggest that hybridization is impacting individuals or populations; therefore, we determined that hybridization has no known effect.

4.7 Ongoing Conservation Measures

4.7.1 Existing Regulatory Mechanisms

Listing Status

The brook floater receives some level of protection in multiple states (see Appendix C); however, protections afforded (e.g., "take" prohibitions) by the listing varies.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the brook floater in 2009 and designated it as Species of Special Concern under Schedule 1 of the Species at Risk Act (SARA) in 2013. SARA listings require development of a management plan and measures to conserve species and prevent further declines. New Brunswick Department of Natural Resources (NBDNR) listed the brook floater under the New Brunswick Species at Risk Act as a species of special concern[5] in 2013[6]. The Nova Scotia Department of Natural Resources (NSDNR) listed the brook floater as threatened[7] in 2013 pursuant to the Nova Scotia Endangered Species Act (NS ESA)[8]. The NS ESA prohibits killing or disturbing species at risk (s11), destroying or disturbing its residence, and destroying or disturbing of core habitat (s13). Penalties, both for individuals and corporations, can be incurred when the NS ESA is violated.

In addition, there are multiple other federal, Canadian, state, and provincial laws or regulations that could influence brook floater viability. The section below focuses on those that address water quality.

State and Federal Stream, Wetland and Water Quality Programs

Section 401 of the federal Clean Water Act (CWA) requires that an applicant for a federal license or permit provide a certification that any discharges from the facility will not degrade water quality or violate water-quality standards, including state-established water quality standard requirements. Section 404 of the CWA established a program to regulate the discharge of dredged and/or fill material into waters of the U.S. Permits to fill wetlands or streams are issued by the U.S. Army Corps of Engineers under Nationwide, Regional General Permits, or Individual Permits and mitigation is required for impacts above minimal levels. In addition, several state laws require setbacks or buffers[9] from aquatic systems, but allow variances/waivers for those restrictions.

Current State regulations regarding pollutants are designed to be protective of aquatic organisms; however, freshwater mollusks may be more susceptible to some pollutants than the test organisms commonly used in bioassays. Additionally, water quality criteria may not incorporate data available for freshwater mussels (March *et al.* 2007, pp. 2066–2067). As stated above, freshwater mollusks are more sensitive than previously known to some chemical pollutants. Several studies have demonstrated that the criteria for ammonia developed by EPA in 1999 were not protective of freshwater mussels (Augspurger *et al.* 2003, p. 2,571; Newton *et al.* 2003, pp. 2559-2560; Mummert *et al.* 2003, pp. 2548-2552). However, in 2013 EPA revised its recommended criteria for ammonia. The new criteria are more stringent and reflect new toxicity data on sensitive freshwater mollusks (78 FR 52192, August 22, 2013; p. 2). All of the states in the range of the brook floater have not yet adopted the new ammonia criteria. State-issued National Pollutant Discharge Elimination System (NPDES), known as State Pollution Discharge Elimination System (SPDES), permits are valid for 5 years, so even after the new criteria are adopted, it could take several years before facilities must comply with the new limits.

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[5] "species of special concern" means a wildlife species that may become a threatened species or an endangered species because of a combination of biological characteristics and identified threats.

[6] http://www1.gnb.ca/0078/SpeciesAtRisk/details-e.asp?ID=72 – accessed 4.25.2018

[7] a species likely to become endangered if limiting factors are not reversed

[8] https://nslegislature.ca/sites/default/files/legc/statutes/endspec.htm – accessed 4.25.2018

[9] A buffer is a strip of trees, plants, or grass along a stream or wetland that naturally filters out dirt and pollution from rain water runoff before it enters rivers, streams, wetlands, and marshes (SELC 2014, p. 2).

Canadian Considerations

The Canada's Fisheries Act (R.S.C, c. F-14) and its regulations may provide protection for the brook floater and its host fish. This Act currently prohibits activities that result in serious harm to fish that are part of a commercial, recreational or Aboriginal fishery, or the fish that support such a fishery. It also prohibits the release of substances deleterious to fish, and activities that disrupt or destroy fish habitat.

The Clean Water Act (New Brunswick 90-136) in the territorial subdivision of New Brunswick regulates impacts to surface waters from construction, vegetation clearing, forestry activities, and the installation of dams or obstructions to water flow, by requiring an approved permit for such activities within 30 meters (98 feet) of a watercourse. Both provincial governments and the Canadian federal government require Environmental Impact Assessment Reviews for major developments, including those near waterways. The Nova Scotia Environment Act[10] requires that all wastewater discharges, construction of dams, and watercourse flow alterations are subject to review and approval.

Summary

Despite existing authorities, such as the Clean Water Act, pollutants continue to impair the water quality throughout the current range of the brook floater. State and federal regulatory mechanisms have helped reduce the negative effects of point source discharges since the 1970s. While new water quality criteria are being developed that take into account more sensitive aquatic species, most criteria currently do not. It is expected that it will take several years to implement new water quality criteria throughout the range.

4.7.2 Recovery Plans/Strategies

The DFO recently published a management plan for the brook floater (DFO 2018, entire). The overall objective of this management plan is to maintain a viable, self-sustaining brook floater population in Canada at current and new locations. Conservation measures are to be implemented under four broad strategies: 1) Protection - Conserve the quality and quantity of brook floater habitat; 2) Management - Mitigate threats to the brook floater and its habitat; 3) Research and Monitoring - Improve knowledge of the brook floater in Canada; and 4) Outreach and Communication - Promote education and awareness of the brook floater and efforts to conserve the species and its habitat.

In the U.S., there are multiple state wildlife action plans across the range of the brook floater that recommends a variety of measures for the species. In addition, the brook floater has been a Northeast Regional Species of Greatest Conservation Need (RSGCN) since 2013. The RSGCN list is a charge of the Northeast Fish and Wildlife Diversity Technical Committee (NEFWDTC) and focuses attention on species with high conservation need. As a result of this attention, the states worked together to fund the Conservation Status of the Brook Floater mussel in the U.S., recently published in 2017 (Wicklow *et al.* 2017, entire).

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[10] https://nslegislature.ca/sites/default/files/legc/PDFs/annual%20statutes/2017%20Fall/c010.pdf – accessed 4.25.2018

The brook floater is one of twelve Vermont freshwater mussel species included in a recovery plan for that state (O'Brien *et al.* 2002, entire). The recovery goal for the Vermont imperiled mussels is to attain multiple reproducing populations (*e.g.,* minimum viable population) that are stable or increasing, are comprised of multiple year/size classes, and cover at least 80 percent of their historical range in Vermont (O'Brien *et al.* 2002, p. 21). The plan included multiple recommended actions to meet the goals, such as monitoring, addressing spills, addressing dam relicensing, and protecting stream buffers.

4.7.3 Conservation Actions

Created in 2016, the Brook Floater Working Group (BFWG) is a collection of managers and scientists from federal and state agencies and academic institutions who specialize in mussel ecology and conservation and technical advisors that specialize in mussel survey methods, propagation and decision science. The BFWG is working on the following goals: standardized survey protocols, species distribution models, development of propagation methods to aid in population restoration, and consistent monitoring designs including rapid assessment and long term survey designs to be used throughout the range. Although highly important in terms of enhanced collaboration, the BFWG is funded via a State Wildlife Grant which expires in 2019. Multiple states, mostly within the southern portion of the range (VA, NC, and SC) have mussel propagation facilities that are actively propagating the brook floater. These propagated animals will then be used to stock or augment existing suitable habitat in each state. These efforts are being used to bolster populations that have seen historical declines, but whose habitat quality has improved to the point that stocking will result in survival of a significant portion of the animals.

4.7.4 Protected Lands

Protecting aquatic habitat through preservation of adjacent upland habitat may help conserve species like the brook floater. For example, some of the largest, most viable populations of the brook floater occur on protected lands. Pisgah and Sumter National Forests, in North Carolina and South Carolina, respectively, protect the majority of the Chattooga River watershed, which contains the largest surviving population of the species (estimated 100,000 + individuals) (T.R. Russ, pers. comm.).

In South Carolina, the Service and the U.S. Forest Service (USFS) have entered into an Interagency Agreement to allow propagation and augmentation of brook floaters on USFS lands (Sumter National Forest).

4.7.5 Habitat Improvement

Habitat improvement for brook floaters and other aquatic species can be accomplished by habitat restoration, maintaining connectivity (removing barriers to provide fish passage), planting and maintaining sufficient riparian buffers (Shultz *et al.* 1995, p. 203), and improving water quality by capturing and treating water and sediment prior to entering into rivers and streams.

4.8 Summary

Our analysis of the past, current, and future influences on what the brook floater needs for long term viability revealed that there are multiple factors (positive and negative) affecting the current status of individual brook floaters, as well as brook floater populations. The primary factors are disjunct populations facing habitat loss or fragmentation, changes in water flows, and degraded water quality from development, energy production, and agriculture. There are limited conservation programs that are specifically targeted at the brook floater or significantly reducing any of the primary stressors. Conservation efforts could improve habitat; however, measures will need to be imposed to ensure good water quality, sufficient flows, temperatures, and substrate for brook floaters to persist into the future.

CHAPTER 5. VIABILITY

We have considered what the brook floater needs for viability and the current condition of those needs (Chapters 2 and 3), and we reviewed the risk factors that are driving the historical, current, and future conditions of the species (Chapter 4). We now consider what the species' future conditions are likely to be. We apply our future forecasts to the concepts of resiliency, redundancy, and representation to describe the future viability of the brook floater.

5.1 Factors Influencing Viability – Overview

As discussed in Chapter 4, development (e.g., urbanization, agriculture and oil and gas development) is a primary source of the major stressors (e.g., sedimentation, water quality impairment, fragmentation) influencing population resilience and ultimately species viability. Thus, we structured future scenarios around levels of development. Other factors considered relate to climate variables.

5.1.1 Development

Development resulting in land use change, which is a primary source of stressors, varies across the landscape in type and intensity. The appropriate spatial scale to project land use must account for that spatial variation in development but avoid a high resolution that would unnecessarily slow down the analysis without improving the overall assessment of the species' future condition. Thus, we evaluated land use at the scale of the AU and took into account effects due to representative area or region. We also kept in mind that the appropriate time scale to project future condition should be consistent with the scientifically reliable projections of the stressors and include multiple time increments to evaluate the species' condition at various points into the future. Our approach to assess future condition for brook floater involved:

1) Developing scenarios based on forecasts of land use (as detailed in Table 4 below);
2) Analyzing the empirical relationship between biological condition and land use, and using those relationships to inform the species' response to future scenarios; and
3) Predicting future condition based on a simple rule set and the opinions of experts who have local knowledge at the state or AU levels.

The analysis of the relationship between biological condition and land use does not attempt to estimate the effects of individual stressors, but uses level of land use to integrate the stressor level effects. This is the logic of the ICM (Schueler *et al.* 2009, entire). Details regarding the methods can be found in Appendices D and E.

5.1.2 Development Scenarios

Two scenarios were developed based on economic-based land use projections from Lawler *et al.* (2014, entire) and predicted energy development (Dunscomb *et al.* 2014; Table 4, p. 20).

- Land use projections: Lawler *et al.* (2014, entire) used economic models to project land use including agricultural or urban development, which are relevant to the brook floater assessment.

    - Scenario 1: land-use change similar to trends from 2007-2012
    - Scenario 2: land-use change similar to trends from 1992-1997

  In both scenarios, agricultural and urban land use is projected to increase. However, Scenario 1 includes a 10 percent increase in crop prices every 5 years relative to Scenario 2. As a result, Scenario 1 has a higher rate of increase in conversion to agriculture than does scenario 2.

- Predicted energy development: Dunscomb *et al.* (2014) identified areas likely to be developed for energy using a model that predicts the probability of energy development on the km2 scale along with greater than 0.65 and greater than 0.9 thresholds (we used only the greater than 0.9 threshold to base the assessment on the higher likelihood of development). They assumed the impact would be similar to impervious surface and translated the effect of energy development in combination with urbanization on stream quality using the model of stream quality to impervious surface reported by Schueler *et al.* (2009, entire) (Note that energy development potentially affects 8 AUs in the Mid-Atlantic Representative Area).

Table 4. Development scenarios used to evaluate brook floater future condition. The scenarios were comprised of economic-based projections of agricultural and urban land use (Lawler *et al.* 2014) combined with the impact of energy development (Dunscomb *et al.* 2014). Dunscomb *et al.* (2014) used a probability of development cutoff of greater than or equal to 0.9 and a spatial resolution of 1 km^2. The same level of energy development applied to both scenarios.

	Land use projections based on economic conditions and past trends	Energy development (Mid-Atlantic Representative Unit only)
Scenario 1	● Land-use change similar to trends from 2007-2012 (favors agriculture).	Impact extends to developed area at a km^2 spatial resolution. Scenario increases.
Scenario 2	● Land-use change similar to trends from 1992-1997 (favors urbanization)	Scenario increases.

5.1.3 Climate Change

We reviewed regional assessments and examined downscaled climate variables for expected climate change within the brook floater's range. The information we compiled was limited to the U.S. portion of the range; sources of information for the Canadian portion of the range had not been identified at the time of this report. The regional assessments, which summarized trends in climate variables (NOAA 2013a and 2013b) and vulnerabilities of fish and wildlife habitat to climate change (Manomet Center for Conservation Sciences and National Wildlife Federation 2013, entire) provided broad patterns. In contrast, downscaled climate variables for indicator populations within each representative area provided seasonal patterns at specific locations based on an ensemble of emission scenarios and global circulation models (GCMs) (Bias Corrected and Downscaled WCRP CMIP3 Climate Projections; https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/#About). Daily means per month within 3 time periods (1961-2000, 2046-2065, 2081-2100) were computed as averages of 53 models distributed across 3 emission paths (SRES A1b, A2, B1).

For the northeast and mid-Atlantic (excluding Virginia), NOAA (2013a) evaluated regional climate trends and future emission scenarios. Key findings include (NOAA 2013a, p. 72-74):

- Climactic events of concern in the northeast include flooding, winter storms (e.g., nor'easters, lake-effect snow, ice), heat waves, and drought.
- Temperatures have increased since 1960 especially in winter and spring seasons, and temperatures are expected to continue to increase. Temperature increase is expected to show little spatial variation within the regions, although the coastal areas are expected to experience smaller increases than inland areas and warming is expected to be higher in the northern portion of NOAA's assessed area. Projected temperatures for 2041-2070 relative to 1971-2000 indicate 13 more days above 95° F (standard deviation [SD] = 7 days) and 26 fewer days below 32° F (SD = 3 days). Projected temperature changes are similar for high and low emission scenarios out to the mid-century but deviate into the late-century period where warming under the high emission scenario is expected to be twice that for the low emission scenario.
- Annual precipitation has been more variable since 1970. Precipitation is expected to increase over the regions except in the southern areas where the direction of change is unclear. Seasonally, precipitation is expected to increase in the winter, spring, and fall, but decrease in the summer. Overall, there is considerable uncertainty associated with predicting precipitation changes.

For the southeast (including Virginia), NOAA (2013b) evaluated regional climate trends and made future projections. Key findings include (NOAA 2013b, pp. 83-85):

- Climatic events of concern in the southeast include heavy rainfall and floods, drought, temperature extremes, and severe storms.
- The southeast has not exhibited a warming trend over the 20th century. Projections indicate significant future warming; however, projections show substantial uncertainty in the magnitude of temperature change within the region. Projected temperature changes are similar for high and low emission scenarios out to the mid-century but deviate into

the late-century period where warming under the high emission scenario is expected to be twice that for the low emission scenario.

- Precipitation is expected to generally increase especially in the north and east of the region within the range of the brook floater. The Appalachian Mountains are expected to experience an increase in the number of days with precipitation exceeding 1 inch. The number of consecutive days with precipitation less than 0.1 inches is expected to have little or no change.

Figures 22 to 27 describe downscaled climate models for indicator AUs that are distributed within occupied AUs in each representative area in the U.S. portion of the range. The indicator AUs, all of which are currently in "high" or "medium" condition, are St. Croix River, New Brunswick, Canada (Canadian Province Representative Area); Bow Bog Creek, NH (Northeast Representative Area); Pine Creek, PA (Mid-Atlantic Representative Area); Penns Creek, PA (Mid-Atlantic Representative Area); Yadkin River, NC (Southeast Representative Area); and Chattooga River, GA (Southeast Representative Area). Summaries are the minimum and maximum daily air temperature and daily precipitation based on ensemble of emission scenarios and general circulation models. (https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/#Projections:%20Subset%20Request)

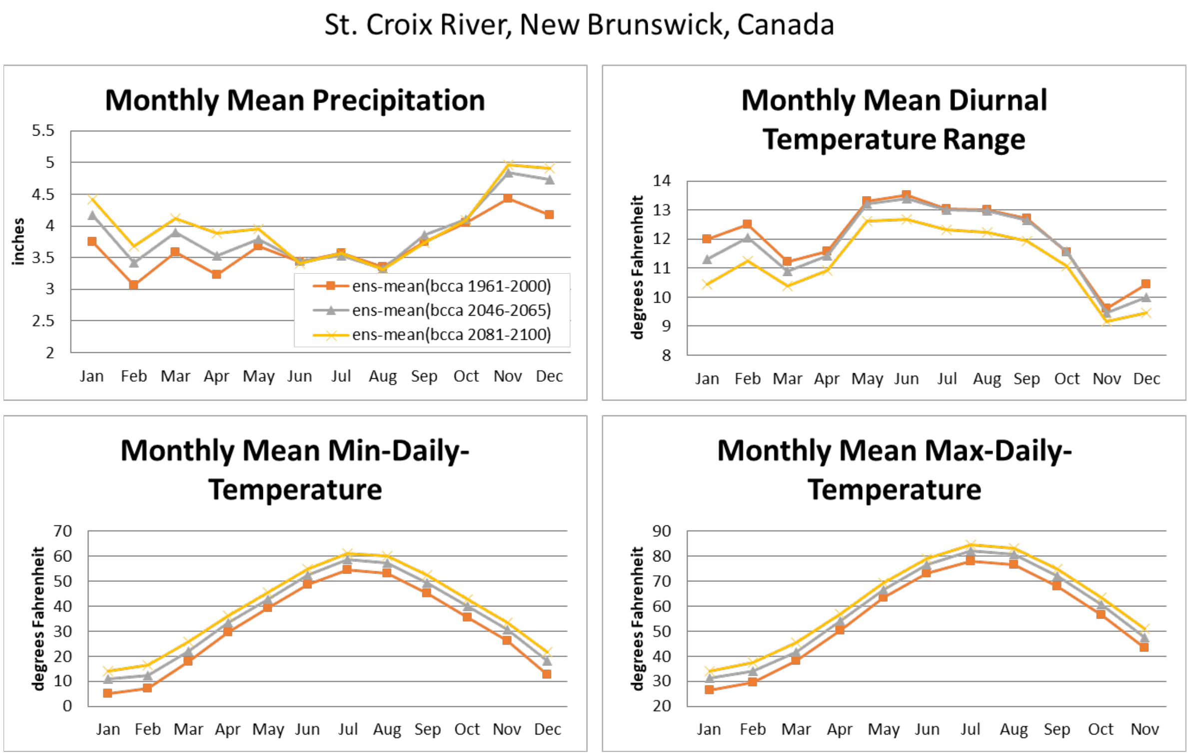


Figure 22. Downscaled climate variables for St. Croix River, New Brunswick, Canada (2 degree bounds including 45.384, -67.349).

Bow Bog Creek, NH in the Northeast

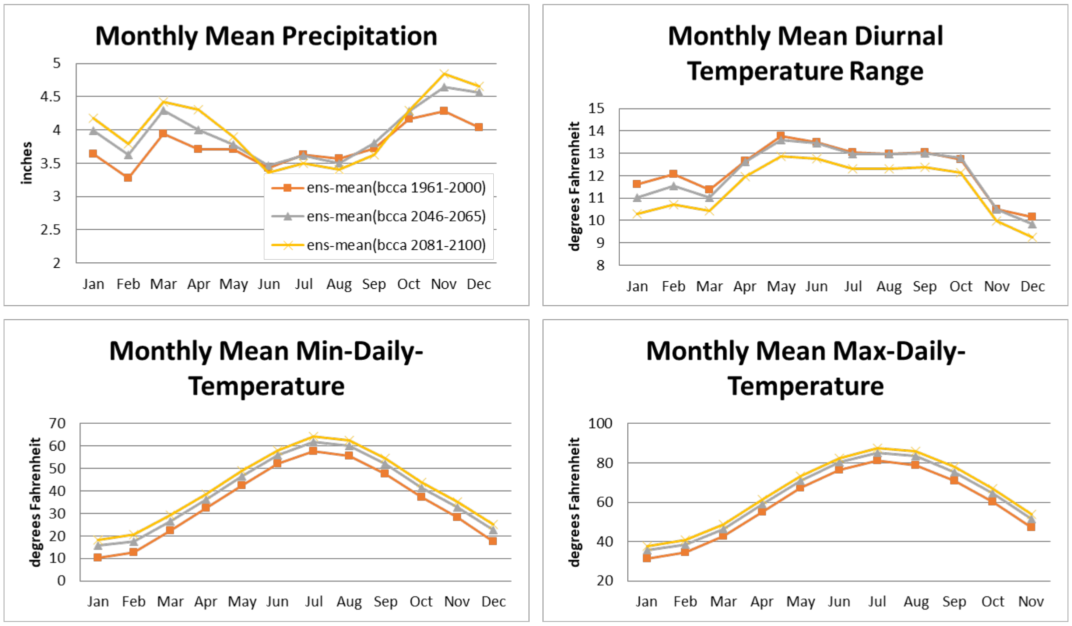


Figure 23. Downscaled climate variables for Bow Bog Creek, NH, in the Northeast Representative Area (2 degree bounds including 43.252, -71.537).

Pine Creek, PA in the Mid-Atlantic Region

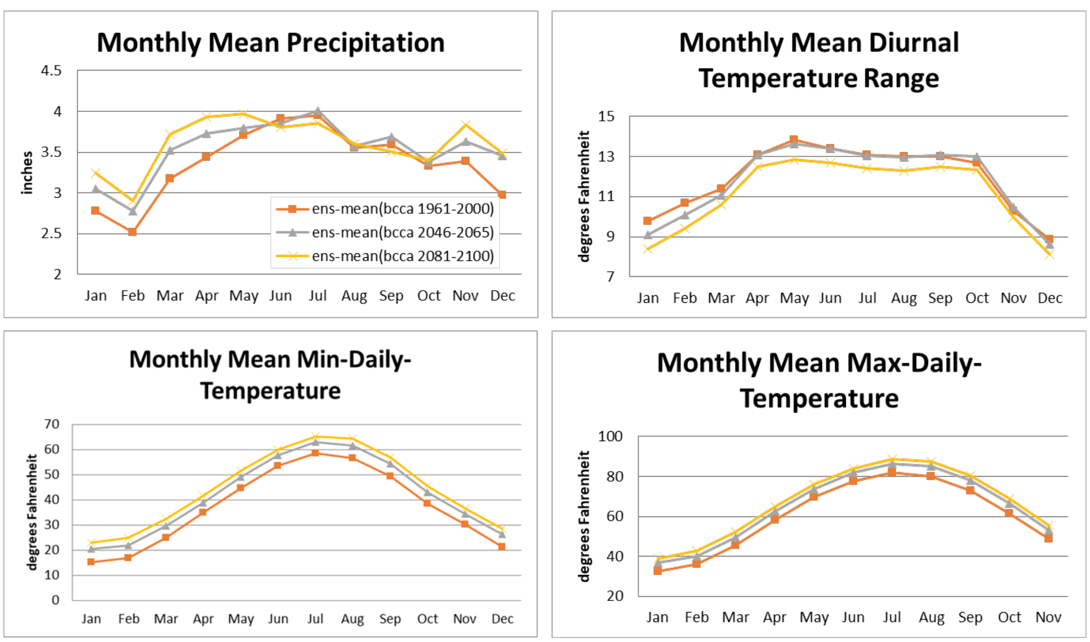


Figure 24. Downscaled climate variables for Pine Creek, PA, in the Mid-Atlantic Representative Area (2 degree bounds including 41.184, -77.272).

Penns Creek, PA in the Mid-Atlantic

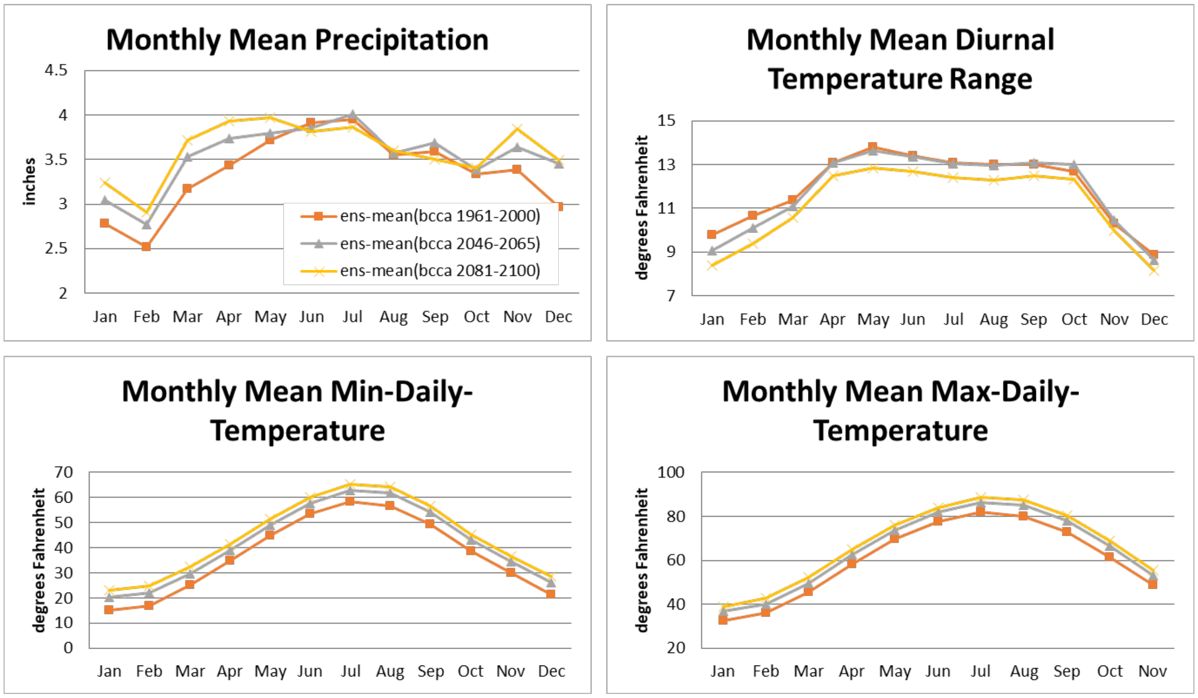


Figure 25. Downscaled climate variables for Penns Creek, PA, in the Mid-Atlantic Representative Area (2 degree bounds including 41.184, -77.272).

Chattooga River, GA in the Southeast

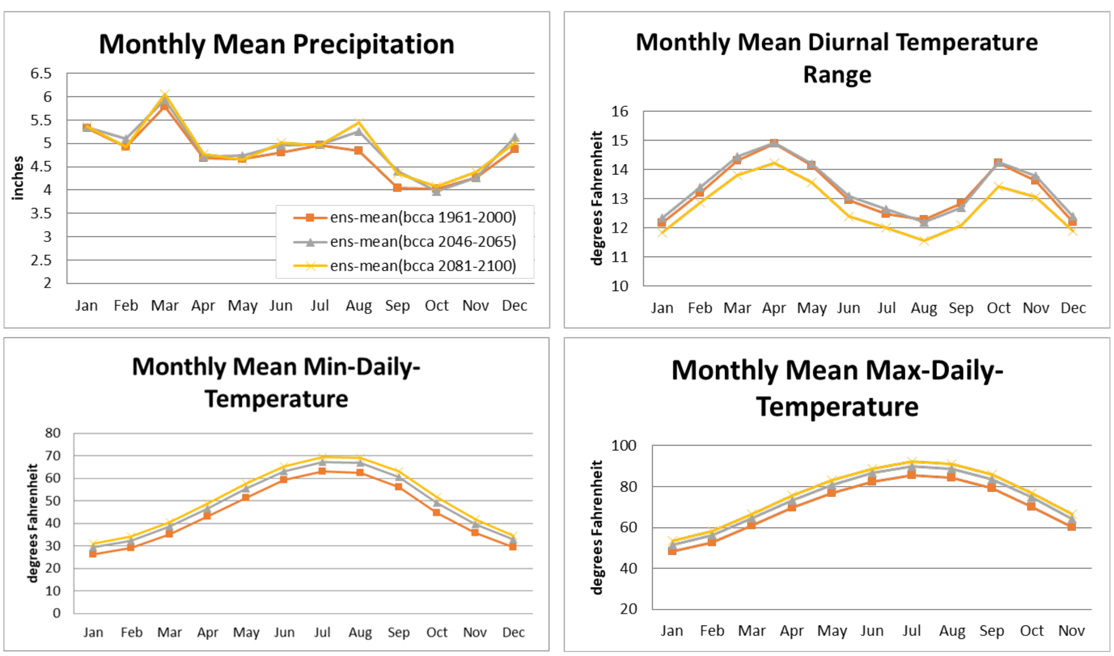


Figure 26. Downscaled climate variables for Chattooga River, GA, in the Southeast Representative Area (2 degree bounds including 34.862, -83.251).

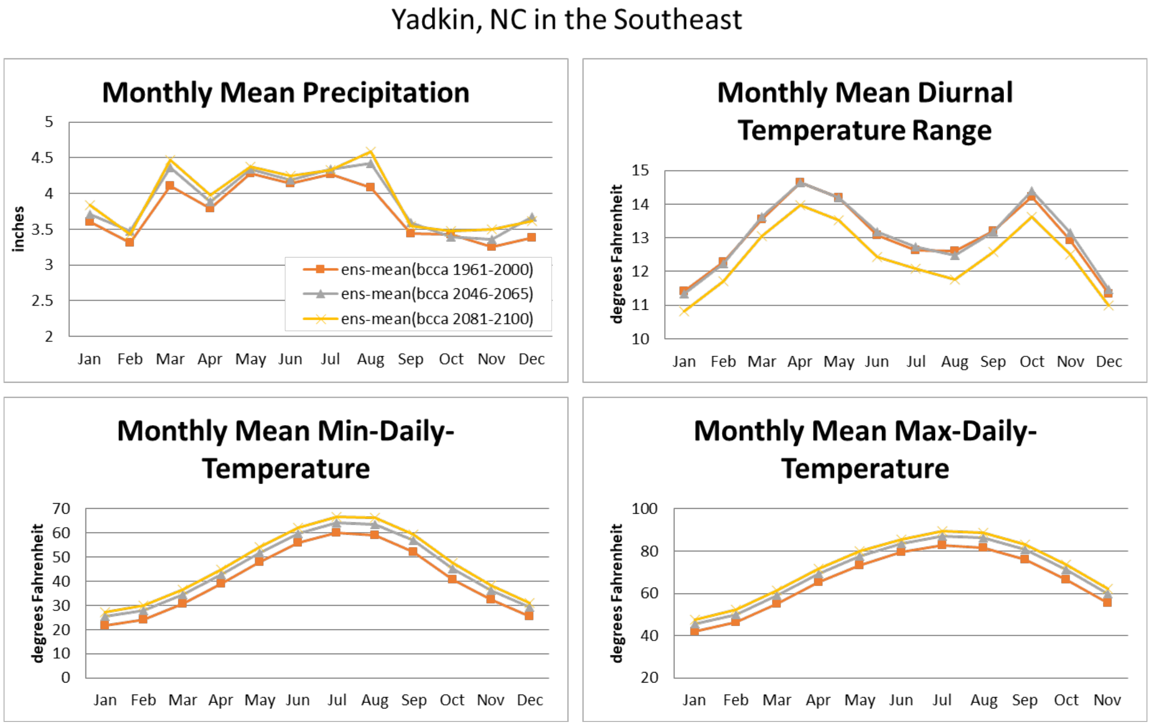


Figure 27. Downscaled climate variables for Yadkin River, NC, in the Southeast Representative Area (2 degree bounds including 36.254, -80.462).

Although our analysis could not relate climate change quantitatively to population condition, regional climate summaries (NOAA 2013a and 2013b) and down-scaled projections (Figures 22-27) along with the land-use change scenarios and analyses were available to the core team when future condition was assessed. The effects of climate change were not expected to be uniformly negative across the species range. The magnitude of change in air temperature does not appear to be large relative to known biological thresholds, and the relationship between air and water temperature, particularly in headwater streams, is affected by ground water input (Briggs *et al.* 2018), which is not known for brook floater AUs. Also, for a species that ranges from the southeast U.S. to Canada, it is not obvious what the effect will be due to the expected rise in air temperature. Change in precipitation is also not uniform across the range with considerable uncertainty associated with predicting precipitation change.

Climate change vulnerability assessments for brook floater ranged from presumed stable (North Atlantic Coast, Mid-Atlantic Coast, Northern Appalachians and Maritime Canada), highly vulnerable (Maine), and extremely vulnerable (New York and West Virginia). See http://climateactiontool.org/species/brook-floater?extents=.

Factors stated for a 'not vulnerable' assessment were:

- Dependent on other species for dispersal
- Has already experienced slight variations in annual precipitation (over the last 50 years)
- Slightly impacted by changes due to human response to climate change.

Factors stated for ‘highly or extremely vulnerable’ assessment were:

- Sensitive to changes in temperature
- Natural and anthropogenic barriers prevent dispersal or shifts in species' range
- Has already experienced variations in annual precipitation (over the last 50 years)
- Dependent on other species for dispersal
- Requires specialized habitat
- Habitat is likely to experience significant declines
- Species distribution is highly fragmented because of habitat loss or populations that are very spread out across the landscape
- Temperature increases may prevent species from surviving in some life stages
- Growth or reproduction may be harmed by additional stress from high temperatures
- Dependent on stable hydrology for survival and reproduction (stream flows)
- Unable to disperse long distances or move across the landscape as conditions change
- Natural and anthropogenic barriers prevent dispersal or shifts in species' range
- Limited genetic diversity within the population (suspected)
- Sensitive to change in the timing of seasons and/or other environmental cues
- Sensitive to disruption of relationship with very few host species that is vulnerable to climate change (cold-water fish)
- Close interactions with another species may be affected by climate change (dependence for habitat or food)
- Habitat may be affected by invasive species that are likely to increase
- Unable to disperse long distances or move across the landscape as conditions change
- Very sensitive to changes in precipitation
- Anthropogenic and natural barriers prevent dispersal or shifts in species' range
- Requires specialized habitat
- Dependent on other species to create habitat
- Slightly impacted by changes due to human response to climate change

5.2 Results

In the absence of additional information, the AUs with “unknown” condition were assumed to remain in that condition; thus, their numbers did not change in future condition projections. In addition, the AUs in Canada did not change because no new information regarding future condition was received during our analysis.

An effort was made to incorporate uncertainty using accepted methods of elicitation (Burgman 2016; Appendix E). The method is called the likelihood point method because 100 points are distributed across population condition categories to reflect future condition in response to each scenario based on the biology of the species, the factors that are affecting its status, and the degree of uncertainty of future predictions. The result is probability of an AU being in a future condition category. The probabilities are used in two ways. First, the prediction of the number of AUs within the condition categories is the sum of the category-specific probabilities. For example, the Table 5 shows 4 AUs with differing levels of uncertainty for future condition; the predicted number of AU’s in a “high” condition is 1.5, which is the sum of 0.82 and 0.68 (rounded to the nearest digit).

Table 5. Example of use of probabilities to predict the number of AUs in a given category.

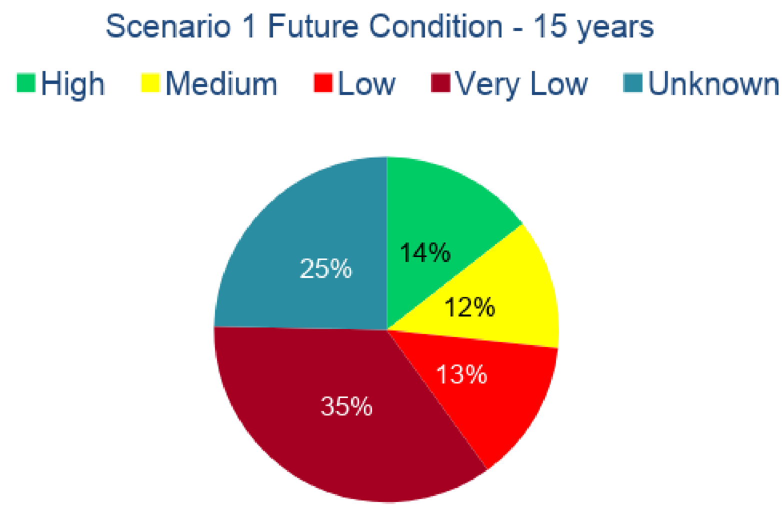
AU	High	Med	Low	Very Low
1	0	0	0.96	0.04
2	0.82	0.04	0.12	0.06
3	0.67	0.27	0.06	0
4	0	0	0	1
Predicted number of AUs	1.5	0.3	1.1	1.1

Second, the uncertainty is presented in the maps of future condition. The condition category with the highest probability is mapped for each AU. However, the highest probability could be as low as 0.26 (nearly equal probability among all four categories) or as high as 1.0 (reflecting certainty in the future condition category). So, the symbology used in the map reflects the relative certainty in the future condition category assignment.

Estimates of the number of populations within each condition category were initially based on projections of development about 30 years from present because the Lawler *et al.* (2014) projected land use to 2051. The estimates for 15 years assumed a linear change between current condition and future condition at 2051 (Appendix E). These estimates are presented in Table 6 for Scenario 1 and Table 7 for Scenario 2.

5.2.1 Scenario 1

Based on our analysis under Scenario 1 (Table 6), out of a total of 239 AUs in the U.S., approximately 8 percent fewer AUs are expected to be in “high” condition and 13 percent more AUs are expected to be in “very low” condition within 30 years. The brook floater is anticipated to have a wide distribution over the next 30 years. However, additional range contraction is anticipated. While brook floater populations are represented across all four representative areas, the proportion of AUs in “medium” to “high” condition varies across these areas (Table 7, Figures 28-33). The Southeast and Northeast Representative Areas are expected to show less change than the mid-Atlantic Representative Area. In the Northeast, 7 percent fewer AUs (34 to 31.5) are expected to be in “high” or “medium” condition. In the Southeast, approximately 2 percent fewer AUs (13 to 12.8) are expected to be in “high” or “medium” condition. In the mid-Atlantic Representative Area where the largest change in resilience and redundancy is expected, the AUs currently in “high” or “medium” condition will be reduced by approximately 32 percent (from 12 to 8.2 AUs) and the AUs in “low” or “very low” will be increased by approximately 6 percent from 69 to 72.8. While brook floater populations continue to occur in scattered populations across all representative areas under this scenario, redundancy will be particularly reduced in the mid-Atlantic as the AUs experience decreased resilience.



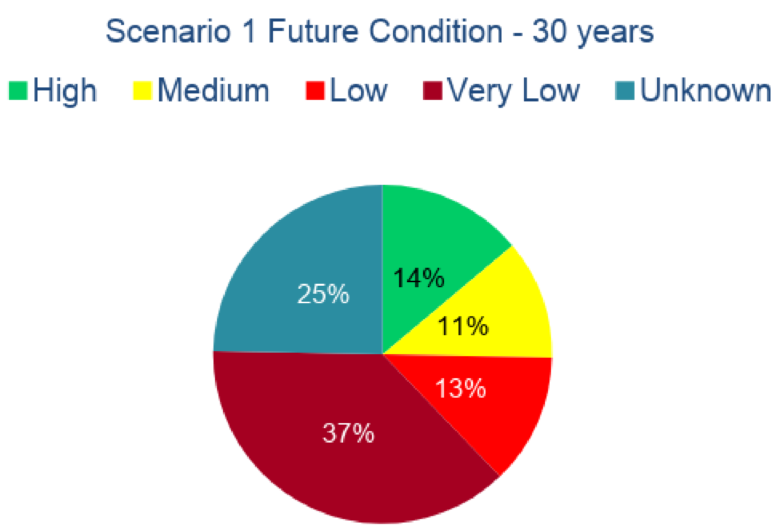


Figure 28. Percentage of brook floater (*Alasmidonta varicosa*) AUs in each condition category rangewide under Scenario 1 (15 years and 30 years from present).

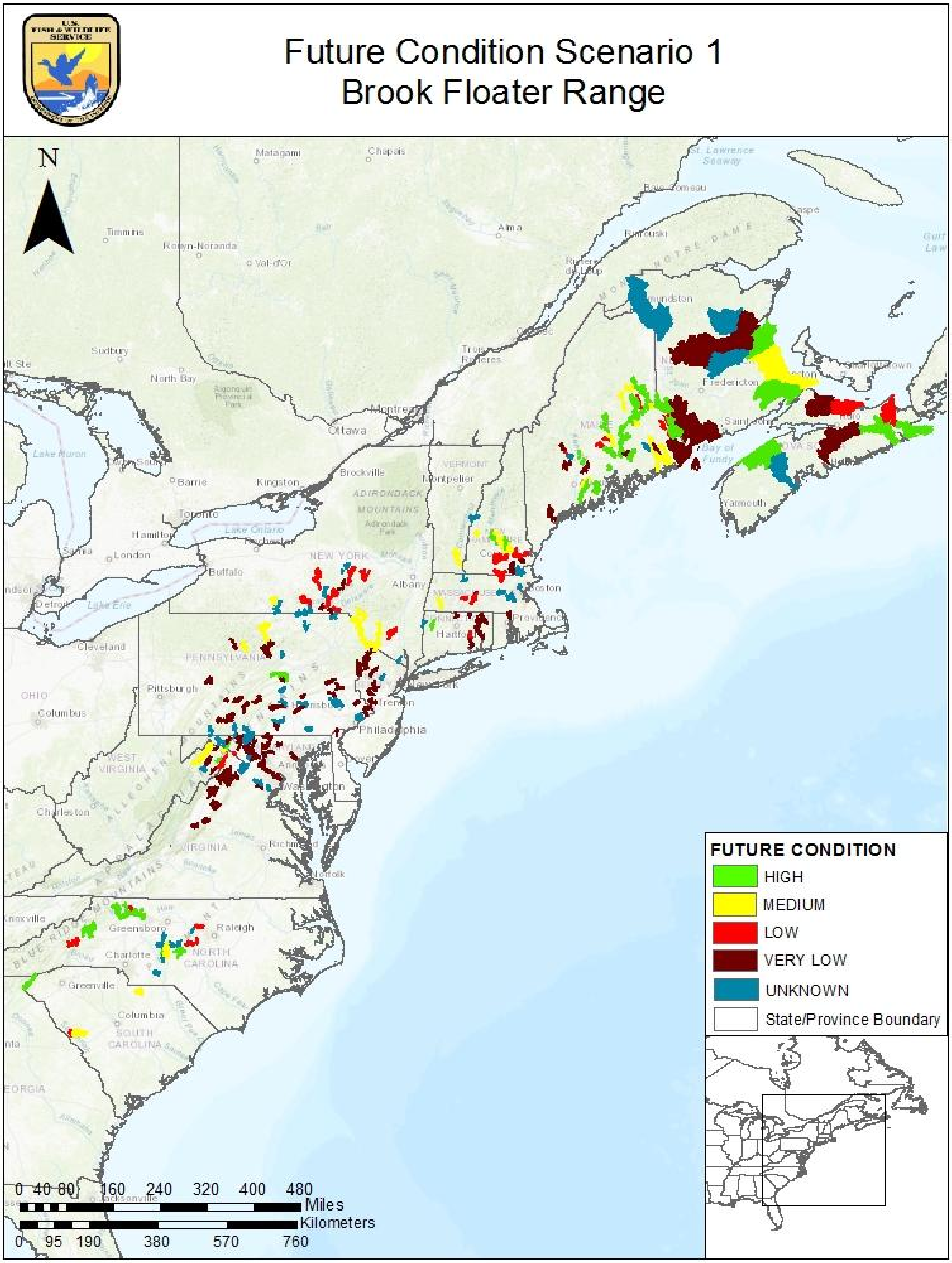


Figure 29. Future condition of brook floater (*Alasmidonta varicosa*) populations for Scenario 1 rangewide approximately 30 years from present.

Table 6. Summary current condition and future condition tables for Scenario 1 by representative area showing predicted numbers of AUs in each condition: High, Medium, Low, Very Low, and Unknown[11].

Current Condition of AUs in each Representative Area						
Representative Area	HIGH	MED	LOW	VERY LOW	UNKNOWN	**TOTAL**
Canadian Provinces	6	2	2	5	4	19
Northeast	17	17	11	20	12	77
Mid-Atlantic	4	8	15	54	35	116
Southeast	9	4	6	0	8	27
Rangewide	**36**	**31**	**34**	**79**	**59**	**239**

Scenario 1 Future Condition of AUs in each Representative Area – 15 years						
Representative Area	HIGH	MED	LOW	VERY LOW	UNKNOWN	**TOTAL**
Canadian Provinces	6	2	2	5	4	19
Northeast	16.2	16.6	10.9	21.3	12	77
Mid-Atlantic	3.4	6.7	13.3	57.6	35	116
Southeast	9	3.9	5.7	0.4	8	27
Rangewide	**34.6**	**29.2**	**31.9**	**84.3**	**59**	**239**

Scenario 1 Future Condition of AUs in each Representative Area – 30 years						
Representative Area	HIGH	MED	LOW	VERY LOW	UNKNOWN	**TOTAL**
Canadian Provinces	6	2	2	5	4	19
Northeast	15.4	16.1	10.9	22.6	12	77
Mid-Atlantic	2.8	5.4	11.6	61.2	35	116
Southeast	9	3.8	5.4	0.8	8	27
Rangewide	**33.2**	**27.3**	**29.9**	**89.6**	**59**	**239**

The maps below (Figures 30-33) show Scenario 1 future condition approximately 30 years from present for brook floater (by AU) within each representative area.

[11] Because uncertainty is incorporated into future condition, the predicted numbers are not necessarily whole numbers and level of certainty is incorporated into maps of future condition (see Appendix E for details).

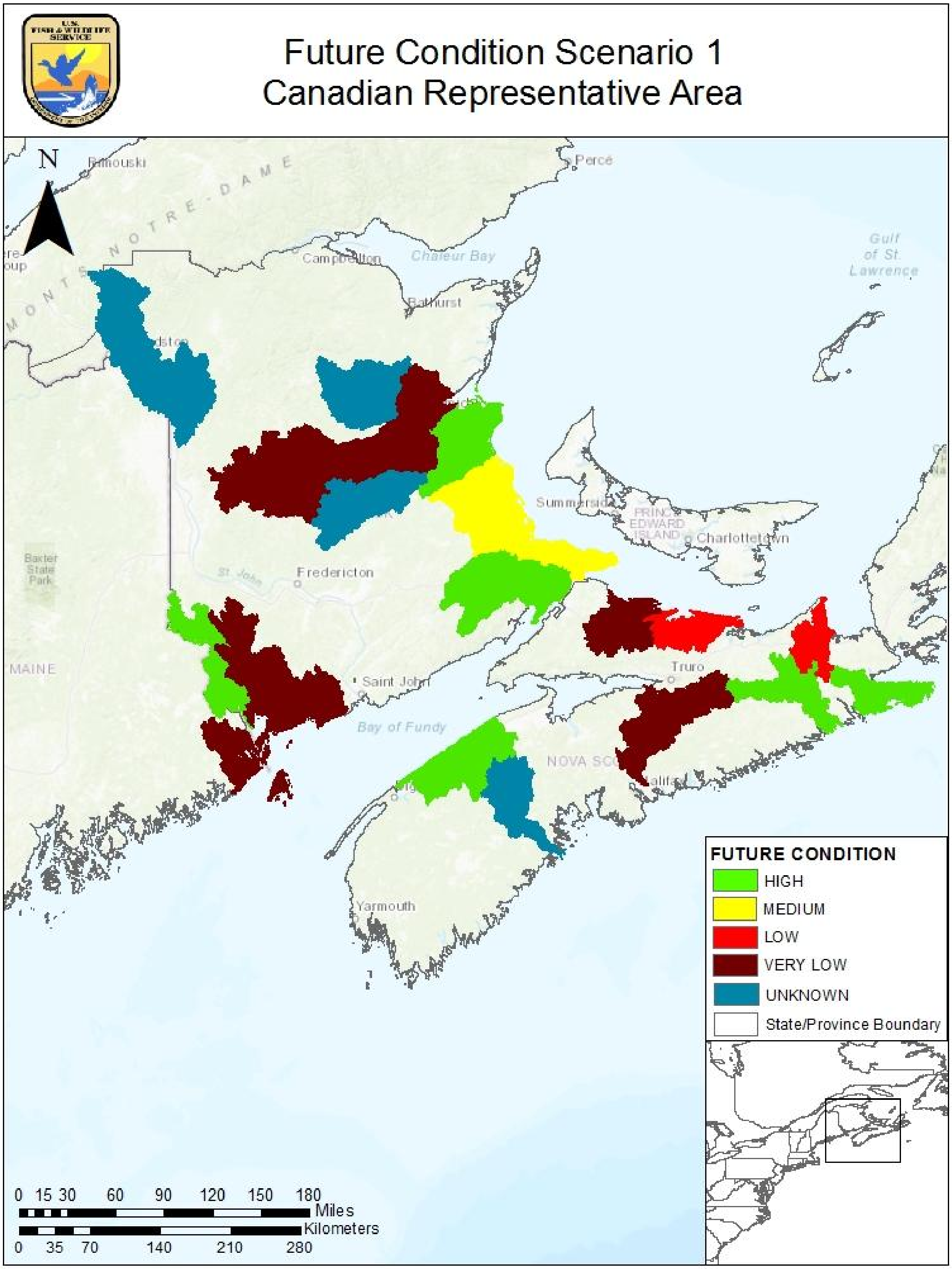


Figure 30. Future condition of brook floater (*Alasmidonta varicosa*) populations for Scenario 1 in the Canadian Representative Area approximately 30 years from present.

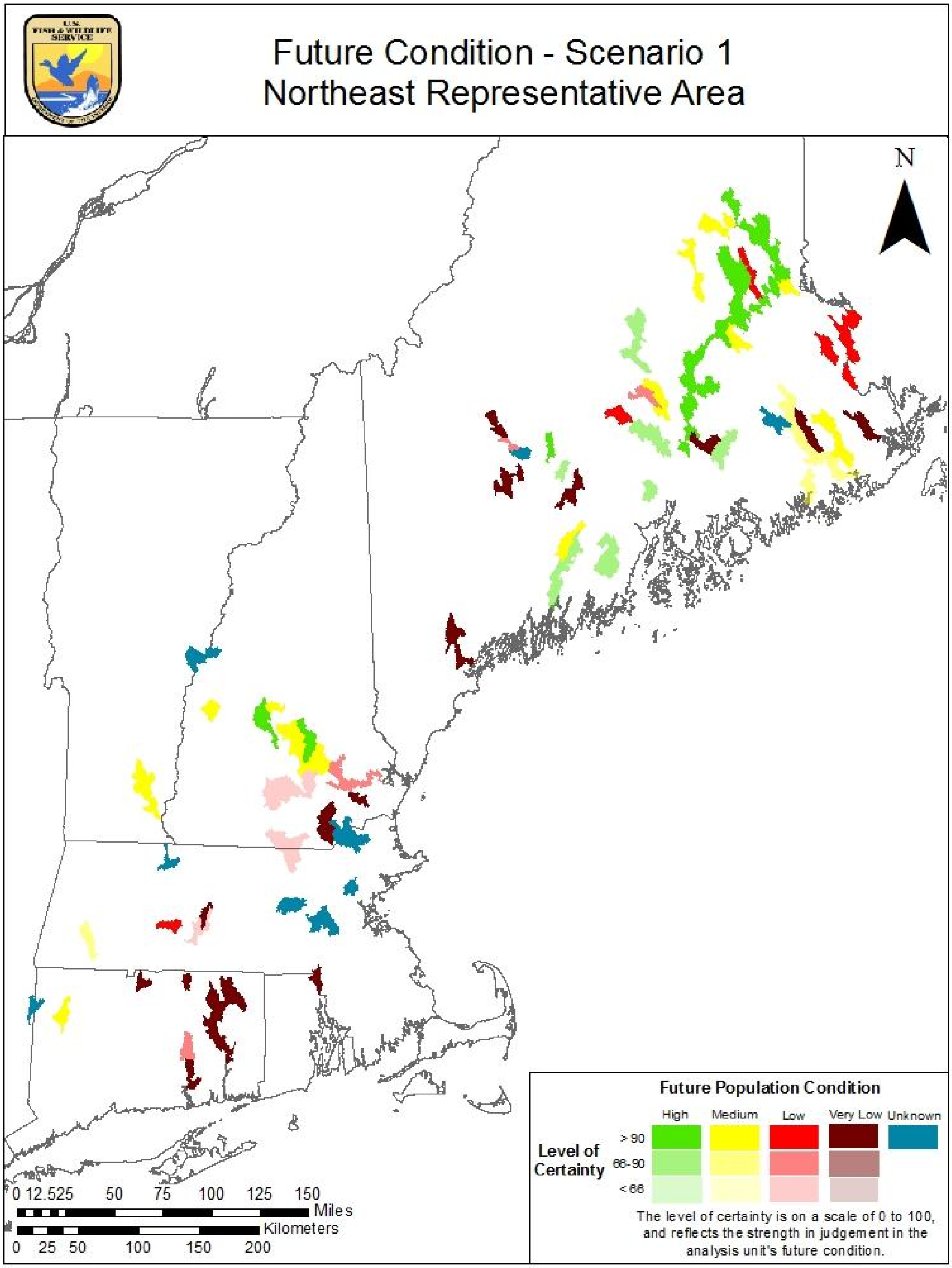


Figure 31. Future condition of brook floater (*Alasmidonta varicosa*) populations for Scenario 1 in the Northeast Representative Area approximately 30 years from present. Level of certainty in future condition corresponds to degree of color transparency (Appendix E). Populations in Unknown category are assumed to remain so.

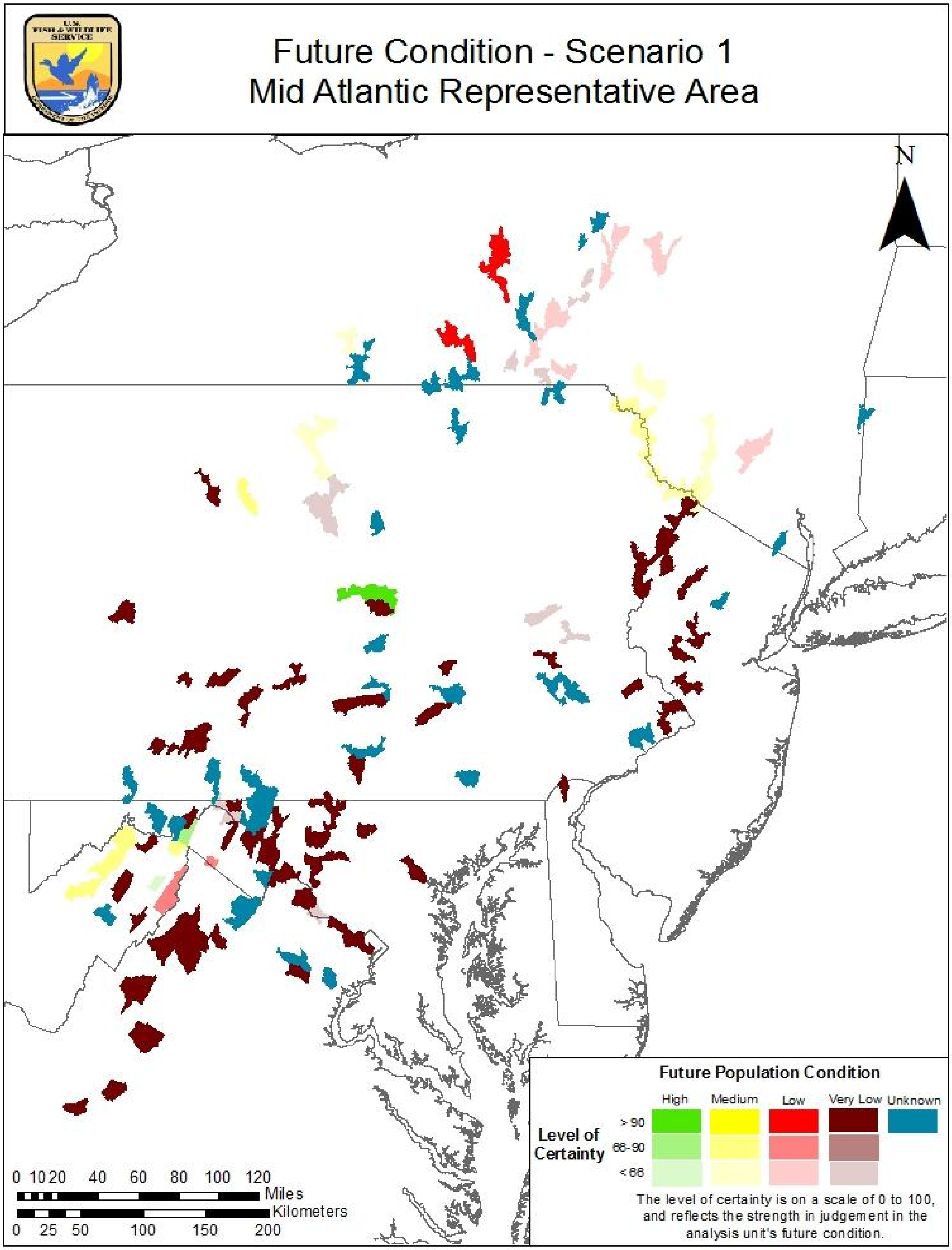


Figure 32. Future condition of brook floater (*Alasmidonta varicosa*) populations for Scenario 1 in the Mid-Atlantic Representative Area approximately 30 years from present. Level of certainty in future condition corresponds to degree of color transparency (Appendix E). Populations in Unknown category are assumed to remain so.

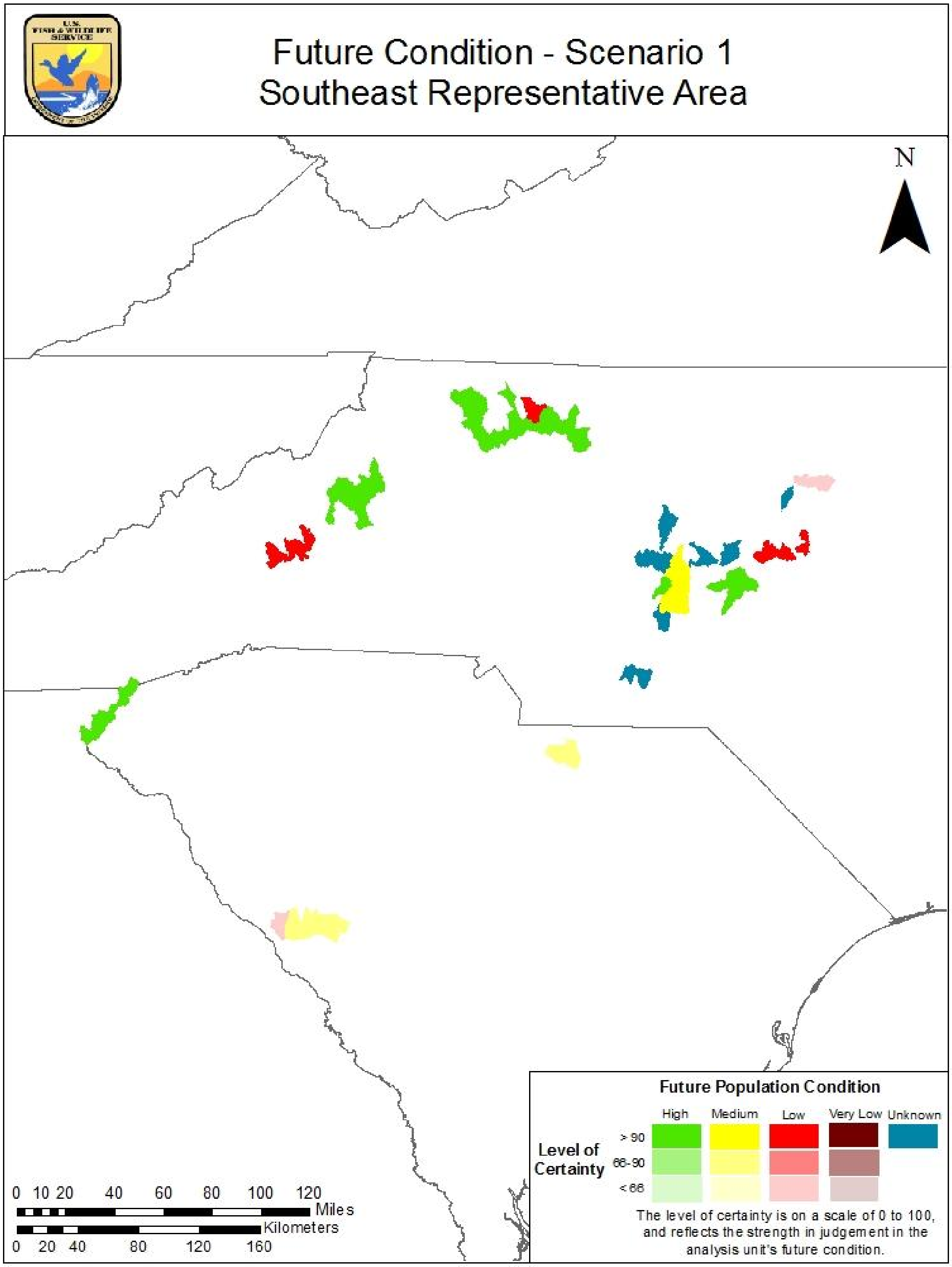


Figure 33. Future condition of brook floater (*Alasmidonta varicosa*) populations for Scenario 1 in the Southeast Representative Area approximately 30 years from present. Level of certainty in future condition corresponds to degree of color transparency (Appendix E). Populations in Unknown category are assumed to remain so.

5.2.2 Scenario 2

Based on our analysis under Scenario 2 (Table 7), out of a total of 239 AUs in the U.S. and Canada, approximately 21 percent fewer AUs are expected to be in “high” condition and 21 percent more AUs are expected to be in “very low” condition AUs within 30 years.

The brook floater is expected to continue to have a wide distribution within 30 years. While brook floater populations are represented across all four representative areas, the proportion of AUs in “medium” to “high” condition varies across these areas (Table 7, Figures 34-39). In the Northeast, 18 percent fewer AUs (34 to 27.8) are expected to be in “high” or “medium” condition. In the Southeast, approximately 11 percent fewer AUs (13 to 11.6) are expected to be in “high” or “medium” condition. The mid-Atlantic is expected to experience the largest decrease in resilience and redundancy, where the expectation is that the AUs in “high” or “medium” condition will be reduced by approximately 43 percent from 12 to 6.9 AUs and that the AUs in “low” or “very low” condition will increase by 7 percent from 69 to 74 percent. While brook floater populations continue to occur in scattered populations across all representative areas under this scenario, redundancy will be reduced in the mid-Atlantic within 30 years as the AUs experience decreased resilience.

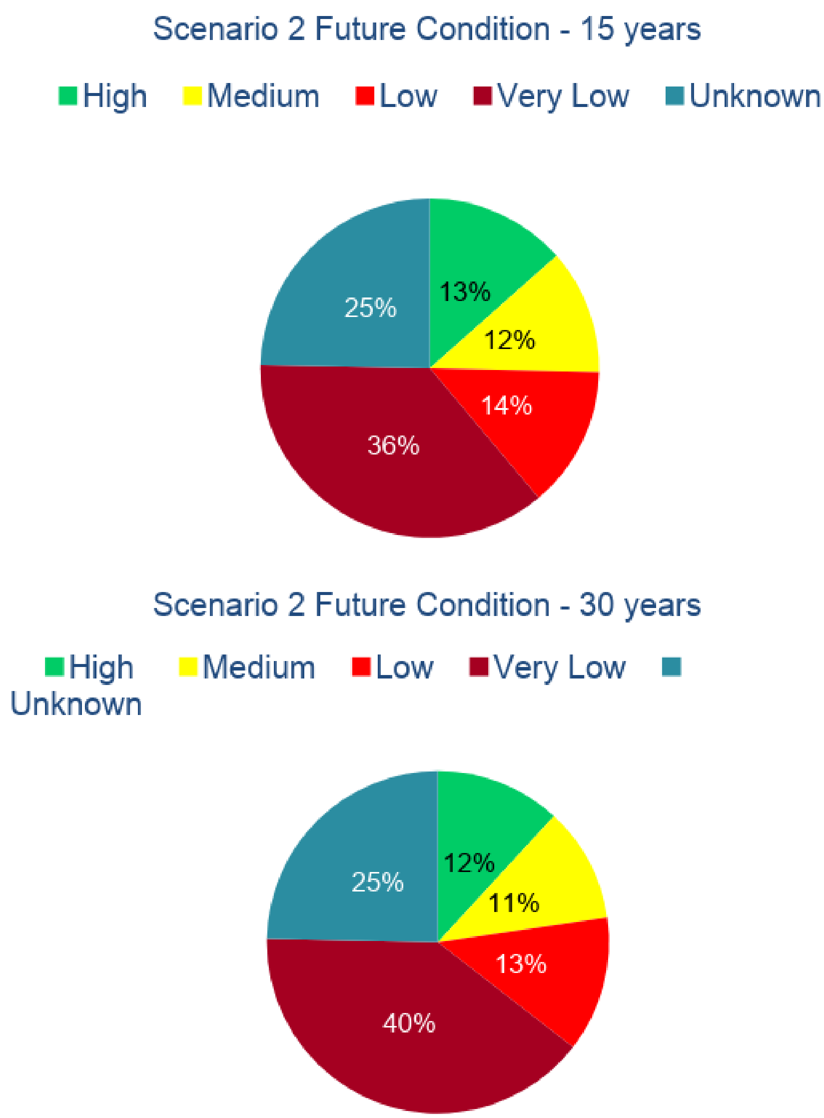


Figure 34. Percentage of brook floater (*Alasmidonta varicosa*) AUs in each condition category rangewide under Scenario 2 (15 years and 30 years from present).

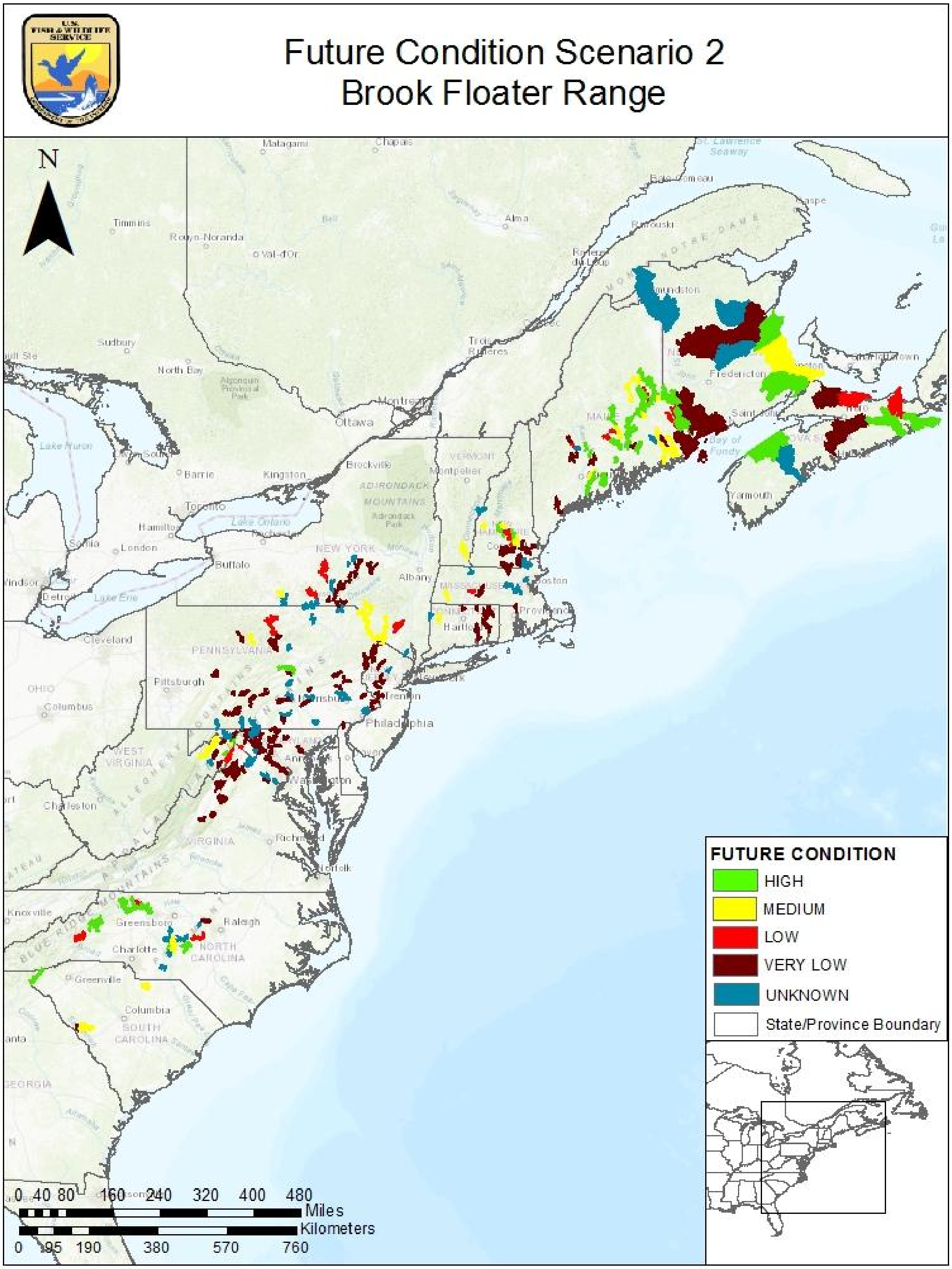


Figure 35. Future condition of brook floater (*Alasmidonta varicosa*) populations for Scenario 2 rangewide approximately 30 years from present.

Table 7. Summary current condition and future condition tables for Scenario 2 by representative area showing predicted numbers of AUs in each condition category: High, Medium, Low, Very Low, and Unknown[12].

Current Condition of AUs in each Representative Area						
Representative Area	HIGH	MED	LOW	VERY LOW	UNKNOWN	**TOTAL**
Canadian Provinces	6	2	2	5	4	19
Northeast	17	17	11	20	12	77
Mid-Atlantic	4	8	15	54	35	116
Southeast	9	4	6	0	8	27
Rangewide	**36**	**31**	**34**	**79**	**59**	**239**

Scenario 2 – Future Condition of AUs in each Representative Area – 15 years						
Representative Area	HIGH	MED	LOW	VERY LOW	UNKNOWN	**TOTAL**
Canadian Provinces	6	2	2	5	4	19
Northeast	15.0	15.9	11.8	22.3	12	77
Mid-Atlantic	3	6.4	12.7	58.8	35	116
Southeast	8.2	4.1	5.8	0.9	8	27
Rangewide	**32.2**	**28.4**	**32.3**	**87**	**59**	**239**

Scenario 2 – Future Condition of AUs in each Representative Area – 30 years						
Representative Area	HIGH	MED	LOW	VERY LOW	UNKNOWN	**TOTAL**
Canadian Provinces	6	2	2	5	4	19
Northeast	13	14.8	12.7	24.7	12	77
Mid-Atlantic	2.1	4.8	10.4	63.7	35	116
Southeast	7.3	4.3	5.5	1.9	8	27
Rangewide	**28.4**	**25.9**	**30.6**	**95.3**	**59**	**239**

The maps below (Figures 36-39) show Scenario 2 future condition approximately 30 years from present for brook floater (by AU) within each representative area.

[12] Because uncertainty is incorporated into future condition, the predicted numbers are not necessarily whole numbers and level of certainty is incorporated into maps of future condition (see Appendix E for details).

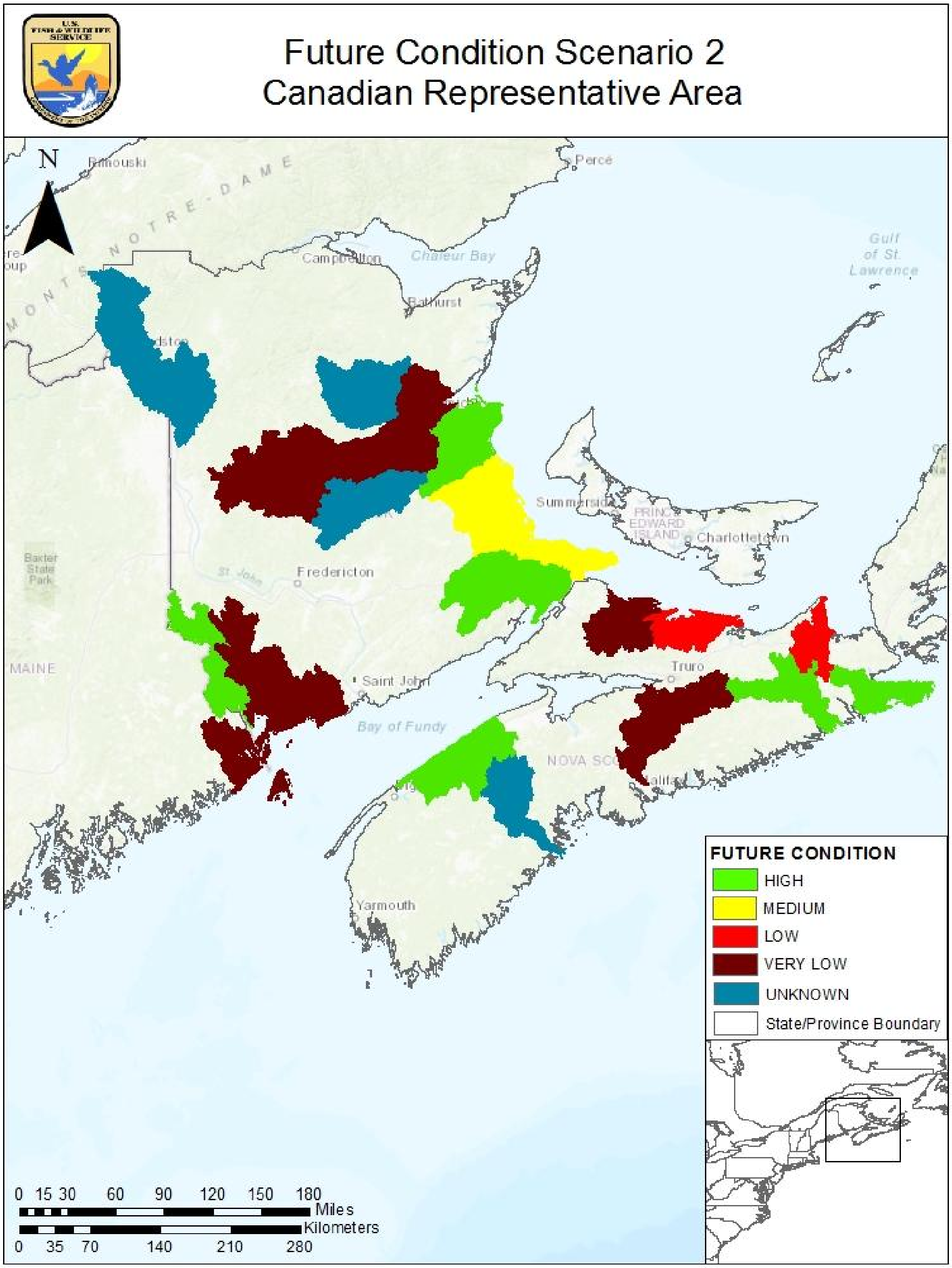


Figure 36. Future condition of brook floater (*Alasmidonta varicosa*) populations for Scenario 2 in the Canadian Representative Area approximately 30 years from present.

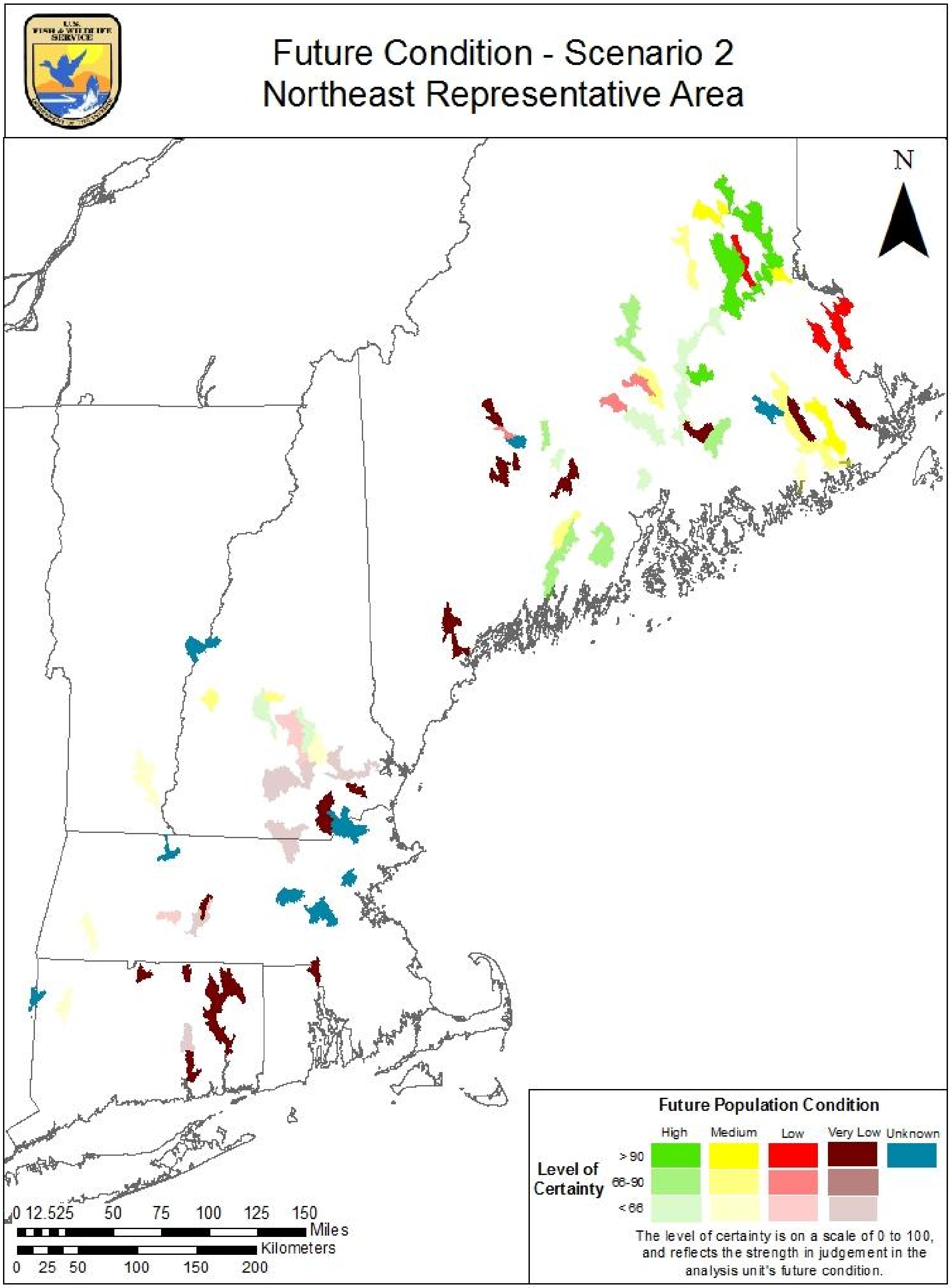


Figure 37. Future condition of brook floater (*Alasmidonta varicosa*) populations for Scenario 2 in the Northeast Representative Area approximately 30 years from present. Level of certainty in future condition corresponds to degree of color transparency (Appendix E). Populations in Unknown category are assumed to remain so.

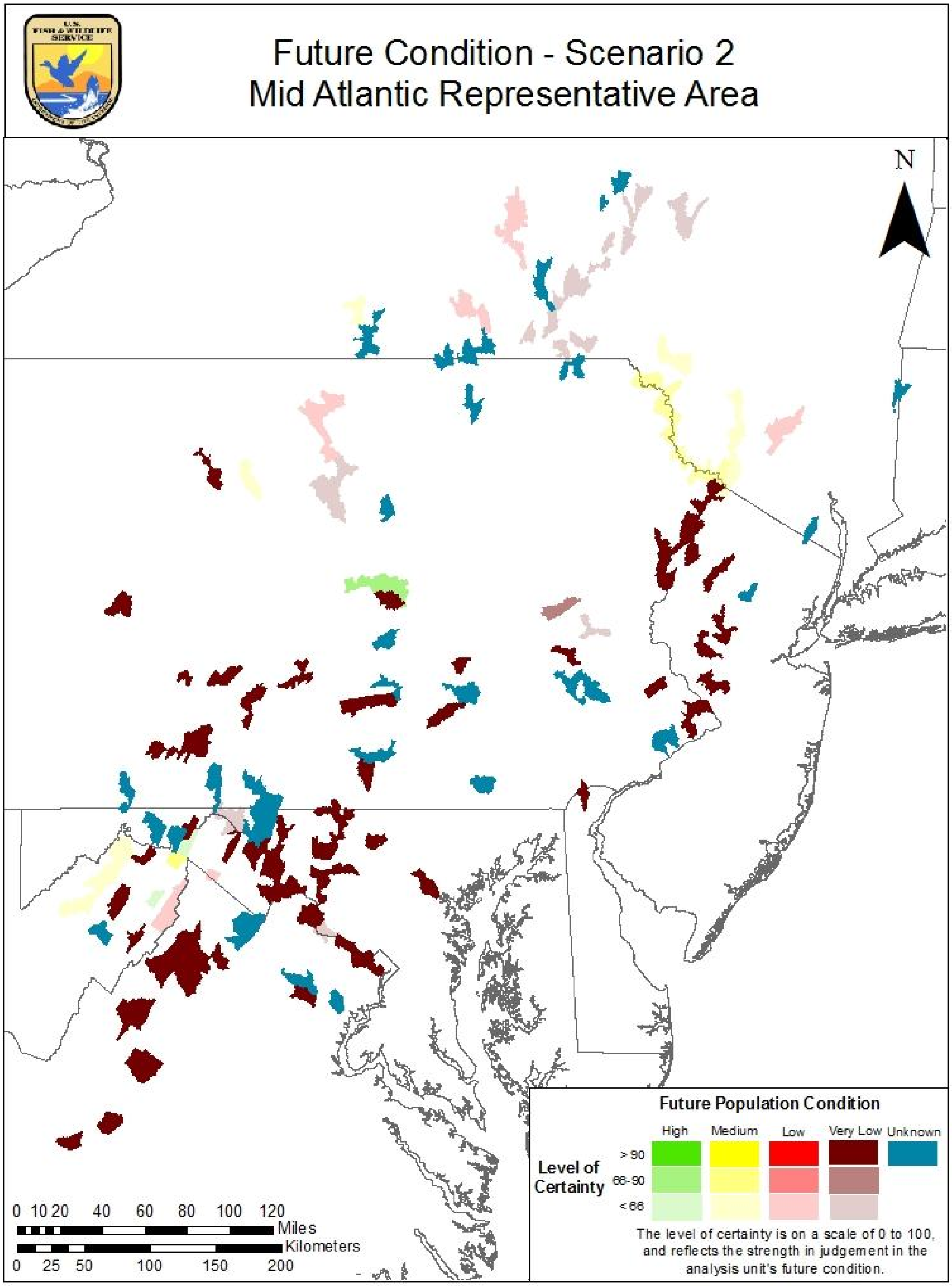


Figure 38. Future condition of brook floater (*Alasmidonta varicosa*) populations for Scenario 2 in the Mid-Atlantic Representative Area approximately 30 years from present. Level of certainty in future condition corresponds to degree of color transparency (Appendix E). Populations in Unknown category are assumed to remain so.

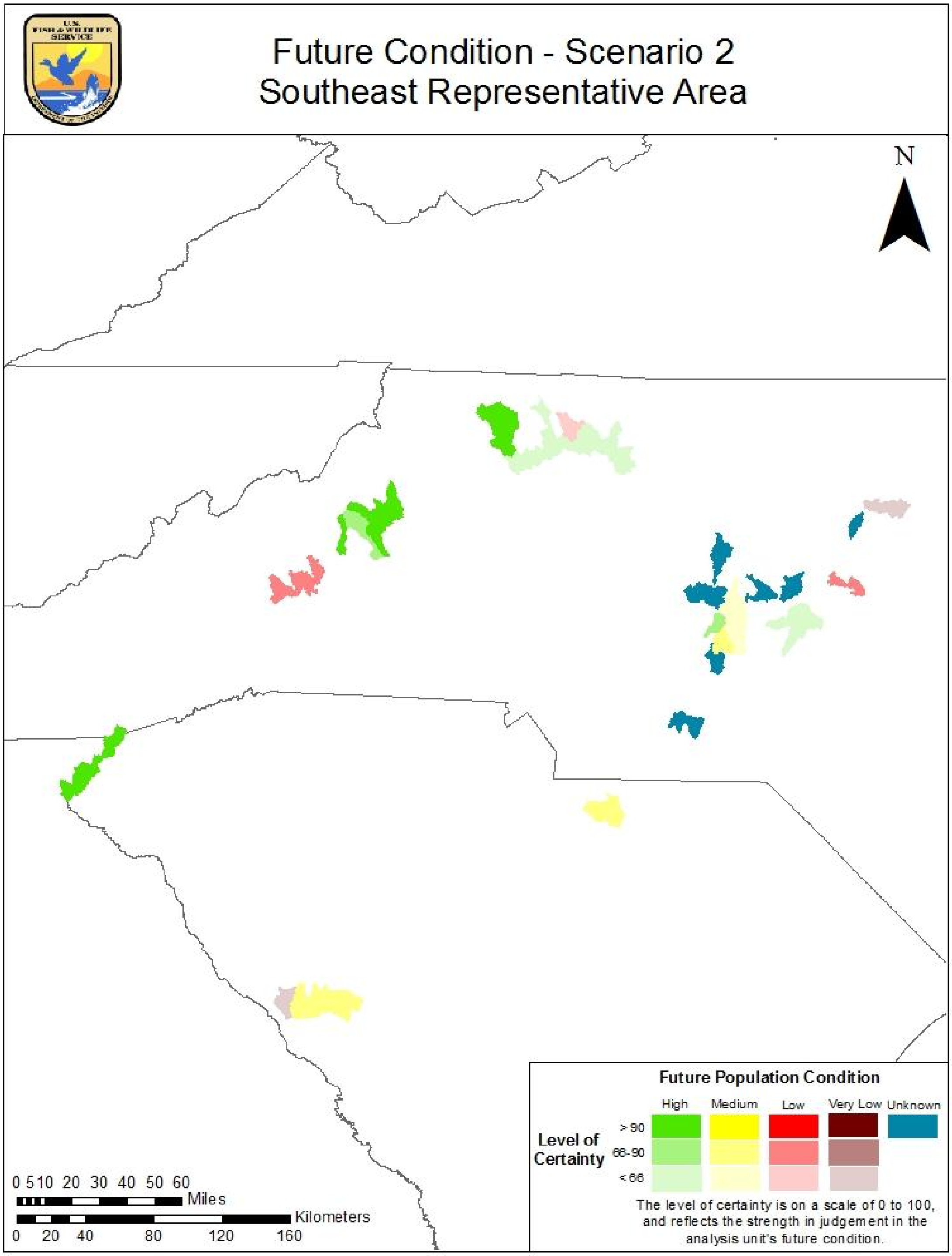


Figure 39. Future condition of brook floater (*Alasmidonta varicosa*) populations for Scenario 2 in the Southeast Representative Area approximately 30 years from present. Level of certainty in future condition corresponds to degree of color transparency (Appendix E). Populations in Unknown category are assumed to remain so.

5.2.3 Summary

Based on our analysis under Scenario 1, out of a total of 239 AUs in the U.S. and Canada, approximately 8 percent fewer AUs are expected to be in high condition and 13 percent more AUs are expected to be in very low condition within 30 years. The Southeast and Northeast Representative Areas are expected to experience some decrease in resilience. In the Northeast, 7 percent fewer AUs (34 to 31.5) are expected to be in high or medium condition. In the Southeast, approximately 2 percent fewer AUs (13 to 12.8) are expected to be in high or medium condition. The mid-Atlantic Representative Area is where the largest change in resilience and redundancy is expected. In the mid-Atlantic, the AUs currently in high or medium condition will be reduced by approximately 32 percent from 12 to 8.2 AUs, and the AUs in low or very low will be increased by approximately 6 percent from 69 to 72.8. While brook floater populations continue to occur in scattered populations across all representative areas under this scenario, redundancy will be reduced especially in the mid-Atlantic as the AUs experience decreased resilience.

Based on our analysis under Scenario 2, reductions in resilience and redundancy are expected to be greater than under Scenario 1. Out of a total of 239 AUs in the U.S. and Canada, approximately 21 percent fewer AUs are expected to be in high condition, and 21 percent more AUs are expected to be in very low condition within 30 years. In the Northeast, 18 percent fewer AUs (34 to 27.8) are expected to be in high or medium condition. In the Southeast, approximately 11 percent fewer AUs (13 to 11.6) are expected to be in high or medium condition. Among the representative areas, the mid-Atlantic is expected to experience the biggest decreases in resilience and redundancy. In the mid-Atlantic, the AUs in high or medium condition will be reduced by approximately 43 percent from 12 to 6.9 AUs and the AUs in low or very low condition will increase by 7 percent from 69 to 74.1. While brook floater populations continue to occur in scattered populations across all representative areas under this scenario, redundancy will be reduced especially in the mid-Atlantic as the AUs experience decreased resilience.

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APPENDICES

APPENDIX A

Similar Looking Species as Brook Floater

The brook floater can sometimes be confused with several species including the triangle floater (*Alasmidonta undulata*) (Figure A1), elktoe (*Alasmidonta marginata*) (Figure A2), creeper (*Strophitus undulatus*), and dwarf wedgemussel (*A. heterodon*) (Nedeau 2008, p. 76, Wicklow et al. 2017, p. 4).

There is overlap among the brook floater, triangle floater, and the elktoe throughout much of the range. Both the elktoe and young triangle floaters can have corrugations on the dorso-posterior slope. However, the elktoe has a more angular shape and can have dark green to black spots or flecks on the green rays which are absent in brook floaters (Figure A3).

Brook floaters can also be confused with triangle floaters. For example, in 2006, two mussels from the James River, Virginia, were tentatively identified as brook floaters, but after DNA analysis, these specimens were identified genetically to be triangle floaters (The Catena Group 2013, p. 8). The triangle floater does have some characteristics that can easily distinguish it from the brook floater. The ventral shell margin is rounded, the posterior end slightly pointed, and the shell is much thicker and lighter in color at the anterior portion of the shell. Additionally, the pseudocardinal teeth in the triangle floater are much larger than those of the brook floater. In females of the brook floater, the mantle around the inhalant and exhalant aperture is prominently barred and tessellated than in the triangle floater (Wicklow *et al.*, 2017 p. 19).

Figure A1: Internal shell right valve (left) and external shell left valve (right) of *Alasmidonta undulata*, photo credit: Barry Wicklow (Wicklow *et al.* 2017, p. 16).

Figure A2. Internal shell right valve (left) and external shell left valve (right) of *Alasmidonta marginata,* photo credit: Barry Wicklow (Wicklow *et al.* 2017, p. 15).

Figure A3. Internal shell right valve (left) and external shell left valve (right) of *Alasmidonta varicosa*, photo credit: Barry Wicklow (Wicklow *et al.* 2017, p. 14).

APPENDIX B

Compiled list of fish known to serve as hosts for brook floater as of May 2018.

Fish species tested	**Fish taxonomic name**	**Number of fish tested**	**Number of juvenile mussels collected**	**Juvenile mussels collected per fish (calculated)**	**Information source**
common shiner	*Luxilius cornutus*	5	27	5.4	Wicklow *et al.* 2017, pp. 10-11
golden shiner	*Notemigonus crysoleucas*	5	27	5.4	Wicklow *et al.* 2017, pp. 10-11
blacknose dace	*Rhinichthys atratulus*	5	4	0.8	Wicklow *et al.* 2017, pp. 10-11
blacknose dace	*Rhinichthys atratulus*	12	15	1.3	Skorupa pers. Comm. 2018
longnose dace	*Rhinichthys cataractae*	4	51	12.8	Wicklow *et al.* 2017, pp. 10-11
longnose dace	*Rhinichthys cataractae*	5	122	24.4	Skorupa pers. Comm. 2018
longnose dace	*Rhinichthys cataractae*	12	190	15.8	Skorupa pers. Comm. 2018
fallfish	*Semotilus corporalis*	1	1	1	Wicklow *et al.* 2017, pp. 10-11

Fish species tested	**Fish taxonomic name**	**Number of fish tested**	**Number of juvenile mussels collected**	**Juvenile mussels collected per fish (calculated)**	**Information source**
margined madtom	*Noturus insignis*	4	42	10.5	Wicklow *et al.* 2017, pp. 10-11
brown bullhead	*Ameiurus nebulosus*	5	5	1	Wicklow *et al.* 2017, pp. 10-11
white sucker (Young of Year)	*Catostomus commersonii*	2	36	18	Wicklow *et al.* 2017, pp. 10-11
slimy sculpin	*Cottus cognatus*	3	10	3.3	Wicklow *et al.* 2017, pp. 10-11
slimy sculpin	*Cottus cognatus*	6	403	67.2	Skorupa pers. Comm. 2018
slimy sculpin	*Cottus cognatus*	6	500	83.3	Skorupa pers. Comm. 2018
yellow perch	*Perca flavescens*	4	17	4.3	Wicklow *et al.* 2017, pp. 10-11
pumpkinseed	*Lepomis gibbosus*	2	2	1	Wicklow *et al.* 2017, pp. 10-11

Fish species tested	**Fish taxonomic name**	**Number of fish tested**	**Number of juvenile mussels collected**	**Juvenile mussels collected per fish (calculated)**	**Information source**
ninespined stickleback	*Pungitius pungitius*	1	Larvae observed on fish in stream	N/A	(COSEWIC, 2009, pp. 5)
brook trout	*Salvelinus fontinalis*	23	7874	342.3	Skorupa pers. Comm. 2018
Atlantic salmon	*Salmo salar*	2	69	34.5	Skorupa pers. Comm. 2018
spotted killifish	*Fundulus luciae*	12	188	15.7	Skorupa pers. Comm. 2018

APPENDIX C

Brook Floater Status by State/Province.

State	NatureServe status[13]	State and Canadian status[14]	SGCN[15]	Notes
Connecticut	S1	Endangered	Y	
Delaware	SX	Endangered	Y	presumed extirpated
District of Columbia	SNR		Y, Tier 2[16]	
Georgia	S2	Imperiled	Y	
Maine	S3	Threatened	Y, Priority 1[17]	
Maryland	S1	Endangered	Y	
Massachusetts	S1	Endangered	Y	
New Hampshire	S1	Endangered	Y	
New Jersey	S1	Endangered	Y	
New York	S1	Threatened	Y	
North Carolina	S1	Endangered	Y	
Pennsylvania	S2	Not listed	Y	

[13] NatureServe. 2017. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available http://explorer.natureserve.org. (Accessed: April 24, 2018).
[14] S1 = Critically imperiled, S2 = Imperiled, S3 = Vulnerable, SX = Presumed Extirpated, SNR = Not Ranked
[15] SGCN refers to species of greatest conservation need
[16] Tier 2 = Species Seen on Occasion
[17] Priority 1 = Highest Priority

State	NatureServe status[13]	State and Canadian status[14]	SGCN[15]	Notes
Rhode Island	SH	Not listed	N	presumed extirpated
South Carolina	SNR	SNR	Y	
Vermont	S1	Threatened	Y, High Priority	
Virginia	S1	Endangered	Y, Tier 1[18]	
West Virginia	S1	Uses Heritage ranking S1	Y	
New Brunswick	S1S2	Special Concern		
Nova Scotia	S1S2	Threatened		

[18] Tier 1 – Critical Conservation Need.

APPENDIX D

Current Condition Tables

Table D1. Overall current condition of Analysis Units (AU) in the United States based on occupied length, reproduction and abundance. AUs are classified as extant if brook floaters have been present in surveys conducted between 1997 and 2017.

* For those units where condition metrics were all unknown but overall current condition is something other than unknown, overall current condition was calculated based on expert opinion (e.g., state or provincial partners and others).

AU	**Watershed**	**AU Stream Name**	**Occupied length**	**Reproduction**	**Abundance (magnitude)**	**Overall Current Condition**	**Known to be extant in the past 20 yrs.**	**Last found**	**Last Year Surveyed**
CT_01	Housatonic River	Housatonic River	unknown	unknown	unknown	UNKNOWN	no	no date historic	no date historic
CT_02	Housatonic River	Shepaug River	1.6 km	stable	100s or 1000s	MEDIUM	yes	2010	2010
CT_03	Connecticut River	Stony Brook	unknown	declining	<10	VERY LOW	yes	2008	2008
CT_04	Thames River	Edison Brook (Shetucket River Watershed)	unknown	unknown	<10	VERY LOW	yes	2012	2012
CT_05	Connecticut River	Jeremy River	1.2 km	unknown	10's	LOW	yes	2008	2008
CT_06	Connecticut River	Muddy Brook	unknown	unknown	0	VERY LOW	yes	2008	2014
CT_07	Thames River	Bungee Brook (Shetucket River	unknown	stable	<10	VERY LOW	yes	2008	2008

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
CT_09	Thames River	Mount Hope River (Shetucket River Watershed)	unknown	unknown	<10	VERY LOW	yes	2012	2012
CT_10	Thames River	Natchaug River (Shetucket River Watershed)	unknown	unknown	<10	VERY LOW	yes	2008	2008
CT_11	Thames River	Shetucket River	unknown	unknown	<10	VERY LOW	yes	2012	2012
DE_01	Delaware River	Red Clay Creek	unknown	unknown	0	VERY LOW	no	1903	2013
MA_01	Connecticut River	West Farmington River (Farmington Watershed)	16 km	unknown	100's	MEDIUM	yes	2007	2007
MA_02	Connecticut River	Connecticut River	unknown	unknown	unknown	UNKNOW N	no	no date historic	no date historic
MA_03	Connecticut River	Batchelor Brook	1.6 km	declining	100's	LOW	yes	2008	2008
MA_04	Connecticut River	Ware River	6.3 km	declining /stable	1000's	LOW	yes	2008	2008

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
MA_05	Connecticut River	Muddy Brook (Chicopee Watershed)	unknown	unknown	<10	VERY LOW	yes	2008	2008
MA_06	Merrimack River	Nisitissit and Nashua River	4km	stable/declining	100's	MEDIUM	yes	2008	2008
MA_07	Merrimack River	Spicket River	unknown	unknown	unknown	UNKNOWN	no	1942	1942
MA_08	Merrimack River	Merrimack River Mainstem	unknown	unknown	unknown	UNKNOWN	no	1866	1866
MA_09	Mystic River	Aberjona River	unknown	unknown	unknown	UNKNOWN	no	1942	1942
MA_10	Merrimac k River	Gates Pond (Concord River Watershed)	unknown	unknown	unknown	UNKNOWN	no	1859	1859
MA_11	Merrimack River	Cochituate Aqueduct (Concord River Watershed)	unknown	unknown	unknown	UNKNOWN	no	no date historic	no date historic
MA_12	Charles River	Bogle Brook	unknown	unknown	unknown	UNKNOWN	no	no date historic	no date historic
MA_13	Blackstone River	Blackstone River	unknown	unknown	0	VERY LOW	no	1841	2010

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
MD_01	Potomac River	Wills Creek	unknown	declining	<10	UNKNOWN	no	no date historic	1992
MD_02	Potomac River	Town Creek	unknown	unknown	unknown	UNKNOWN	no	1960's	1990's
MD_03	Potomac River	Potomac River / Rockwell Run	unknown	unknown	unknown	UNKNOWN	no	no date historic	no date historic
MD_04	Potomac River	Potomac River / Willett Run	unknown	unknown	<10	VERY LOW	yes	2007	2007
MD_05 *	Potomac River	Potomac River / Ditch Run / Cherry Run	unknown	unknown	unknown	LOW	yes	no date	no date
MD_06	Potomac River	Licking Creek	unknown	unknown	<10	VERY LOW	yes	2007	2007
MD_07	Potomac River	Potomac River / Camp Spring Run	unknown	unknown	unknown	UNKNOWN	no	no date historic	no date historic
MD_08	Potomac River	Conococheague Creek / Rockdale Run	unknown	unknown	unknown	UNKNOWN	no	1973	1996
MD_09	Potomac River	Conococheague Creek / Meadow Brook	unknown	unknown	<10	UNKNOWN	no	1973	1996
MD_10	Potomac River	Antietam Creek	unknown	unknown	<10	VERY LOW	no	shell only	1997

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
MD_11	Potomac River	Potomac River / Rattlesnake Run	unknown	unknown	0	VERY LOW	no	no date	2013
MD_12	Potomac River	Potomac River / Piney Run	unknown	unknown	0	VERY LOW	no	no date	2013
MD_13	Potomac River	Toms Creek	unknown	declining	<10	VERY LOW	yes	1993	2007
MD_14	Potomac River	Monocacy River	10 km	declining	10's	VERY LOW	yes	2007	2007
MD_15	Potomac River	Linganore Creek	unknown	declining	<10	VERY LOW	yes	1960	2006
MD_16	Potomac River	Potomac River / Limestone Branch	unknown	unknown	0	VERY LOW	no	no date	2013
MD_17 *	Potomac River	Potomac River / Seldon Island	unknown	unknown	unknown	LOW	yes	2013	2013
MD_18	Potomac River	Potomac River / Nichols Run / Pimmit Run	unknown	unknown	0	VERY LOW	no	no date historic	no date historic
MD_19	Potomac River	Little Pipe Creek	unknown	declining	<10	VERY LOW	no	1960's	2007
MD_20	Gwynns Falls	Gwynns Falls	unknown	unknown	<10	VERY LOW	no	1955	1997
ME_01	Penobscot River	West Branch Mattawamkeag River	7.6 km	stable	1000's	HIGH	yes	2017	2017

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
ME_02	Penobscot River	Fish Stream (West Branch Mattawamkeag River)	9.5 km	stable	100's	MEDIUM	yes	2017	2017
ME_03	Penobscot River	East Branch Mattawamkeag River	unknown	stable	100's	HIGH	yes	2017	2017
ME_04	Penobscot River	Mattawamkeag River	62 km	stable/increasing	1000's	HIGH	yes	2015	2015
ME_05	Penobscot River	Baskahegan Stream - Mattawamkeag River	7 km	stable	100's	MEDIUM	yes	2015	2017
ME_06	Penobscot River	Mattakeunk Stream - Mattawamkeag River	12 km	stable	100's or 1000's	MEDIUM	yes	2015	2015
ME_07	Penobscot River	Wytopitlock Stream - Mattawamkeag River	unknown	stable	<10	LOW	yes	2015	2015

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
ME_08	Penobscot River	Macwahoc Stream - tributary to the Molunkus Stream, which is trib to the Mattawamkeag	9 km	stable/increasing	10,000's	HIGH	yes	2015	2015
ME_09	Penobscot River	Molunkus Stream	35 km	unknown	10,000's	HIGH	yes	2015	2015
ME_10	Penobscot River	East Branch Penobscot River	30 km	stable	10's	MEDIUM	yes	2017	2017
ME_11	Penobscot River	East Branch Pleasant River / Pleasant River	20 km	stable	1000's	HIGH	yes	2017	2017
ME_12	Penobscot River	Penobscot River	116 km	STABLE	1000's	HIGH	yes	2011	2011
ME_13	Penobscot River	Great Works Stream	unknown	unknown	<10	VERY LOW	no	1995	1995
ME_14	Penobscot River	Passadumkeag River	unknown	stable	1000's	HIGH	yes	2009	2009
ME_15	Penobscot River	West Branch Dead Stream	unknown	unknown	10’s	LOW	yes	1995	1995
ME_16	Penobscot River	Dead Stream	likely >10	stable	100's	MEDIUM	yes	2009	2009

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
ME_17	Penobscot River	Allen Stream	unknown	unknown	10's	LOW	yes	2013	2013
ME_18	Penobscot River	Kenduskeag Stream	likely >14 km	stable / increasing	1000's	HIGH	yes	2009	2009
ME_19	West Branch Union River	West Branch Union River	11km	stable / increasing	1000's	HIGH	yes	2015	2015
ME_20	Saint Croix River	Tomah Stream	unknown	stable	10's	LOW	yes	2006	2006
ME_21	Saint Croix River	Saint Croix River	unknown	stable	10's	LOW	yes	2006	2006
ME_22	Dennys River	Dennys River	unknown	stable	<10	VERY	yes	2013	2013
ME_23	Machias River (Washingt on County)	Machias River (Washington County)	31 km	stable	10's	MEDIUM	yes	2014	2014
ME_24	Machias River	West Branch Machias River	unknown	unknown	<10	UNKNOWN	no	no date	2014
ME_25	Machias River	Chain Lake Stream (Old Stream)	unknown	unknown	0	VERY LOW	no	1994	2014
ME_26	Machias River	East Machias River	25 km	stable	10's	MEDIUM	yes	2014	2014
ME_27	Pleasant River (Washington County)	Pleasant River	unknown	stable	100's	MEDIUM	yes	2011	2011

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
ME_28	Penobscot River	Marsh Stream	7.2km	stable/increasing	1000's	HIGH	yes	2009	2009
ME_29	Kennebec River Basin	Gilman Stream (Carrabasset River)	unknown	unknown	<10	VERY LOW	yes	2009	2009
ME_30	Kennebec River Basin	Carrabassett River	21 km	stable	10's	LOW	yes	2016	2016
ME_31	Kennebec River Basin	Kennebec River	unknown	unknown	<10	UNKNOWN	yes	2000	2000
ME_32	Kennebec River Basin	Sandy River	0	extirpated; MDIFW:	0	VERY LOW	no	no date	2013
ME_33	Kennebec River Basin	Wesserunsett Stream	unknown	stable	1000's	HIGH	yes	2015	2015
ME_34	Kennebec River Basin	Carrabassett Stream	>10km	stable	100's	HIGH	yes	2009	2009
ME_35	Kennebec River Basin	Sebasticook River	unknown	extirpated MDIFW:	<10	VERY LOW	no	no date historic	no date historic
ME_36	Saint George River	Saint George River	9.6km	stable	100's	HIGH	yes	2009	2009
ME_37	Sheepscot River	West Branch of the Sheepscot River	6.8km	Stable / increasing	1000's	MEDIUM	yes	2011	2011

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
ME_38	Sheepscot River	Sheepscot River	18.8km	declining	10,000's	HIGH	yes	2011	2011
ME_39	Casco Bay Basin	Pleasant River (Cumberland Co.)	9.6 km	extirpated	10's	VERY LOW	yes	2011	2011
ME_40	Casco Bay Basin	Presumpscot River	0	unknown	0	VERY LOW	no	2011	2011
NC_01	Santee	Catawba River	25km	unknown	100s to low 1,000s	LOW	yes	2011	2011
NC_02	Santee	Linville River	17km	unknown	low 1,000s	HIGH	yes	no date	no date
NC_03	Santee	Warrior Fork	18km	unknown	low 1,000s	HIGH	yes	no date	no date
NC_04	Santee	John's River	72km	unknown	10,000s	HIGH	yes	no date	no date
NC_05	Yadkin / Upper Pee Dee	Roaring River	49km	unknown	1,000s to 10,000	HIGH	yes	2016	2016
NC_06	Yadkin / Upper Pee Dee	Yadkin River	100km +	unknown	1,000s to low 10,000s	HIGH	yes	no date	no date
NC_07	Yadkin / Upper Pee Dee	Mitchell River	38km	unknown	1,000s	HIGH	yes	no date	no date
NC_08	Yadkin / Upper Pee Dee	Fisher River	unknown/ historical	unknown	unknown	LOW	yes	2014	2016

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
NC_09	Cape Fear	New Hope Creek	unknown	unknown	<10	LOW	yes	mid 2000's	2017
NC_10 *	Cape Fear	Collins Creek	unknown	unknown	unknown	UNKNOWN	no	no date	no date
NC_11	Upper Pee Dee	Caraway Creek	unknown	unknown	unknown	UNKNOWN	no	no date	no date
NC_12	Upper Pee Dee	Uwharrie River / Betty McGees Creek	11km	unknown	100s to low 1,000s	UNKNOWN	no	no date	no date
NC_13	Upper Pee Dee	Uwharrie River / Hannahs Creek	unknown	unknown	unknown	UNKNOWN	no	no date	no date
NC_14	Upper Pee Dee	Little River/West Fork/Dicks Creek	53km	unknown	100s to low 1,000s	MEDIUM	yes	2000	2000
NC_15	Upper Pee Dee	Barnes Creek	11 km	unknown	100's to low 1000's	HIGH	yes	no date	no date
NC_16	Upper Pee Dee	Little River/Denson's Creek	53 km	unknown	100's	MEDIUM	yes	2000	2000
NC_17	Upper Pee Dee	Rocky Creek	unknown	unknown	unknown	UNKNOW N	no	no date	no date
NC_18	Cape Fear	Bachelor Creek	unknown	unknown	unknown	UNKNOW N	no	no date	no date
NC_19	Upper Pee Dee	Brush Creek	unknown	unknown	unknown	UNKNOW N	no	no date	2017

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
NC_20	Cape Fear	Deep River	65km	unknown	1,000s	HIGH	yes	2017	2017
NC_21	Cape Fear	Rocky River	52km	unknown	100s	LOW	yes	2017	2017
NC_22	Cape Fear	Haw River	unknown/historical	unknown	unknown	LOW	yes	2002	2002
NC_23	Cape Fear	Brown Creek	unknown	unknown	unknown	UNKNOW N	no	no date	no date
NJ_01	Passaic River	Mahwah River	unknown	unknown	unknown	UNKNOWN	no	no date	1995
NJ_02	Delaware River	Delaware River / Hornbecks / Shimer	unknown	unknown	0	VERY LOW	yes	2001	2011
NJ_03	Delaware River	Flat Brook	unknown	unknown	<10	VERY LOW	yes	2001	2001
NJ_04	Delaware River	Delaware River / Vancampens Brook	unknown	unknown	unknown	VERY LOW	yes	2001	2001
NJ_05	Delaware River	Paulins Kill	unknown	unknown	0	VERY LOW	no	1895	2008
NJ_06	Delaware River	Musconetcong River	unknown	unknown	0	VERY LOW	yes	2013	2013
NJ_07	Passaic River	Whippany River	unknown	unknown	0	UNKNOWN	no	no date	2005
NJ_08	Raritan River	Lamington River	unknown	unknown	<10	VERY LOW	yes	2017	2017
NJ_09	Raritan River	North Branch Raritan River	unknown	unknown	0	VERY LOW	no	no date	2008

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
NJ_10	Raritan River	South Branch Raritan River	unknown	unknown	0	VERY LOW	no	no date	2014
NJ_11	Raritan River	Stony Brook	unknown	stable	<10	VERY LOW	yes	2011	2016
NJ_12 *	Delaware River	Delaware River / Buck Creek	unknown	unknown	unknown	VERY LOW	yes	no date	no date
NH_01	Connecticut River	Connecticut River	unknown	declining	0	UNKNOWN	no	no date historic	no date historic
NH_02	Connecticut River	North Branch of the sugar River	unknown	declining	1000's	MEDIUM	yes	2006	2006
NH_03	Merrimack River	Pemigewasset River - Merrimack River	unknown	stable	100's	MEDIUM	yes	2013	2013
NH_04	Merrimack River	Blackwater River / Mountain Brook	unknown	unknown	1000's	HIGH	yes	1996	1996
NH_05	Merrimack River	Merrimack River / Tannery Brook	unknown	stable	100's	MEDIUM	yes	2013	2013
NH_06	Merrimack River	Merrimack River (Soucook River)	unknown	declining	1000s	HIGH	yes	1993	1993

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
NH_07	Merrimack River	Piscataquog River	unknown	declining	100's	LOW	yes	2011	2011
NH_08	Merrimack River	Merrimack River (Suncook River)	unknown	declining	1000s	MEDIUM	yes	2013	2013
NH_09	Lamprey River	Lamprey River / Pawtuckaway River	unknown	declining	100's	LOW	yes	2014	2014
NH_10	Exeter River	Exeter River	unknown	unknown	0	VERY LOW	no	2011	2011
NH_11	Merrimack River	Merrimack River (Beaver Brook)	unknown	unknown	<10	VERY LOW	yes	2003	2003
NY_01	Susquehanna River	Cohocton River	unknown	unknown	100s	MEDIUM	yes	2015	2015
NY_02	Susquehanna River	Chemung River / Tioga River	unknown	unknown	unknown	UNKNOWN	no	no date	no date
NY_03	Susquehanna River	Chemung River	unknown	unknown	100s	UNKNOWN	yes	2009	2009
NY_04	Susquehanna River	Susquehanna River / Parks / Sackett / Hunts	unknown	unknown	unknown	UNKNOWN	no	no date	no date

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
NY_05	Susquehanna River	Catatonk Creek / Michigan Creek	unknown	unknown	10's	LOW	yes	2011	2011
NY_06 *	Susquehanna River	Tioughnioga River	unknown	unknown	unknown	LOW	yes	no date	no date
NY_07	Susquehanna River	Otselic River / Tioughnioga River	unknown	unknown	unknown	UNKNOWN	no	no date	no date
NY_08 *	Susquehanna River	Chenango River / Ockerman / Spring / Thomas / Wheeler	unknown	unknown	unknown	LOW	yes	2011	2011
NY_09 *	Susquehanna River	Susquehanna River / Patterson Creek	unknown	unknown	unknown	LOW	no	no date	no date
NY_10 *	Susquehanna River	Susquehanna River / Carlin Creek	unknown	unknown	unknown	LOW	no	no date	no date
NY_11 *	Susquehanna River	Susquehanna River / Occanum	unknown	unknown	unknown	LOW	no	no date	no date
NY_12 *	Susquehanna River	Chenango River / Lyon / Thompson	unknown	unknown	unknown	LOW	no	no date	no date

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
NY_13 *	Susquehanna River	Unadilla River	unknown	unknown	unknown	LOW	no	no date	no date
NY_14	Susquehanna River	Upper Sangerfield River	unknown	unknown	unknown	UNKNOWN	yes	2009	2009
NY_15	Susquehanna River	Lower Sangerfield River	unknown	unknown	unknown	UNKNOWN	no	no date	no date
NY_16 *	Susquehanna River	Oaks Creek	unknown	unknown	unknown	LOW	yes	no date	no date
NY_17	Delaware River	East Branch Delaware River/Beaver Kill	150km Note: this includes portion of the Delaware outside of NY State	unknown	100s	MEDIUM	yes	no date	no date

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
NY_18	Delaware River	Delaware River	150km Note: this includes portion of the Delaware outside of NY State	unknown	100s	MEDIUM	yes	2001	2001
NY_19	Neversink River	Neversink River	65km from mouth to Neversink reservoir	unknown	100s	MEDIUM	yes	2005	2005
NY_20 *	Hudson River	Shawangunk Kill	unknown	unknown	unknown	LOW	yes	no date	no date
NY_21	Housatonic River	Housatonic River	unknown	unknown	unknown	UNKNOWN	no	no date	no date
NY_22	Passaic River	Mahwah River (Ramapo)	unknown	unknown	unknown	UNKNOWN	no	1994	1994
PA_01	West Branch Susquehanna River	Cush Cushion Creek	unknown	unknown	0	VERY LOW	no	1908	2011

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
PA_02	West Branch Susquehanna River	Driftwood Branch Sinnemahoning Creek	unknown	stable	0	VERY LOW	no	pre-1919	pre-1919
PA_03	West Branch Susquehanna River	Kettle Creek	unknown	increasing	100's	MEDIUM	yes	2011	2011
PA_04	West Branch Susquehanna	Upper Pine Creek	unknown	unknown	1000's	HIGH	yes	2015	2015
PA_05	West Branch Susquehanna River	Lower Pine Creek	unknown	unknown	10's	LOW	yes	2008	2008
PA_06	West Branch Susquehanna River	West Branch Susquehanna River	unknown	unknown	unknown	UNKNOWN	no	1908	2011
PA_07	Lower Susquehanna	Penns Creek	25 km	stable	1000s	HIGH	yes	2017	2017
PA_08	Lower Susquehanna	Middle Creek	unknown	unknown	0	VERY LOW	no	no date	2008
PA_09	Lower Susquehanna	Susquehanna River / Bargers Run	unknown	unknown	unknown	UNKNOWN	no	no date	no date
PA_10	Juniata Subbasin	Frankstown Branch	unknown	unknown	0	VERY LOW	no	1981	2010

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
PA_11	Juniata Subbasin	Raystown Branch	unknown	unknown	0	VERY LOW	no	1966	2010
PA_12	Juniata Subbasin	Aughwick Creek	unknown	unknown	<10	VERY LOW	no	no date	2008
PA_13	Juniata Subbasin	Tuscarora Creek	unknown	unknown	<10	VERY LOW	yes	2008	2008
PA_14	Lower Susquehanna	Fishing Creek	unknown	unknown	unknown	UNKNOWN	no	no date	no date
PA_15	Lower Susquehanna	Conodoguinet Creek	unknown	unknown	0	VERY LOW	no	no date	2008
PA_16	Lower Susquehanna	Swatara Creek	unknown	unknown	0	VERY LOW	yes	2003	2003
PA_17	Lower Susquehanna	Quittapahilla Creek	unknown	unknown	unknown	UNKNOWN	no	1995	1995
PA_18	Lower Susquehanna	Conewago Creek - west	unknown	unknown	<10	VERY LOW	yes	2016	2016
PA_19	Lower Susquehanna	Muddy Creek	unknown	unknown	unknown	UNKNOWN	no	no date	no date
PA_20	Lower Susquehanna	Bermudian Creek	unknown	unknown	unknown	UNKNOWN	no	1995	1995
PA_21	Lower Susquehanna	Conewago Creek	unknown	unknown	0	VERY LOW	no	no date	2008
PA_22	Potomac River Basin	Conococheague Creek	unknown	unknown	Unknown	UNKNOWN	no	1996	1996

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
PA_23	Potomac River	Tonoloway Creek	unknown	unknown	Unknown	UNKNOWN	no	no date	2004
PA_24	Juniata Subbasin	Raystown Branch / Sandy Run / Tub Mill Run / Cumberland Valley	unknown	unknown	0	VERY LOW	no	no date	2010
PA_25	Middle Susquehanna	Susquehanna River	unknown	unknown	unknown	UNKNOWN	no	no date	no date
PA_26	Upper Susquehanna	Susquehanna River	unknown	unknown	unknown	UNKNOWN	no	no date	no date
PA_27	Delaware River	Delaware River	>58 km	unknown	10’s	MEDIUM	yes	2000	2000
PA_28 *	Delaware River	Delaware River Hormbeck / Shimer	unknown	unknown	unknown	VERY LOW	yes	no date	no date
PA_29	Delaware River	Marshalls Creek	unknown	unknown	<10	VERY LOW	yes	2001	2001
PA_30	Delaware River	Lizard Creek	unknown	unknown	10's	LOW	yes	2008	2008
PA_31	Delaware River	Jordan Creek	100m	unknown	100's	MEDIUM	yes	2011	2011
PA_32	Schuylkill River	Sacony Creek	unknown	unknown	0	VERY LOW	no	1910	2015

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
PA_33	Schuylkill River	Manatawny Creek	unknown	unknown	unknown	UNKNOWN	no	1960's	1960's
PA_34	Schuylkill River	Swamp Creek	unknown	unknown	unknown	UNKNOWN	no	1912	1912
PA_35	Delaware River	Neshaminy Creek / Pine Run	unknown	unknown	unknown	VERY LOW	no	1909	2007
PA_36	Delaware River	Neshaminy Creek	unknown	unknown	0	VERY LOW	no	1909	2007
PA_37	Delaware River	Pennypack Creek	unknown	unknown	unknown	UNKNOWN	no	1912	1994
PA_38	Delaware River	Frankfort Creek	unknown	unknown	unknown	UNKNOWN	yes	1997	1997
SC_01	Chattooga	Chattooga River	40km	increasing	100,000+	HIGH	yes	2017	2017
SC_02	Savannah	Stevens Creek	45 km	unknown	10s	LOW	yes	2008	2008
SC_03	Savannah	Stevens Creek/Turkey Creek/Log Creek	103km	unknown	100s to low 1,000s	MEDIUM	yes	2008	2008
SC_04	Lynches	Lynches River / Flat Creek	33km	unknown	100s to low 1,000s	MEDIUM	yes	2011	2011
VT_01	Connecticut River	Hanover	unknown	unknown	unknown	UNKNOWN	yes	1915	no date

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
VT_02	Connecticut River	West River	25 km	declining	1000's	MEDIUM	yes	2014	2014
VA_01	North Fork Shenandoah	Cedar Creek	none	unknown	<10	VERY LOW	no	no date	2003
VA_02	North Fork Shenandoah	North Fork Shenandoah River / Tumbling Toms / Narrow	unknown	unknown	0	VERY LOW	no	no date	2008
VA_03	North Fork Shenandoah	North Fork Shenandoah River / Molly Booth Run	unknown	unknown	0	VERY LOW	no	no date	2008
VA_04	South Fork Shenandoah	South Fork Shenandoah River / Mannassas / Punches / Flint	unknown	unknown	<10	VERY LOW	no	no date	2013
VA_05	Shenandoah	Shenandoah River	unknown	unknown	unknown	UNKNOWN	no	no date	no date
VA_06	Middle Potomac	Bull Run	unknown	declining	unknown	UNKNOWN	no	1996	1996
VA_07	Middle Potomac	Broad Run	unknown	unknown	<10	VERY LOW	no	1998	2007

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
VA_08	Middle Potomac	Occaquan River	unknown	declining	unknown	UNKNOWN	no	1938	1938
VA_09	North Fork Shenandoah	Holmans Creek	unknown	declining	<10	VERY LOW	no	no date	2008
VA_10	North Fork Shenandoah	Smith Creek	none	unknown	<10	VERY LOW	no	no date	2011
VA_11	South Fork Shenandoah	South Fork Shenandoah River / Boone / Hawksbill	unknown	unknown	0	VERY LOW	no	no date	2009
VA_12	South Fork Shenandoah	South River	unknown	declining	0	VERY LOW	no	no date	2003
WV_01	Potomac	Patterson Creek	67 km	unknown	100's	MEDIUM	yes	2017	2017
WV_02	Potomac	South Branch Potomac River / Abernathy	unknown	unknown	0	VERY LOW	no	1985	2006
WV_03	Potomac	South Branch Potomac River / Sawmill / McDowell	unknown	unknown	unknown	UNKNOWN	no	no date	no date
WV_04	Potomac	South Branch Potomac River	unknown	unknown	unknown	UNKNOWN	no	no date	no date

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Known to be extant in the past 20 yrs.	Last found	Last Year Surveyed
WV_05	Potomac	Cacapon River / Pine Draft / North River	>10	unknown	1000's	HIGH	yes	2017	2017
WV_06	Potomac	Lost River	unknown	unknown	<10	VERY LOW	no	1939	2005
WV_07	Potomac	Cacapon River / Cacapon Springs/Mill Branch	unknown	unknown	10's	LOW	yes	2017	2017
WV_08	Potomac	Cacapon River / Critton Run	unknown	unknown	100's	MEDIUM	yes	2017	2017
WV_09	Potomac	Cacapon River / Conner Hollow	Length?	declining	100's	HIGH	yes	2017	2017
WV_10	Potomac	Back Creek / Warm Springs	unknown	unknown	<10	VERY LOW	no	no date	2008
WV_11	Potomac	Back Creek / Outlet	unknown	declining	0	VERY LOW	no	1953	2008
WV_12	Potomac	Opequon Creek	unknown	unknown	<10;	VERY LOW	no	no date	2008
WV_13	Potomac	Potomac River	unknown	unknown	0	VERY LOW	no	no date	2006
WV_14	Potomac	Shenandoah River	unknown	unknown	unknown	UNKNOW N	no	1937	2010

Table D2. Overall current condition of Analysis Units (AU) in Canada based on occupied length, reproduction and abundance. AUs are classified as extant if brook floaters have been present in surveys conducted between 1997 and 2017.

AU	Watershed	NHN = National Hydro Network ID number	Occupied length	Reproduction	Abundance (magnitude)	Overall Condition	Extant	Last found	Last Year Surveyed
NB_01	Upper Saint John	01AF00	unknown	unknown	unknown	UNKNOWN	no	1960	1960
NB_02	Northwest Miramichi River	01BQ00	unknown	unknown	unknown	UNKNOWN	no	no date	no date
NB_03	Southwest Miramichi	01BO00	unknown	unknown	unknown	VERY LOW	yes	2001	2008
NB_04	Taxis River (Southwest Miramichi River)	01BM0	unknown	unknown	<10	VERY LOW	yes	2010	2010
NB_05	Southwest Miramichi Central	01BN00	unknown	unknown	unknown	UNKNOWN	no	no date	no date
NB_06	Kouchibouguacis River, NB/ Miramichi	1BR000	28 km	increasing	1000's	HIGH	yes	2017	2017
NB_07	Weisner Brook (Shediac)/ Bouctouche	1BS000	8.5 km	increasing	1000's	MEDIUM	yes	2007	2007
NB_08	Petitcodiac River (mainstem)	01BU00	23 km	increasing	1000's	HIGH	yes	2006	2006
NB_09	Scoudouc River	01BT00	2 km	increasing	100's	MEDIUM	yes	2005	2005
NB_10	Magaguadavic River	01AQ00	1 km	unknown	10's	VERY LOW	yes	2001	2001
NB_11	St. Croix River	1AR000	11 km	unknown	1000's	HIGH	yes	no date	no date
NS_01	Wallace River	01DN00	5 km	unknown	<10	VERY LOW	yes	2017	2017
NS_02	French (Mattatail Lake)	01DO00	1 km	unknown	10's	LOW	yes	2000	2000
NS_03	Salmon River	01DR00	1 km	unknown	100's	LOW	yes	2010	2010
NS_04	St. Mary's River/ Lochaber and Eden Lakes	01EQ00	30 km	increasing	1000's	HIGH	yes	2010	2010

AU	Watershed	NHN = National Hydro Network ID number	Occupied length	Reproduction	Abundance (magnitude)	Overall Condition	Extant	Last found	Last Year Surveyed
NS_05	St. Mary's River	01EO00	unknown	unknown	1000's	HIGH	yes	2010	2010
NS_06	Gays River	01DG00	3 km	declining	<10	VERY LOW	yes	2017	2017
NS_07	LaHave River	01EF00	6 km	unknown	unknown	UNKNOWN	no	no date	no date
NS_08	Annapolis River	01DC00	18 km	increasing	1000's	HIGH	yes	2010	2010

Table D3. Changes suggested in current condition during the peer and partner review period in June 2018.

AU	Watershed	AU Stream Name	Occupied length	Reproduction	Abundance (magnitude)	Overall Current Condition	Extant	Last found	Last Year Surveyed	Suggested changes
ME_24	Machias River	West Branch Machias River	unknown	unknown	0	UNKNOWN	no	no date	2014	Should be very low
ME_31	Kennebec River Basin	Kennebec River	unknown	unknown	<10	UNKNOWN	yes	2000	2000	should be very low
NC_09	Cape Fear	New Hope Creek	unknown	unknown	<10	LOW	yes	mid 2000's	2017	should be very low
NC_19	Upper Pee Dee	Brush Creek	unknown	unknown	0	UNKNOW N	no	no date	2017	should be very low
NH_04	Merrimack River	Blackwater River / Mountain Brook	unknown	unknown	1000's	HIGH	yes	1996	1996	should be unknown
NH_06	Merrimack River	Merrimack River (Soucook River)	unknown	declining	1000s	HIGH	yes	1993	1993	should be unknown
NY_03	Susquehanna River	Chemung River	unknown	unknown	<10	UNKNOWN	yes	2009	2009	this should be very low
NY_09	Susquehanna River	Susquehanna River / Patterson Creek	unknown	unknown	unknown	LOW	yes	no date	no date	should be unknown
NY_10	Susquehanna River	Susquehanna River / Carlin Creek	unknown	unknown	unknown	LOW	yes	no date	no date	should be unknown
NY_11	Susquehanna River	Susquehanna River / Occanum	unknown	unknown	unknown	LOW	yes	no date	no date	should be unknown
NY_12	Susquehanna River	Chenango River / Lyon / Thompson	unknown	unknown	unknown	LOW	yes	no date	no date	should be unknown
NY_13	Susquehanna River	Unadilla River	unknown	stable	unknown	LOW	yes	no date	no date	should be unknown
NY_14	Susquehanna River	Upper Sangerfield River	unknown	unknown	<10	UNKNOWN	yes	2009	2009	should be very low
PA_38	Delaware River	Frankfort Creek	unknown	unknown	<10	UNKNOWN	yes	1997	1997	should be very low
WV_14	Potomac	Shenandoah River	unknown	unknown	0	UNKNOW N	no	1937	2010	should be very low

APPENDIX E

Modeling the relationship between development and brook floater population condition

Purpose

We modeled the relationship between development (urbanization, crop land and oil and gas) and brook floater population condition to confirm that development is a stressor and to help predict brook floater response to future development scenarios. The model uses a space-for-time substitution (Picket 1989, pp. 122-124). Given the available data, the model fit, and the purpose of the model, it is an approximate but reasonable approach to provide one line of evidence for the future condition. The current development data comes from NLCD 2001 (we also used NLCD 2006 with similar results). The population information comes from a range of times over the past 20 years. The model output is one line of evidence along with the impervious cover model (Schueler 2009) and local knowledge that was used to forecast future condition.

Data

The data available for modeling included:

- The current condition of brook floater populations based on relative abundance, distribution, and evidence of recruitment within analytical units (AU) defined by occupied HUC12s or connected HUC12s across the species' range from ME to GA excluding Canada. Current condition is presented in the SSA report (Chapter 3)
- Land use in agricultural (crops) and urban categories based on NLCD 2001 ((Lawler *et al.* 2014) to represent baseline land use summarized within AU. (We fit models to both NLCD 2001 and 2006 data and found the inferences were not materially different. We used the data from 2001 to be consistent with Lawler *et al.* (2014), which was the source for projected development)
- Current percent of watershed occupied by well pads based on Merriam *et al.* (2018).
- Projected land use in agricultural (crops) and urban categories based on development forecasts by Lawler *et al.* (2014) summarized within AU.
- Probability of oil and gas development within AU based on analyses by Dunscomb et al. (2014) using probability ≥0.9 to predict development. Energy development was merged with urban development based on the assumption that the impact of the km^2 area of development is similar to impervious surface following the vulnerability assessment by Dunscomb *et al.* (2014).[19]

[19] The assumption that an impact of urbanization is correlated with imperious surface is empirically based and the literature supporting that assumption is reviewed by Schueler *et al.* (2009). Dunscomb *et al.* (2014) made the assumption that the impact of energy development in total is similar to the impact of impervious surface at the 1 km^2 scale. We agree this is a strongly precautionary assumption. To examine the sensitivity of the Future Condition predictions to that assumption, we repeated the analysis assuming that the energy development impact was limited to 2 well pads would be developed per sq km (Kelly Maloney, USGS, pers. comm.) and that the size of each well pad site would encompass 25,000 m^2 (0.025 km^2) as reported by Slonecker and Milheim (2015). The assumption that the

Model

Ordinal regression is an appropriate statistical modeling approach for our purposes because the response variable in this case is a set of ordered categories (e.g., the population condition categories: High, Medium, Low, Very Low) and the explanatory variables are a mix of continuous (e.g., percent land use) and categorical (e.g., region) variables (Agresti 2012 p. 752). The statistical model can be written as:

$$log\left(\frac{P(Y \le j)}{1 - P(Y \le j)}\right) = \alpha_j - \left(\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p\right) \quad j = 1,2, \ldots, J-1$$

where Y is the population condition for an AU, J is the number of levels of population condition, α_j are the intercept terms, and β_j are the parameters associated with each of the explanatory variables (e.g., the x_i, I = 1, 2, …, p). The explanatory variables are development levels for different types of development and the regions within which the AU is located. The model estimates the effects of different types of development. We contrasted the probability that population condition would be in very low or low condition based on future levels of development relative to current levels of development. That is, we used the model to calculate the ratio $R = \frac{P(Y \le Low\ condition\ |\ Future\ development)}{P(Y \le Low\ condition\ |\ Current\ development)}$ as a measure of change in species risk due to change in development. For example, R = 1.32 indicates a (1-R)*100 or 32 percent increase in species risk.

Software packages within R (clm, ordinal) were used to fit the models. Model comparison and selection used likelihood ratio tests and AIC, and available test evaluated the goodness-of-fit and the proportional odds assumption.

Results

The models indicated significant effects of development and region (Table E1). There was no evidence of non-proportional odds using the nominal test function in R for Model 3 (Table E1), which can be interpreted as a test for goodness-of-fit. The coefficients for development were negative (-0.08, SE = 0.025 for urban development and -0.03, SE = 0.033 for agricultural development) indicating an inverse relationship between development and population condition. The effect of urban development is larger and less variable than the effect for agricultural development as indicated by the magnitude and variance of the model coefficients. Urban development has a strong negative effect and agriculture has a weak negative effect at this scale of analysis. The relationship between agriculture and population condition is highly variable, as evidenced by wide confidence intervals.

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land use impact is limited to the well pad sites is quite restrictive, but along with the Dunscomb assumption, the two assumptions book-end the range of potential impact. Energy development potentially affects 8 AUs in the Mid-Atlantic region. Six of those AUs are currently in Low condition and would not increase in population condition under any either assumption. One is currently in Medium condition, and one is currently in High condition. The Future Condition of these later two AUs would be less likely to decline under the assumption that the impact was limited to well pad sites.

The model indicates that for low levels of development population condition will range widely depending on local factors not in the model. However, as development increases the model indicates that population condition is very unlikely to be in high or medium condition. Where development is at low levels, local conditions may be favorable or unfavorable for reproduction and survival.

There is a strong regional effect with the model estimating that populations in the Mid-Atlantic have elevated risk relative to the other regions. For a population in the Mid-Atlantic, its probability of being in low or very low condition is high regardless of level of development relative to the other regions. Because of this strong regional effect, it's best to interpret the relative change from model results. For example, interpretation of the ratio (R) as a measure of change in species risk due to change in development (Table E2).

Table E1. Model selection and comparison statistics from ordinal regression of brook floater population condition as a function of agricultural and urban land use (NLCD 2001). For AIC, the smaller the number, the better the model. For the Likelihood Ratio Test, a non-significant P-value indicates the more complex model fits better – M3 is more complex than M1 or M2, and M4 is more complex than M3.

Model	**Description**	**AIC**	**Likelihood Ratio Test**
M1	Intercept only model; regional effect	391.715	
M2	Ag and urban land cover effects	399.871	
M3	Ag and urban land cover and regional effects	379.678	M1 vs M3 to test for development effect: P = 0.0003 M2 vs M3 to test for regional effect: P = 5.58e-06
M4	Ag and urban land cover and regional effects including interaction between urban and regional effects	380.452	M3 vs M4 to test for significant interaction: P = 0.20

Table E2. Input data and results from ordinal regression relating population condition to levels of development. Input data are current condition and levels of development in 2001 for the 165 analysis units (AU) with recent brook floater data within regions (representative areas or RA) of the US portion of the species range. Future scenarios 1 and 2 are based on development projections by Lawler *et al.* (2014) – see Chapter 5 of the SSA report for more detail on the scenarios. The M3 (Table A1) was used to calculate the probability that population condition is low or very low based levels of development (P[Y ≤ Low]). The ratio (R) of P(Y ≤ Low) for future development relative to current development is a measure of change in condition due to a change in development. Energy development in the future scenarios is from Dunscomb *et al.* (2014) and is incorporated as urban based on the high impact assumption.

			Current (NLCD 2001)				Future Scenario 1					Future Scenario 2				
RA	AU	Current Condition	Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	R	Ag (%)	Urban (%)	Energy (%)	P(Y≤Low)	R
NE	CT_02	Medium	1.47	5.26	0.00	0.47	10.67	9.75	0.00	0.63	1.37	4.92	12.08	0.00	0.63	1.35
NE	CT_05	Low	0.77	12.80	0.00	0.60	9.46	17.09	0.00	0.74	1.23	3.51	21.07	0.00	0.76	1.26
NE	MA_01	Medium	0.20	7.01	0.00	0.49	2.34	11.68	0.00	0.60	1.23	1.00	12.11	0.00	0.59	1.22
NE	MA_03	Low	0.82	8.95	0.00	0.53	11.53	13.04	0.00	0.69	1.31	5.53	14.74	0.00	0.68	1.28
NE	MA_04	Low	1.06	11.86	0.00	0.59	7.33	17.62	0.00	0.73	1.25	3.50	18.67	0.00	0.72	1.23
MA	MD_05	Low	4.44	9.83	0.00	0.83	5.11	19.47	0.00	0.91	1.10	3.52	20.45	0.00	0.91	1.10
NE	ME_06	Medium	2.25	3.10	0.00	0.43	13.27	5.00	0.00	0.57	1.32	6.07	6.68	0.00	0.54	1.25
NE	ME_10	Medium	0.11	1.41	0.00	0.38	10.73	3.53	0.00	0.52	1.37	4.18	5.05	0.00	0.49	1.29
NE	ME_11	High	0.98	2.37	0.00	0.41	0.62	7.06	0.00	0.49	1.22	1.52	6.92	0.00	0.50	1.24
NE	ME_12	High	1.64	8.11	0.00	0.52	14.13	10.00	0.00	0.66	1.27	6.44	11.70	0.00	0.63	1.21
NE	ME_15	Low	2.95	3.15	0.00	0.44	8.29	6.37	0.00	0.55	1.26	5.29	7.02	0.00	0.54	1.23
NE	ME_16	Medium	1.08	2.16	0.00	0.40	6.83	4.37	0.00	0.50	1.24	3.12	5.24	0.00	0.48	1.20
NE	ME_17	Low	9.44	5.25	0.00	0.54	22.72	7.56	0.00	0.68	1.25	13.58	9.47	0.00	0.65	1.21
NE	ME_18	High	6.29	14.54	0.00	0.68	19.38	16.58	0.00	0.79	1.16	11.36	18.11	0.00	0.77	1.13
NE	ME_19	High	1.99	1.90	0.00	0.41	1.34	6.91	0.00	0.50	1.23	2.26	6.83	0.00	0.50	1.25
NE	ME_23	Medium	2.79	1.93	0.00	0.41	4.41	5.55	0.00	0.50	1.21	3.43	5.80	0.00	0.49	1.20
NE	ME_27	Medium	2.46	5.89	0.00	0.49	5.57	9.87	0.00	0.59	1.22	4.04	10.13	0.00	0.58	1.20
NE	ME_28	High	4.01	6.90	0.00	0.52	1.29	14.16	0.00	0.63	1.22	3.98	13.59	0.00	0.65	1.24
NE	ME_30	Low	3.91	6.28	0.00	0.51	2.74	12.48	0.00	0.61	1.22	4.97	12.17	0.00	0.63	1.24

RA	AU	Current Condition	Current (NLCD 2001) Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	Future Scenario 1 Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	R	Future Scenario 2 Ag (%)	Urban (%)	Energy (%)	P(Y≤Low)	R
NE	ME_33	High	7.31	5.61	0.00	0.53	4.18	11.84	0.00	0.62	1.18	6.88	11.46	0.00	0.63	1.21
NE	ME_34	High	9.36	6.45	0.00	0.56	10.87	11.51	0.00	0.66	1.19	9.78	11.77	0.00	0.66	1.18
NE	ME_36	High	4.99	5.87	0.00	0.51	6.63	11.20	0.00	0.62	1.23	5.85	11.25	0.00	0.62	1.22
NE	ME_37	Medium	3.53	6.17	0.00	0.50	17.23	9.97	0.00	0.68	1.36	9.30	11.49	0.00	0.65	1.30
NE	ME_38	High	2.26	5.16	0.00	0.47	6.65	10.18	0.00	0.61	1.29	4.81	10.51	0.00	0.60	1.27
SE	NC_01	Low	0.61	7.53	0.00	0.28	14.23	9.26	0.00	0.42	1.54	5.46	10.68	0.00	0.37	1.34
SE	NC_03	High	0.34	6.20	0.00	0.26	7.69	9.24	0.00	0.37	1.44	2.42	10.31	0.00	0.34	1.33
SE	NC_04	High	0.20	2.67	0.00	0.21	6.67	5.23	0.00	0.29	1.41	2.23	6.24	0.00	0.27	1.32
SE	NC_05	High	0.33	3.88	0.00	0.23	16.83	6.91	0.00	0.41	1.85	1.00	7.67	0.00	0.29	1.28
SE	NC_06	High	1.04	7.99	0.00	0.29	29.01	13.58	0.00	0.61	2.20	5.17	15.48	0.00	0.46	1.60
SE	NC_07	High	0.79	8.01	0.00	0.29	37.29	11.09	0.00	0.63	2.28	8.57	13.90	0.00	0.46	1.61
SE	NC_08	Low	2.39	8.70	0.00	0.31	52.21	12.22	0.00	0.71	2.37	14.00	15.07	0.00	0.53	1.72
SE	NC_14	Medium	0.75	7.05	0.00	0.27	22.27	13.07	0.00	0.56	2.11	5.61	14.45	0.00	0.44	1.64
SE	NC_15	High	0.45	1.51	0.00	0.20	14.92	6.11	0.00	0.38	1.97	5.24	7.20	0.00	0.31	1.62
SE	NC_16	Medium	0.60	6.86	0.00	0.27	20.84	12.13	0.00	0.53	2.04	8.31	13.48	0.00	0.45	1.69
SE	NC_20	High	1.08	4.11	0.00	0.23	38.95	7.84	0.00	0.59	2.65	19.12	10.47	0.00	0.49	2.16
SE	NC_21	Low	0.45	3.68	0.00	0.23	18.61	9.64	0.00	0.47	2.17	6.88	10.87	0.00	0.39	1.78
SE	NC_22	Low	0.08	2.37	0.00	0.21	10.11	6.49	0.00	0.34	1.70	3.62	7.34	0.00	0.30	1.49
NE	NH_02	Medium	0.50	3.59	0.00	0.43	14.10	5.79	0.00	0.59	1.40	5.73	7.48	0.00	0.55	1.30
NE	NH_03	Medium	1.05	7.17	0.00	0.50	14.41	9.52	0.00	0.66	1.33	5.78	11.62	0.00	0.63	1.26
NE	NH_04	High	0.97	2.60	0.00	0.41	15.43	5.34	0.00	0.59	1.46	5.60	7.89	0.00	0.55	1.36
NE	NH_05	Medium	3.58	14.96	0.00	0.67	16.87	17.29	0.00	0.78	1.18	7.98	19.41	0.00	0.76	1.15
NE	NH_06	High	1.20	10.71	0.00	0.57	15.32	13.29	0.00	0.72	1.28	5.96	15.60	0.00	0.69	1.23
NE	NH_07	Low	0.72	17.46	0.00	0.68	8.98	21.93	0.00	0.80	1.18	3.66	23.88	0.00	0.79	1.16
NE	NH_08	Medium	1.46	8.31	0.00	0.52	15.05	11.39	0.00	0.69	1.33	6.21	13.60	0.00	0.66	1.27
NE	NH_09	Low	0.84	12.55	0.00	0.60	5.87	18.42	0.00	0.74	1.23	2.84	19.75	0.00	0.73	1.23
MA	NY_01	Medium	14.9	4.50	0.01	0.82	16.00	8.98	0.86	0.88	1.07	9.97	10.57	0.86	0.87	1.06

RA	AU	Current Condition	Current (NLCD 2001) Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	Future Scenario 1 Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	R	Future Scenario 2 Ag (%)	Urban (%)	Energy (%)	P(Y≤Low)	R
			9													
MA	NY_05	Low	4.75	4.51	0.00	0.77	20.53	9.86	0.00	0.89	1.17	12.87	11.81	0.00	0.89	1.16
MA	NY_06	Low	13.32	10.04	0.00	0.87	27.93	13.80	0.00	0.93	1.07	18.51	15.73	0.00	0.92	1.06
MA	NY_08	Low	3.87	10.95	0.00	0.84	15.64	17.38	6.80	0.95	1.14	9.76	18.43	6.80	0.95	1.13
MA	NY_11	Low	2.47	5.60	0.00	0.77	6.68	16.90	1.02	0.91	1.19	4.43	17.52	1.02	0.90	1.18
MA	NY_12	Low	5.86	7.22	0.00	0.81	17.76	12.16	11.78	0.96	1.18	11.14	13.27	11.78	0.95	1.18
MA	NY_13	Low	14.08	2.29	0.00	0.79	19.73	7.79	0.00	0.87	1.10	14.36	8.61	0.00	0.86	1.09
MA	NY_16	Low	6.53	5.18	0.00	0.79	15.80	10.76	2.24	0.90	1.15	10.72	11.56	2.24	0.89	1.14
MA	NY_17	Medium	0.57	2.98	0.00	0.71	3.11	6.34	0.00	0.78	1.10	1.86	6.68	0.00	0.78	1.09
MA	NY_18	Medium	0.68	5.42	0.00	0.75	4.03	10.86	0.00	0.84	1.12	2.11	11.19	0.00	0.83	1.11
MA	NY_19	Medium	2.62	6.67	0.00	0.78	3.57	14.33	0.00	0.87	1.11	2.04	14.81	0.00	0.87	1.11
MA	NY_20	Low	5.75	5.79	0.00	0.79	9.31	12.20	0.00	0.88	1.11	5.37	13.26	0.00	0.87	1.10
MA	PA_03	Medium	0.12	0.86	0.00	0.67	0.72	1.47	4.86	0.76	1.14	0.38	1.70	4.86	0.77	1.14
MA	PA_04	High	2.79	1.90	0.26	0.71	5.46	4.21	20.26	0.94	1.32	2.32	5.20	20.26	0.93	1.32
MA	PA_30	Low	8.14	7.27	0.00	0.82	7.15	17.85	0.00	0.91	1.11	4.02	20.41	0.00	0.91	1.11
SE	SC_02	Low	0.00	4.69	0.00	0.24	6.26	9.21	0.00	0.35	1.53	4.13	9.42	0.00	0.34	1.47
SE	SC_03	Medium	1.11	4.53	0.00	0.24	14.00	10.05	0.00	0.44	1.86	8.94	10.54	0.00	0.40	1.70
SE	SC_04	Medium	1.22	3.60	0.00	0.23	11.69	9.54	0.00	0.41	1.83	5.55	10.14	0.00	0.36	1.63
NE	VT_02	Medium	0.48	4.59	0.00	0.74	12.77	7.33	0.00	0.84	1.15	5.27	8.92	0.00	0.83	1.12
MA	WV_01	Medium	0.62	5.27	0.00	0.75	3.39	10.74	0.00	0.83	1.12	2.99	10.69	0.00	0.83	1.11
MA	WV_05	High	0.05	4.50	0.00	0.73	3.33	10.47	0.00	0.83	1.14	3.66	10.16	0.00	0.83	1.14
MA	WV_07	Low	0.15	4.00	0.00	0.73	3.67	9.79	0.00	0.83	1.14	3.39	9.59	0.00	0.82	1.14
MA	WV_08	Medium	0.07	2.30	0.00	0.70	2.04	7.90	0.00	0.79	1.14	2.14	7.67	0.00	0.79	1.14
MA	WV_09	High	0.20	4.31	0.00	0.73	1.55	9.05	0.00	0.81	1.10	1.42	8.85	0.00	0.80	1.10
NE	CT_03	Very Low	6.09	18.20	0.00	0.73	15.36	31.24	0.00	0.90	1.23	6.88	36.43	0.00	0.91	1.24

			Current (NLCD 2001)				Future Scenario 1					Future Scenario 2				
RA	AU	Current Condition	Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	R	Ag (%)	Urban (%)	Energy (%)	P(Y≤Low)	R
NE	CT_04	Very Low	0.70	6.53	0.00	0.48	5.76	8.78	0.00	0.57	1.19	2.10	10.96	0.00	0.58	1.21
NE	CT_06	Very Low	0.46	5.38	0.00	0.46	3.82	11.61	0.00	0.61	1.34	1.36	13.25	0.00	0.62	1.35
NE	CT_07	Very Low	0.54	7.78	0.00	0.51	8.89	10.26	0.00	0.63	1.25	4.33	13.81	0.00	0.65	1.29
NE	CT_08	Very Low	1.19	6.87	0.00	0.49	11.71	9.38	0.00	0.63	1.29	5.85	13.91	0.00	0.67	1.35
NE	CT_09	Very Low	0.45	6.75	0.00	0.49	6.28	9.15	0.00	0.58	1.21	3.14	11.42	0.00	0.60	1.24
NE	CT_10	Very Low	0.56	12.83	0.00	0.60	5.82	14.66	0.00	0.68	1.13	2.86	16.86	0.00	0.69	1.15
NE	CT_11	Very Low	1.78	14.22	0.00	0.64	11.39	19.17	0.00	0.78	1.23	4.57	23.87	0.00	0.80	1.25
MA	DE_01	Very Low	6.93	23.88	0.00	0.94	6.79	62.77	0.00	0.99	1.06	2.30	67.57	0.00	0.99	1.06
NE	MA_05	Very Low	0.54	6.76	0.00	0.49	3.97	12.33	0.00	0.62	1.29	1.80	12.93	0.00	0.61	1.27
NE	MA_06	Medium	0.79	16.01	0.00	0.66	7.21	25.72	0.00	0.83	1.26	3.28	27.19	0.00	0.83	1.26
NE	MA_13	Very Low	0.36	26.95	0.00	0.81	3.13	35.34	0.00	0.89	1.10	1.09	35.94	0.00	0.89	1.10
MA	MD_04	Very Low	0.84	5.26	0.00	0.75	1.70	9.90	0.00	0.82	1.09	1.41	10.05	0.00	0.82	1.09
MA	MD_06	Very Low	2.98	3.42	0.00	0.74	3.98	14.74	0.00	0.87	1.19	1.84	16.08	0.00	0.88	1.19
MA	MD_10	Very Low	21.54	27.37	0.00	0.97	8.89	41.96	0.00	0.98	1.01	5.00	44.17	0.00	0.98	1.01
MA	MD_11	Very Low	12.92	7.65	0.00	0.85	15.92	20.52	0.00	0.94	1.11	10.56	21.89	0.00	0.94	1.11
MA	MD_12	Very Low	2.02	8.58	0.00	0.80	8.67	24.41	0.00	0.94	1.18	4.71	25.51	0.00	0.94	1.17
MA	MD_13	Very Low	11.87	7.80	0.00	0.85	7.93	25.26	0.00	0.94	1.12	4.47	27.73	0.00	0.95	1.12
MA	MD_14	Very Low	15.27	10.37	0.00	0.88	11.84	35.87	0.00	0.98	1.11	6.10	38.95	0.00	0.97	1.11
MA	MD_15	Very Low	15.99	11.54	0.00	0.89	10.04	34.46	0.00	0.97	1.09	6.39	37.34	0.00	0.97	1.09
MA	MD_16	Very Low	10.79	4.08	0.00	0.80	8.12	37.99	0.00	0.97	1.23	4.71	37.79	0.00	0.97	1.22
MA	MD_17	Low	12.19	14.49	0.00	0.90	4.39	46.58	0.00	0.98	1.09	3.30	46.15	0.00	0.98	1.09

			Current (NLCD 2001)				Future Scenario 1					Future Scenario 2				
RA	AU	Current Condition	Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	R	Ag (%)	Urban (%)	Energy (%)	P(Y≤Low)	R
MA	MD_18	Very Low	3.96	43.71	0.00	0.98	1.57	56.25	0.00	0.99	1.01	1.19	56.27	0.00	0.99	1.01
MA	MD_19	Very Low	24.02	8.12	0.00	0.89	8.18	31.06	0.00	0.96	1.09	3.93	32.82	0.00	0.96	1.09
MA	MD_20	Very Low	3.01	78.05	0.00	1.00	1.07	89.10	0.00	1.00	1.00	0.80	89.12	0.00	1.00	1.00
NE	ME_01	High	0.58	1.55	0.00	0.39	29.94	2.45	0.00	0.64	1.69	10.00	4.66	0.00	0.53	1.39
NE	ME_02	Medium	6.93	2.89	0.00	0.47	30.87	4.70	0.00	0.68	1.44	16.28	7.09	0.00	0.63	1.34
NE	ME_03	High	0.12	0.89	0.00	0.37	29.17	1.87	0.00	0.63	1.73	9.03	4.01	0.00	0.51	1.39
NE	ME_04	High	0.28	1.45	0.00	0.38	19.56	2.86	0.00	0.58	1.54	6.87	4.66	0.00	0.50	1.33
NE	ME_05	Medium	1.02	3.53	0.00	0.43	27.35	5.15	0.00	0.67	1.58	11.03	7.36	0.00	0.59	1.39
NE	ME_07	Low	0.05	0.88	0.00	0.37	31.78	1.77	0.00	0.64	1.78	10.57	4.00	0.00	0.52	1.44
NE	ME_08	High	0.10	1.11	0.00	0.38	29.72	1.98	0.00	0.64	1.73	9.50	3.92	0.00	0.51	1.39
NE	ME_09	High	3.26	3.24	0.00	0.44	32.43	4.35	0.00	0.69	1.55	13.30	6.73	0.00	0.60	1.36
NE	ME_13	Very Low	0.11	1.01	0.00	0.37	4.58	3.47	0.00	0.46	1.24	1.73	4.15	0.00	0.45	1.20
NE	ME_14	High	0.31	1.18	0.00	0.38	9.69	3.07	0.00	0.50	1.33	3.71	4.47	0.00	0.47	1.26
NE	ME_20	Low	0.02	0.24	0.00	0.36	1.61	3.59	0.00	0.44	1.22	1.06	3.83	0.00	0.43	1.22
NE	ME_21	Low	0.15	0.84	0.00	0.37	0.73	2.21	0.00	0.40	1.08	0.50	2.31	0.00	0.40	1.08
NE	ME_22	Very Low	3.08	1.85	0.00	0.42	4.14	5.26	0.00	0.49	1.19	3.26	5.50	0.00	0.49	1.18
NE	ME_25	Very Low	2.42	1.15	0.00	0.40	5.43	5.91	0.00	0.51	1.31	4.07	6.22	0.00	0.51	1.29
NE	ME_26	Medium	0.60	0.95	0.00	0.38	2.27	4.03	0.00	0.45	1.20	1.60	4.24	0.00	0.45	1.20
NE	ME_29	Very Low	0.50	2.76	0.00	0.41	1.07	7.37	0.00	0.50	1.24	1.83	7.26	0.00	0.51	1.25
NE	ME_32	Very Low	6.49	5.09	0.00	0.51	6.81	10.86	0.00	0.62	1.23	6.98	10.86	0.00	0.62	1.23
NE	ME_35	Very Low	3.70	8.40	0.00	0.55	16.31	11.51	0.00	0.70	1.28	9.60	12.70	0.00	0.67	1.24
NE	ME_39	Very Low	1.89	11.95	0.00	0.60	8.21	18.65	0.00	0.75	1.27	4.28	19.87	0.00	0.75	1.25
NE	ME_40	Very Low	0.54	34.71	0.00	0.88	5.41	40.30	0.00	0.92	1.06	2.46	41.18	0.00	0.92	1.05
SE	NC_02	High	0.03	1.41	0.00	0.19	1.81	2.68	0.00	0.22	1.14	0.53	3.03	0.00	0.22	1.12
SE	NC_09	Low	0.30	25.97	0.00	0.60	17.43	33.63	0.00	0.81	1.39	2.71	35.68	0.00	0.76	1.28
NE	NH_10	Very Low	2.36	11.02	0.00	0.58	11.12	17.92	0.00	0.76	1.31	5.68	19.84	0.00	0.75	1.29

RA	AU	Current Condition	Current (NLCD 2001)				Future Scenario 1					Future Scenario 2				
			Ag (%)	Urban (%)	Energy (%)	P(Y≤Low)	Ag (%)	Urban (%)	Energy (%)	P(Y≤Low)	R	Ag (%)	Urban (%)	Energy (%)	P(Y≤Low)	R
NE	NH_11	Very Low	1.26	30.83	0.00	0.85	6.84	35.42	0.00	0.90	1.07	3.12	36.80	0.00	0.90	1.06
MA	NJ_03	Very Low	3.52	2.90	0.00	0.73	3.52	2.93	0.00	0.74	1.00	3.52	2.93	0.00	0.74	1.00
MA	NJ_05	Very Low	6.17	6.76	0.00	0.81	2.49	17.23	0.00	0.89	1.10	1.68	17.45	0.00	0.89	1.10
MA	NJ_06	Very Low	1.66	14.90	0.00	0.87	0.58	24.24	0.00	0.92	1.07	0.43	24.23	0.00	0.92	1.07
MA	NJ_08	Very Low	32.50	7.23	0.00	0.90	4.02	44.01	0.00	0.98	1.10	4.37	43.95	0.00	0.98	1.10
MA	NJ_09	Very Low	15.64	38.93	0.00	0.98	1.68	64.27	0.00	0.99	1.01	1.66	64.19	0.00	0.99	1.01
MA	NJ_10	Very Low	25.00	15.04	0.00	0.93	6.31	37.67	0.00	0.97	1.05	6.82	37.58	0.00	0.97	1.05
MA	NJ_11	Very Low	19.23	13.25	0.00	0.91	2.89	48.16	0.00	0.98	1.08	2.97	48.06	0.00	0.98	1.08
MA	NJ_12	Very Low	9.79	49.90	0.00	0.99	3.38	66.59	0.00	0.99	1.01	1.91	67.62	0.00	0.99	1.00
MA	NY_09	Low	1.02	51.40	0.00	0.98	4.51	56.46	6.56	0.99	1.01	2.91	56.73	6.56	0.99	1.01
MA	NY_10	Low	2.07	15.32	0.02	0.87	8.43	24.96	2.77	0.95	1.10	5.38	25.53	2.77	0.95	1.09
MA	PA_01	Very Low	3.58	6.39	0.05	0.78	15.96	14.33	0.00	0.91	1.16	7.20	17.77	0.00	0.91	1.16
MA	PA_02	Very Low	0.19	3.77	0.00	0.72	1.36	5.78	0.00	0.76	1.06	0.65	6.04	0.00	0.76	1.05
MA	PA_05	Low	1.12	2.09	0.43	0.70	2.57	4.32	44.10	0.98	1.41	1.34	4.82	44.10	0.98	1.41
MA	PA_07	High	23.18	9.54	0.00	0.90	13.02	16.07	0.00	0.91	1.02	8.42	19.65	0.00	0.92	1.03
MA	PA_08	Very Low	17.69	9.23	0.00	0.88	9.21	15.56	0.00	0.90	1.03	6.30	18.30	0.00	0.91	1.04
MA	PA_10	Very Low	4.63	6.04	0.00	0.79	5.42	9.94	0.00	0.84	1.06	3.64	12.76	0.00	0.86	1.09
MA	PA_11	Very Low	4.07	4.72	0.00	0.77	3.89	8.51	0.00	0.81	1.06	1.92	9.77	0.00	0.82	1.07
MA	PA_12	Very Low	7.18	5.76	0.00	0.80	6.78	10.97	0.00	0.85	1.07	3.20	13.10	0.00	0.86	1.07
MA	PA_13	Very Low	5.84	4.34	0.00	0.77	6.87	8.36	0.00	0.83	1.07	2.80	10.64	0.00	0.83	1.08
MA	PA_15	Very Low	11.13	24.40	0.00	0.95	5.60	34.55	0.00	0.97	1.02	3.12	40.13	0.00	0.97	1.03

			Current (NLCD 2001)				Future Scenario 1					Future Scenario 2				
RA	AU	Current Condition	Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	R	Ag (%)	Urban (%)	Energy (%)	P(Y≤Low)	R
MA	PA_16	Very Low	13.51	13.56	0.00	0.90	8.82	19.45	0.00	0.92	1.03	5.10	24.65	0.00	0.94	1.04
MA	PA_18	Very Low	14.04	10.75	0.00	0.88	12.09	29.66	0.00	0.96	1.10	5.07	37.14	0.00	0.97	1.10
MA	PA_21	Very Low	21.61	2.60	0.00	0.83	13.09	22.90	0.00	0.95	1.15	6.29	27.00	0.00	0.95	1.16
MA	PA_24	Very Low	4.83	10.77	0.00	0.84	5.41	15.73	0.00	0.89	1.05	2.65	16.85	0.00	0.89	1.05
MA	PA_28	Very Low	5.19	11.65	0.00	0.85	4.14	15.12	0.00	0.88	1.03	3.89	15.33	0.00	0.88	1.03
MA	PA_29	Very Low	10.15	9.87	0.00	0.86	2.64	20.59	0.00	0.91	1.06	2.04	20.99	0.00	0.91	1.06
MA	PA_31	Medium	17.83	33.99	0.00	0.98	4.97	59.11	0.00	0.99	1.01	4.11	59.21	0.00	0.99	1.01
MA	PA_32	Very Low	34.60	12.31	0.00	0.93	11.42	37.09	0.00	0.98	1.06	5.42	44.28	0.00	0.98	1.06
MA	PA_35	Very Low	26.13	21.36	0.00	0.96	9.10	44.29	0.00	0.98	1.03	4.40	46.87	0.00	0.98	1.03
MA	PA_36	Very Low	11.41	50.14	0.00	0.99	5.71	65.77	0.00	0.99	1.00	3.31	67.35	0.00	0.99	1.00
SE	SC_01	High	0.20	2.54	0.00	0.21	1.19	3.66	0.00	0.23	1.10	0.39	3.75	0.00	0.23	1.08
MA	VA_01	Very Low	3.87	7.48	0.00	0.80	20.97	13.78	0.00	0.92	1.15	12.93	14.29	0.00	0.90	1.13
MA	VA_02	Very Low	2.06	10.43	0.00	0.82	18.79	15.85	0.00	0.93	1.13	10.08	16.43	0.00	0.91	1.10
MA	VA_03	Very Low	0.33	6.74	0.00	0.77	8.58	10.64	0.00	0.86	1.12	4.87	10.95	0.00	0.84	1.10
MA	VA_04	Very Low	0.39	10.42	0.00	0.81	9.55	15.04	0.00	0.90	1.11	5.35	15.40	0.00	0.89	1.09
MA	VA_07	Very Low	11.17	34.81	0.00	0.97	12.99	48.62	0.00	0.99	1.02	8.00	49.48	0.00	0.99	1.01
MA	VA_09	Very Low	7.15	9.62	0.00	0.84	35.65	15.43	0.00	0.94	1.12	17.57	16.78	0.00	0.93	1.10
MA	VA_10	Very Low	3.40	8.49	0.00	0.81	18.74	12.93	0.00	0.91	1.13	9.57	13.67	0.00	0.89	1.10
MA	VA_11	Very Low	3.20	10.89	0.00	0.84	20.05	14.08	0.00	0.92	1.10	9.27	15.14	0.00	0.90	1.08
MA	VA_12	Very Low	2.05	27.31	0.00	0.94	13.90	31.05	0.00	0.97	1.03	5.21	31.68	0.00	0.96	1.02

			Current (NLCD 2001)				Future Scenario 1					Future Scenario 2				
RA	AU	Current Condition	Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	Ag (%)	Urban (%)	Energy (%)	P (Y≤Low)	R	Ag (%)	Urban (%)	Energy (%)	P(Y≤Low)	R
MA	VA_13	Very Low	4.26	10.67	0.00	0.84	19.95	15.21	0.00	0.92	1.10	7.56	16.09	0.00	0.90	1.07
MA	WV_02	Very Low	0.18	2.88	0.00	0.71	3.06	9.49	0.00	0.82	1.16	3.16	8.90	0.00	0.81	1.15
MA	WV_03	Very Low	0.05	1.83	0.00	0.69	2.10	6.02	0.00	0.77	1.12	1.88	5.83	0.00	0.77	1.11
MA	WV_06	Very Low	0.11	3.77	0.00	0.72	4.45	6.72	0.00	0.79	1.10	2.48	7.19	0.00	0.79	1.09
MA	WV_11	Very Low	2.60	3.68	0.00	0.74	6.24	12.35	0.00	0.86	1.17	5.04	12.09	0.00	0.86	1.16
MA	WV_12	Very Low	9.34	16.66	0.00	0.91	13.60	26.73	0.00	0.96	1.06	11.65	26.00	0.00	0.95	1.05
MA	WV_13	Very Low	1.71	11.30	0.00	0.83	9.18	19.55	0.00	0.92	1.11	6.15	20.46	0.00	0.92	1.11

APPENDIX F
Methods for Future Condition

This appendix describes the assessment of brook floater future condition in response to scenarios representing levels of development. At a conceptual level (Figure F1), development is a primary source of major stressors, which play an important role in influencing population resilience and ultimately species viability. The types of development relevant to brook floater includes urban sprawl, land conversion to agriculture, and oil and gas development with associated infrastructure. Thus, we structured future scenarios around levels of development.

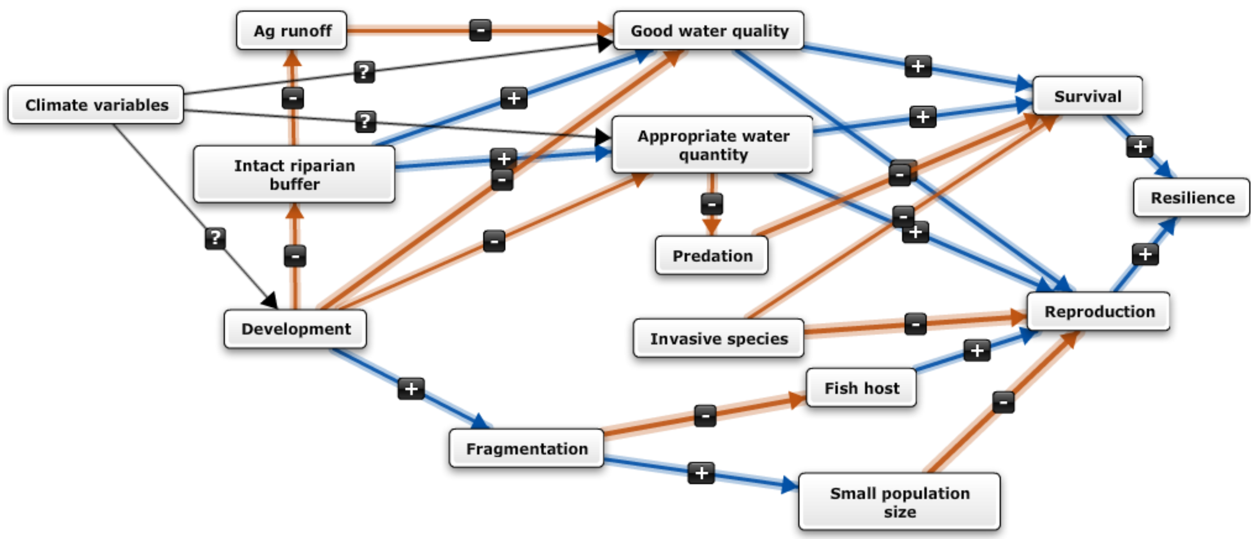

Figure F1. Factors influencing brook floater population resiliency.

Habitat factors include fish hosts, water quality and quantity. Interspecific interactions, including predation or competition, can be influenced by habitat and influence brook floater vital rates directly. Stressors that influence brook floater and habitat include development effects on habitat or fragmentation effects on brook floater or co-occurring species. Climate can affect habitat or interact with other stressors, such as development. Positive influences are indicated with a blue arrow and + symbol; negative influences are indicated with orange arrow and – symbol; influences with high uncertainty are indicated with a black arrow and '?' symbol.

Development varies across the landscape in type and intensity. The appropriate spatial scale to project development must account for that spatial variation in development but avoid a high resolution that would unnecessarily slow down the analysis without improving the overall assessment of the species future condition. Thus, we evaluated development at the scale of the AU (as defined previously) and took into account effects due to representative area or region. The appropriate time scale to project future condition must be consistent with the scientifically reliable projections of the stressors, and include multiple time increments to support consideration of foreseeable future.

Our approach to assess future condition for brook floater involved:

1) Developing scenarios based on development forecasts,
2) Analyzing the empirical relationship between biological condition and level of development and using those relationships to inform species response to future scenarios, and
3) Predicting future condition from a simple rule set and experts who have local knowledge at the state or analytical unit levels.

Developing Scenarios based on development forecasts

The rules of thumb for scenario planning are to include 2 to 5 scenarios (Schwartz 1996, Cornish 2004). The numbers of scenarios should capture the range of plausible futures in order to assess the species-risk profile. The final numbers of scenarios and levels of stressors within a scenario depend on available data. We identified data for forecasts relevant to the brook floater assessment. To be useful for the assessment, forecasts needed to be available throughout the brook floater range, be projected at least 3 generations or at least 2 decades in to the future, be at a scale that could be summarized at the analytical unit scale (HUC12 or combinations of HUC12s), and include sources for the major stressors as previously defined. The data that were included in the future scenarios are presented in Table F1.

Table F1. Data for development projections included in future scenarios.

Source	Data
Urban and agricultural development	Projected land use at 2051 for several economic-based scenarios at the 100 m resolution, which is a realistic size for average land-use change: Lawler *et al.* 2014. Projected land-use change impacts on ecosystem services in the United States. Proceedings of the National Academy of Sciences 111:7492-7497. Lawler *et al.* (2014) projected development for various economic growth assumptions and compared future land use with land use in 2001 from the NLCD. They developed two projections relevant to the brook floater assessment. One closely resembles trends from 2007-2012, which were characterized by high crop demand accounting for 10% increase in crop prices every 5 years relative to 1990s scenario (i.e., 'pro-ag' scenario in Lawler *et al.* 2014). The other was characterized by land-use change based on 1992-1997, which tended to favor urban development (i.e., 'ref' scenario in Lawler *et al.* 2014).

Energy development	Probability of energy development across Marcellus and Utica plays at 1 km^2 scale: Dunscomb J.K., J.S. Evans, J.M. Strager, M.P. Strager, and J.M. Kiesecker. 2014. Assessing Future Energy Development across the Appalachian Landscape Conservation Cooperative. Charlottesville (VA): The Nature Conservancy. 48 pp with appendices. Appalachian Landscape Conservation Cooperative Grant #2012-02. Dunscomb *et al.* (2014) applied probability cutoffs of ≥0.65 and ≥0.9 to identify areas likely to be developed for oil and gas. (Here we use only the ≥0.9 cutoff to determine areas likely to be developed for oil and gas to base the assessment on the higher likelihood of development.) Numbers of cleared and permitted well pad sites in the Upper Susquehanna: Merriam, E.R., Petty, J.T., Maloney, K.O., Young, J.A., Faulkner, S.P., Slonecker, E.T., Milheim, L.E., Hailegiorgis, A. and Niles, J., 2018. Brook trout distributional response to unconventional oil and gas development: Landscape context matters. Science of the Total Environment: 628, pp.338-349. Size of well pad sites: Slonecker, E.T. and Milheim, L.E. 2015. Landscape disturbance from unconventional and conventional oil and gas development in the Marcellus Shale region of Pennsylvania, USA. Environments, 2(2), pp. 200-220.

Two scenarios were developed based on economic-based land use projections from Lawler *et al.* (2014) and assumed impact of energy development (Table F2).

- Land-use projections: Lawler *et al.* (2014) used economic models to project land use including agricultural or urban development following two scenarios, which are relevant to brook floater assessment.
    - Scenario 1: land-use change similar to trends from 2007-2012
    - Scenario 2: land-use change similar to trends from 1992-1997
    - In both scenarios, agricultural and urban land use is projected to increase. However, scenario 1 includes a 10 percent increase in crop prices every 5 years relative to scenario 2. As a result, scenario 1 has a higher rate of increase in conversion to agriculture than does scenario 2.
- Impact of energy development: Dunscomb *et al.* (2014) identified areas likely to be developed for energy using a model that predicts the probability of energy development on the km^2 scale along with >0.65 and >0.9 thresholds (we used only the >0.9 threshold to base the assessment on the higher likelihood of development). They assumed the impact would be similar to impervious surface and translated the effect of energy

development on stream quality using the model of stream quality to impervious surface reported by Schueler *et al.* (2009). (Note that energy development potentially affects 8 of 81 AU's in the Mid-Atlantic ranked as High, Medium, Low, or Very Low. Six of those are currently in Low condition. One is currently in Medium condition, and one is currently in High condition.)

Table F2. Development scenarios used to evaluate brook floater future condition. The scenarios were comprised of economic based projections of agricultural and urban land use (Lawler *et al.* 2014) combined with impact of energy development (Dunscomb *et al.* 2014). Dunscomb *et al.* (2014) used a probability of development cutoff of ≥0.9.

	Land use projections based on economic conditions and past trends	Energy development
Scenario 1	● Land-use change similar to trends from 2007-2012	Impact extends to developed area at a km^2 spatial resolution
Scenario 2	● Land-use change similar to trends from 1992-1997	Impact extends to developed area at a km^2 spatial resolution

For each AU, we summarized the percent of the watershed in agriculture and urban land use for the two economic scenarios of Lawler *et al.* (2014). Also, we summarized the percent of each analytical unit likely to be developed for oil and gas based on Dunscomb *et al.* (2014).

Empirical relationships between biological condition and level of development and using those relationships to inform species response to future scenarios

Schueler *et al.* (2009) reviewed the literature on the effect of impervious cover on stream quality and reformulated the Impervious Cover Model (ICM) to include several transitional categories, which relate percent of a watershed in impervious surface to stream quality. Impervious surface is relevant to the brook floater assessment because urban land use creates impervious surface. Also, depending on underlying assumptions, environmental effects from energy development due to cleared lands for sites and roads, run-off, and spills can be similar to those of impervious surface. The ICM is a 'wedge-shaped' model in the sense that for low impervious surface there can be a wide range in stream qualities (i.e., the fat end of the wedge) but as impervious surface increases stream quality is reduced (i.e., the wedge narrows to a point).

We modeled the relationship between current population condition (as previously described) and land cover (agricultural and urban) from 2001 NLCD and used that relationship to inform species response to future scenarios. We used 2001 NLCD for consistency with the analysis by Lawler *et al.* (2014), but we fit a model using 2006 NLCD data and the results were not materially different. We focused on agricultural and urban land use because these were *a priori* identified as major stressors, and we did not include other land use cover types which are highly correlated with agriculture and urbanization, such as forest cover. We fit ordinal regression models to evaluate relative importance of land use and regional effects, and to predict probabilities of population condition based on future development scenarios. Ordinal regression can be thought of as an extension of logistic regression where the dependent variable includes multiple categories (i.e., multinomial) rather than just two categories (i.e., binomial). Also, in ordinal regression the multiple categories are ordered, which is the case for population condition – Very Low is less than Low, which is less than Medium, which is less than High. Model results include the probabilities of a population being in the four condition categories based on the region and land use levels of the surrounding watershed. We describe the ordinal regression modeling in more detail within a separate Appendix on modeling current condition.

The ICM (Schueler *et al.* 2009) was used to convert levels of development into stream quality category for current and projected levels of development. The ordinal regression model was used to estimate the probability that a population is in the low or very low condition based on levels of development and region where the watershed is located. That probability was calculated for both current and projected levels of development to measure the expected effect on brook floater due to change in development. Current and future development, stream quality, model-based population condition probabilities, current condition, and local knowledge are used to inform prediction of future condition for each population under each scenario (Figure F2).

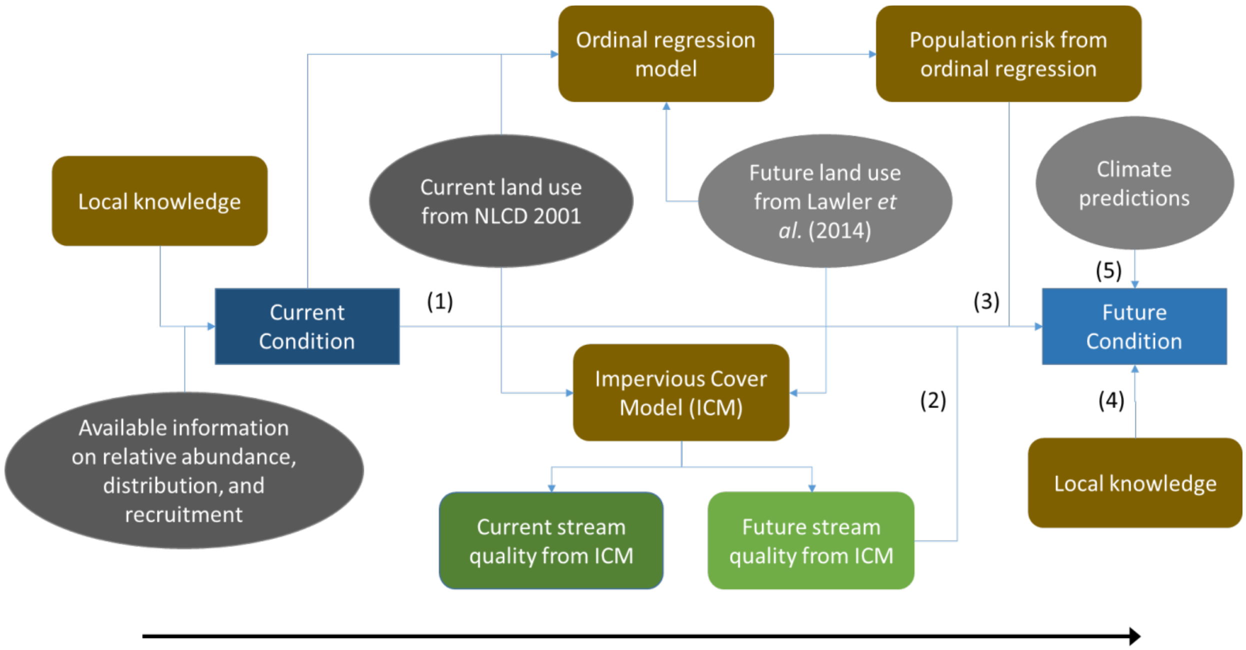

Figure F2. Diagram of the process and lines of evidence used to predict future condition.

Available information on relative abundance, distribution, and recruitment along with local knowledge determined current condition. An ordinal regression model was fit using current condition and current land use (Appendix E). The impervious surface model (Schueler *et al.* 2009) was used to predict stream quality. The lines of evidence for future condition were (Figure F2): (1) current condition, (2) current compared to future stream quality, (3) risk of change in population condition from ordinal regression, (4) local knowledge, and (5) climate predictions (Table F3).

Predicting future condition from a simple rule set and experts who have local knowledge at the state or analytical unit levels

Although reliable projections of major stressors (e.g., Lawler *et al.* 2014, entire, Dunscomb *et al.* 2014, entire) and straight-forward models to translate stressors to environmental condition (i.e., ICM and ordinal regression model), a single predictive model that integrates future stressors with current condition to predict future condition is not available. Thus, the SSA team needed to develop a process to elicit expert judgement to forecast the species' response to future stressor scenarios for each AU. The SSA team members considered each population's current condition along with the information on stressors/species response relationships and local knowledge (Figure F2). Then, the core team forecast future condition based on a simple rule set (Table F3). (The development projections are in Table F4.) The rule set determined the future condition for the majority but not all of the populations. For the populations not covered by the rule set, the core team followed a deliberative process using the likelihood point method and a modified-Delphi approach (Burgman 2016, p. 214). In the likelihood point method, 100 points are distributed across the population condition categories to reflect future condition in response to each scenario based on the biology of the species, the factors that are affecting its status, and the degree of uncertainty of future predictions. A team member could use local knowledge to correct a future condition assigned by the rule set. Team members noted their logic train when scoring future condition.

Individual team member scores were averaged to arrive at a summary score (Table F5). The scores in Table F5 are the expert elicited probabilities that a population will be in a condition category about 30 years from present. The scores at the 15-year mark were calculated as the midpoint between current condition and condition at 30 years, which assumes linear change. The numbers of populations within each condition category were estimated by the sum of the scores divided by 100 (Figure F3).

Table F3. Simple rule set used to forecast future condition (FC) based on current condition (CC), predicted land use, and empirical relationships between land use and population condition, and to identify those cases where expert elicitation was needed.

Rule set (implemented in order):
1) If CC = "Unknown", then FC = "Unknown"
2) If CC = "Very Low", then FC = "Very Low"
3) If expected change in stream quality and population condition are not significant, then FC = CC.
4) If stream quality index under a future scenario is 'sensitive', then FC = CC.
5) If stream quality index under a future scenario is 'non-supporting' or 'urban', then FC is 'low' or 'very low'. If stream quality index under a future scenario is 'urban', then FC is 'very low'.
6) If expected change in stream quality or population condition are significant, then determine FC by expert elicitation through deliberation among SSA team and outside expert review.

The scenarios are described in Table F2, but Scenario 1 is characterized by an increased rate of agriculture land use change and Scenario 2 is characterized by increased rate of urban land use change (Lawler *et al.* 2014). Both scenarios included the energy impact, which affected a few AUs. The 3 Rs are shown in Figure F3: Representation is the regions, Resilience is the condition categories, and Redundancy is the number of populations weighted by condition category (high gets the most weight, low gets very little weight and very low gets no weight).

Current Condition

Region	HIGH	MED	LOW	VERY LOW	Total AUs
MA	4	8	15	54	**81**
NE	17	17	11	20	**65**
SE	9	4	6	0	**19**
Range (US)	30	29	32	74	**165**

Future Condition Scenario 1

Region	15 years HIGH	15 years MED	15 years LOW	15 years VERY LOW	30 years HIGH	30 years MED	30 years LOW	30 years VERY LOW
MA	3.4	6.7	13.3	57.6	2.8	5.4	11.6	61.2
NE	16.2	16.6	10.9	21.3	15.4	16.1	10.9	22.6
SE	9.0	3.9	5.7	0.4	9.0	3.8	5.4	0.8
Range (US)	28.6	27.2	29.9	79.3	27.3	25.3	27.8	84.6

Future Condition Scenario 2

Region	15 years HIGH	15 years MED	15 years LOW	15 years VERY LOW	30 years HIGH	30 years MED	30 years LOW	30 years VERY LOW
MA	3.0	6.4	12.7	58.8	2.1	4.8	10.4	63.7
NE	15.0	15.9	11.8	22.3	13.0	14.8	12.7	24.7
SE	8.2	4.1	5.8	0.9	7.3	4.3	5.5	1.9
Range (US)	26.2	26.4	30.3	82.1	22.4	23.8	28.6	90.2

Figure F3. Numbers of populations within each condition category for current and future based on development scenarios at 15 year and 30 years from present.

Table F4. Land cover (%) for analysis units within the US range of brook floater. Current crop and urban land cover is from NLCD 2001 as used by Lawler *et al.* (2014), and current energy land cover is cleared and permitted well pad sites (Merriam *et al.* 2018). Future crop and urban land cover are projections under two economic scenarios from Lawler *et al.* (2014), see Table E2 for scenario descriptions. Future energy development is based on projections from Dunscomb *et al.* (2014) and two assumptions regarding energy development impact (high energy impact (HI) and low energy impact (LI) see text for details). Current and future stream quality based on the Impervious Cover Model (Schueler *et al.* 2009) using urban and energy land cover as input. Levels of stream quality are: Sensitive (S), Impacted (I), Nonsupporting (N), and Urban (U); transition levels are indicated by combinations of corresponding letters (e.g., S/I is the transition between Sensitive and Impacted stream quality). RA = Representative Area; AU = Analytical Unit; CC = Current Condition.

			Current Land Cover (%)			**Future Land Cover (%): Scenario 1 (S1)**		**Future Land Cover (%): Scenario 2 (S2)**		**Future Energy Pr(development ≥ 0.9)**		**Stream quality (Schueler *et al.* 2009)**				
RA	**AU**	**CC**	**Crops**	**Urban**	**Energy**	**Crops**	**Urban**	**Crops**	**Urban**	**High Impact (HI)**	**Low Impact (LI)**	**Current**	**S 1 (HI)**	**S 2 (HI)**	**S 1 (LI)**	**S 2 (LI)**
NE	CT_02	Medium	1.47	5.26	0.00	10.67	9.75	4.92	12.08	0.00	0.00	S/I	S/I	I	S/I	I
NE	CT_05	Low	0.77	12.80	0.00	9.46	17.09	3.51	21.07	0.00	0.00	I	I	I/N	I	I/N
NE	MA_01	Medium	0.20	7.01	0.00	2.34	11.68	1.00	12.11	0.00	0.00	S/I	I	I	I	I
NE	MA_03	Low	0.82	8.95	0.00	11.53	13.04	5.53	14.74	0.00	0.00	S/I	I	I	I	I
NE	MA_04	Low	1.06	11.86	0.00	7.33	17.62	3.50	18.67	0.00	0.00	I	I	I	I	I
MA	MD_05	Low	4.44	9.83	0.00	5.11	19.47	3.52	20.45	0.00	0.00	S/I	I	I/N	I	I/N
NE	ME_06	Medium	2.25	3.10	0.00	13.27	5	6.07	6.68	0.00	0.00	S	S/I	S/I	S/I	S/I
NE	ME_10	Medium	0.11	1.41	0.00	10.73	3.53	4.18	5.05	0.00	0.00	S	S	S/I	S	S/I
NE	ME_11	High	0.98	2.37	0.00	0.62	7.06	1.52	6.92	0.00	0.00	S	S/I	S/I	S/I	S/I
NE	ME_12	High	1.64	8.11	0.00	14.13	10	6.44	11.7	0.00	0.00	S/I	I	I	I	I
NE	ME_15	Low	2.95	3.15	0.00	8.29	6.37	5.29	7.02	0.00	0.00	S	S/I	S/I	S/I	S/I
NE	ME_16	Medium	1.08	2.16	0.00	6.83	4.37	3.12	5.24	0.00	0.00	S	S	S/I	S	S/I
NE	ME_17	Low	9.44	5.25	0.00	22.72	7.56	13.58	9.47	0.00	0.00	S/I	S/I	S/I	S/I	S/I
NE	ME_18	High	6.29	14.54	0.00	19.38	16.58	11.36	18.11	0.00	0.00	I	I	I	I	I
NE	ME_19	High	1.99	1.90	0.00	1.34	6.91	2.26	6.83	0.00	0.00	S	S/I	S/I	S/I	S/I
NE	ME_23	Medium	2.79	1.93	0.00	4.41	5.55	3.43	5.80	0.00	0.00	S	S/I	S/I	S/I	S/I

			Current Land Cover (%)			Future Land Cover (%): Scenario 1 (S1)		Future Land Cover (%): Scenario 2 (S2)		Future Energy Pr(development ≥ 0.9)		Stream quality (Schueler *et al.* 2009)				
RA	AU	CC	Crops	Urban	Energy	Crops	Urban	Crops	Urban	High Impact (HI)	Low Impact (LI)	Current	S 1 (HI)	S 2 (HI)	S 1 (LI)	S 2 (LI)
NE	ME_27	Medium	2.46	5.89	0.00	5.57	9.87	4.04	10.13	0.00	0.00	S/I	S/I	I	S/I	I
NE	ME_28	High	4.01	6.90	0.00	1.29	14.16	3.98	13.59	0.00	0.00	S/I	I	I	I	I
NE	ME_30	Low	3.91	6.28	0.00	2.74	12.48	4.97	12.17	0.00	0.00	S/I	I	I	I	I
NE	ME_33	High	7.31	5.61	0.00	4.18	11.84	6.88	11.46	0.00	0.00	S/I	I	I	I	I
NE	ME_34	High	9.36	6.45	0.00	10.87	11.51	9.78	11.77	0.00	0.00	S/I	I	I	I	I
NE	ME_36	High	4.99	5.87	0.00	6.63	11.2	5.85	11.25	0.00	0.00	S/I	I	I	I	I
NE	ME_37	Medium	3.53	6.17	0.00	17.23	9.97	9.3	11.49	0.00	0.00	S/I	S/I	I	S/I	I
NE	ME_38	High	2.26	5.16	0.00	6.65	10.18	4.81	10.51	0.00	0.00	S/I	I	I	I	I
SE	NC_01	Low	0.61	7.53	0.00	14.23	9.26	5.46	10.68	0.00	0.00	S/I	S/I	I	S/I	I
SE	NC_03	High	0.34	6.20	0.00	7.69	9.24	2.42	10.31	0.00	0.00	S/I	S/I	I	S/I	I
SE	NC_04	High	0.20	2.67	0.00	6.67	5.23	2.23	6.24	0.00	0.00	S	S/I	S/I	S/I	S/I
SE	NC_05	High	0.33	3.88	0.00	16.83	6.91	1	7.67	0.00	0.00	S	S/I	S/I	S/I	S/I
SE	NC_06	High	1.04	7.99	0.00	29.01	13.58	5.17	15.48	0.00	0.00	S/I	I	I	I	I
SE	NC_07	High	0.79	8.01	0.00	37.29	11.09	8.57	13.9	0.00	0.00	S/I	I	I	I	I
SE	NC_08	Low	2.39	8.70	0.00	52.21	12.22	14	15.07	0.00	0.00	S/I	I	I	I	I
SE	NC_14	Medium	0.75	7.05	0.00	22.27	13.07	5.61	14.45	0.00	0.00	S/I	I	I	I	I
SE	NC_15	High	0.45	1.51	0.00	14.92	6.11	5.24	7.2	0.00	0.00	S	S/I	S/I	S/I	S/I
SE	NC_16	Medium	0.60	6.86	0.00	20.84	12.13	8.31	13.48	0.00	0.00	S/I	I	I	I	I
SE	NC_20	High	1.08	4.11	0.00	38.95	7.84	19.12	10.47	0.00	0.00	S	S/I	I	S/I	I
SE	NC_21	Low	0.45	3.68	0.00	18.61	9.64	6.88	10.87	0.00	0.00	S	S/I	I	S/I	I
SE	NC_22	Low	0.08	2.37	0.00	10.11	6.49	3.62	7.34	0.00	0.00	S	S/I	S/I	S/I	S/I
NE	NH_02	Medium	0.50	3.59	0.00	14.1	5.79	5.73	7.48	0.00	0.00	S	S/I	S/I	S/I	S/I
NE	NH_03	Medium	1.05	7.17	0.00	14.41	9.52	5.78	11.62	0.00	0.00	S/I	S/I	I	S/I	I
NE	NH_04	High	0.97	2.60	0.00	15.43	5.34	5.6	7.89	0.00	0.00	S	S/I	S/I	S/I	S/I
NE	NH_05	Medium	3.58	14.96	0.00	16.87	17.29	7.98	19.41	0.00	0.00	I	I	I	I	I
NE	NH_06	High	1.20	10.71	0.00	15.32	13.29	5.96	15.6	0.00	0.00	I	I	I	I	I

			Current Land Cover (%)			Future Land Cover (%): Scenario 1 (S1)		Future Land Cover (%): Scenario 2 (S2)		Future Energy Pr(development ≥ 0.9)		Stream quality (Schueler *et al.* 2009)				
RA	AU	CC	Crops	Urban	Energy	Crops	Urban	Crops	Urban	High Impact (HI)	Low Impact (LI)	Current	S 1 (HI)	S 2 (HI)	S 1 (LI)	S 2 (LI)
NE	NH_07	Low	0.72	17.46	0.00	8.98	21.93	3.66	23.88	0.00	0.00	I	I/N	I/N	I/N	I/N
NE	NH_08	Medium	1.46	8.31	0.00	15.05	11.39	6.21	13.6	0.00	0.00	S/I	I	I	I	I
NE	NH_09	Low	0.84	12.55	0.00	5.87	18.42	2.84	19.75	0.00	0.00	I	I	I	I	I
MA	NY_01	Medium	14.99	4.50	0.01	16	8.98	9.97	10.57	0.86	0.04	S	S/I	I	S/I	I
MA	NY_05	Low	4.75	4.51	0.00	20.53	9.86	12.87	11.81	0.00	0.00	S	S/I	I	S/I	I
MA	NY_06	Low	13.32	10.04	0.00	27.93	13.8	18.51	15.73	0.00	0.00	I	I	I	I	I
MA	NY_08	Low	3.87	10.95	0.00	15.64	17.38	9.76	18.43	6.80	0.34	I	I/N	N	I	I
MA	NY_11	Low	2.47	5.60	0.00	6.68	16.9	4.43	17.52	1.02	0.05	S/I	I	I	I	I
MA	NY_12	Low	5.86	7.22	0.00	17.76	12.16	11.14	13.27	11.78	0.59	S/I	I/N	N	I	I
MA	NY_13	Low	14.08	2.29	0.00	19.73	7.79	14.36	8.61	0.00	0.00	S	S/I	S/I	S/I	S/I
MA	NY_16	Low	6.53	5.18	0.00	15.8	10.76	10.72	11.56	2.24	0.11	S/I	I	I	I	I
MA	NY_17	Medium	0.57	2.98	0.00	3.11	6.34	1.86	6.68	0.00	0.00	S	S/I	S/I	S/I	S/I
MA	NY_18	Medium	0.68	5.42	0.00	4.03	10.86	2.11	11.19	0.00	0.00	S/I	I	I	I	I
MA	NY_19	Medium	2.62	6.67	0.00	3.57	14.33	2.04	14.81	0.00	0.00	S/I	I	I	I	I
MA	NY_20	Low	5.75	5.79	0.00	9.31	12.2	5.37	13.26	0.00	0.00	S/I	I	I	I	I
MA	PA_03	Medium	0.12	0.86	0.00	0.72	1.47	0.38	1.7	4.86	0.24	S	S/I	S/I	S	S
MA	PA_04	High	2.79	1.90	0.26	5.46	4.21	2.32	5.2	20.26	1.01	S	I/N	N	S/I	S/I
MA	PA_30	Low	8.14	7.27	0.00	7.15	17.85	4.02	20.41	0.00	0.00	S/I	I	I/N	I	I/N
SE	SC_02	Low	0.00	4.69	0.00	6.26	9.21	4.13	9.42	0.00	0.00	S	S/I	S/I	S/I	S/I
SE	SC_03	Medium	1.11	4.53	0.00	14	10.05	8.94	10.54	0.00	0.00	S	I	I	I	I
SE	SC_04	Medium	1.22	3.60	0.00	11.69	9.54	5.55	10.14	0.00	0.00	S	S/I	I	S/I	I
NE	VT_02	Medium	0.48	4.59	0.00	12.77	7.33	5.27	8.92	0.00	0.00	S	S/I	S/I	S/I	S/I
MA	WV_01	Medium	0.62	5.27	0.00	3.39	10.74	2.99	10.69	0.00	0.00	S/I	I	I	I	I
MA	WV_05	High	0.05	4.50	0.00	3.33	10.47	3.66	10.16	0.00	0.00	S	I	I	I	I
MA	WV_07	Low	0.15	4.00	0.00	3.67	9.79	3.39	9.59	0.00	0.00	S	S/I	S/I	S/I	S/I
MA	WV_08	Medium	0.07	2.30	0.00	2.04	7.9	2.14	7.67	0.00	0.00	S	S/I	S/I	S/I	S/I

			Current Land Cover (%)			Future Land Cover (%): Scenario 1 (S1)		Future Land Cover (%): Scenario 2 (S2)		Future Energy Pr(development ≥ 0.9)		Stream quality (Schueler *et al.* 2009)				
RA	**AU**	**CC**	**Crops**	**Urban**	**Energy**	**Crops**	**Urban**	**Crops**	**Urban**	**High Impact (HI)**	**Low Impact (LI)**	**Current**	**S 1 (HI)**	**S 2 (HI)**	**S 1 (LI)**	**S 2 (LI)**
MA	WV_09	High	0.20	4.31	0.00	1.55	9.05	1.42	8.85	0.00	0.00	S	S/I	S/I	S/I	S/I
NE	CT_03	Very Low	6.09	18.20	0.00	15.36	31.24	6.88	36.43	0.00	0.00	I	N	N	N	N
NE	CT_04	Very Low	0.70	6.53	0.00	5.76	8.78	2.1	10.96	0.00	0.00	S/I	S/I	I	S/I	I
NE	CT_06	Very Low	0.46	5.38	0.00	3.82	11.61	1.36	13.25	0.00	0.00	S/I	I	I	I	I
NE	CT_07	Very Low	0.54	7.78	0.00	8.89	10.26	4.33	13.81	0.00	0.00	S/I	I	I	I	I
NE	CT_08	Very Low	1.19	6.87	0.00	11.71	9.38	5.85	13.91	0.00	0.00	S/I	S/I	I	S/I	I
NE	CT_09	Very Low	0.45	6.75	0.00	6.28	9.15	3.14	11.42	0.00	0.00	S/I	S/I	I	S/I	I
NE	CT_10	Very Low	0.56	12.83	0.00	5.82	14.66	2.86	16.86	0.00	0.00	I	I	I	I	I
NE	CT_11	Very Low	1.78	14.22	0.00	11.39	19.17	4.57	23.87	0.00	0.00	I	I	I/N	I	I/N
MA	DE_01	Very Low	6.93	23.88	0.00	6.79	62.77	2.3	67.57	0.00	0.00	I/N	N/U	N/U	N/U	N/U
NE	MA_05	Very Low	0.54	6.76	0.00	3.97	12.33	1.8	12.93	0.00	0.00	S/I	I	I	I	I
NE	MA_06	Medium	0.79	16.01	0.00	7.21	25.72	3.28	27.19	0.00	0.00	I	N	N	N	N
NE	MA_13	Very Low	0.36	26.95	0.00	3.13	35.34	1.09	35.94	0.00	0.00	N	N	N	N	N
MA	MD_04	Very Low	0.84	5.26	0.00	1.7	9.9	1.41	10.05	0.00	0.00	S/I	S/I	I	S/I	I
MA	MD_06	Very	2.98	3.42	0.00	3.98	14.74	1.84	16.08	0.00	0.00	S	I	I	I	I

			Current Land Cover (%)			**Future Land Cover (%): Scenario 1 (S1)**		**Future Land Cover (%): Scenario 2 (S2)**		**Future Energy Pr(development ≥ 0.9)**		**Stream quality (Schueler *et al.* 2009)**				
RA	**AU**	**CC**	**Crops**	**Urban**	**Energy**	**Crops**	**Urban**	**Crops**	**Urban**	**High Impact (HI)**	**Low Impact (LI)**	**Current**	**S 1 (HI)**	**S 2 (HI)**	**S 1 (LI)**	**S 2 (LI)**
		Low														
MA	MD_10	Very Low	21.54	27.37	0.00	8.89	41.96	5	44.17	0.00	0.00	N	N	N	N	N
MA	MD_11	Very Low	12.92	7.65	0.00	15.92	20.52	10.56	21.89	0.00	0.00	S/I	I/N	I/N	I/N	I/N
MA	MD_12	Very Low	2.02	8.58	0.00	8.67	24.41	4.71	25.51	0.00	0.00	S/I	I/N	N	I/N	N
MA	MD_13	Very Low	11.87	7.80	0.00	7.93	25.26	4.47	27.73	0.00	0.00	S/I	N	N	N	N
MA	MD_14	Very Low	15.27	10.37	0.00	11.84	35.87	6.1	38.95	0.00	0.00	I	N	N	N	N
MA	MD_15	Very Low	15.99	11.54	0.00	10.04	34.46	6.39	37.34	0.00	0.00	I	N	N	N	N
MA	MD_16	Very Low	10.79	4.08	0.00	8.12	37.99	4.71	37.79	0.00	0.00	S	N	N	N	N
MA	MD_17	Low	12.19	14.49	0.00	4.39	46.58	3.3	46.15	0.00	0.00	I	N	N	N	N
MA	MD_18	Very Low	3.96	43.71	0.00	1.57	56.25	1.19	56.27	0.00	0.00	N	N	N	N	N
MA	MD_19	Very Low	24.02	8.12	0.00	8.18	31.06	3.93	32.82	0.00	0.00	S/I	N	N	N	N
MA	MD_20	Very Low	3.01	78.05	0.00	1.07	89.1	0.8	89.12	0.00	0.00	U	U	U	U	U
NE	ME_01	High	0.58	1.55	0.00	29.94	2.45	10	4.66	0.00	0.00	S	S	S	S	S
NE	ME_02	Medium	6.93	2.89	0.00	30.87	4.7	16.28	7.09	0.00	0.00	S	S	S/I	S	S/I
NE	ME_03	High	0.12	0.89	0.00	29.17	1.87	9.03	4.01	0.00	0.00	S	S	S	S	S
NE	ME_04	High	0.28	1.45	0.00	19.56	2.86	6.87	4.66	0.00	0.00	S	S	S	S	S
NE	ME_05	Medium	1.02	3.53	0.00	27.35	5.15	11.03	7.36	0.00	0.00	S	S/I	S/I	S/I	S/I

			Current Land Cover (%)			Future Land Cover (%): Scenario 1 (S1)		Future Land Cover (%): Scenario 2 (S2)		Future Energy Pr(development ≥ 0.9)		Stream quality (Schueler *et al.* 2009)				
RA	AU	CC	Crops	Urban	Energy	Crops	Urban	Crops	Urban	High Impact (HI)	Low Impact (LI)	Current	S 1 (HI)	S 2 (HI)	S 1 (LI)	S 2 (LI)
NE	ME_07	Low	0.05	0.88	0.00	31.78	1.77	10.57	4	0.00	0.00	S	S	S	S	S
NE	ME_08	High	0.10	1.11	0.00	29.72	1.98	9.5	3.92	0.00	0.00	S	S	S	S	S
NE	ME_09	High	3.26	3.24	0.00	32.43	4.35	13.3	6.73	0.00	0.00	S	S	S/I	S	S/I
NE	ME_13	Very Low	0.11	1.01	0.00	4.58	3.47	1.73	4.15	0.00	0.00	S	S	S	S	S
NE	ME_14	High	0.31	1.18	0.00	9.69	3.07	3.71	4.47	0.00	0.00	S	S	S	S	S
NE	ME_20	Low	0.02	0.24	0.00	1.61	3.59	1.06	3.83	0.00	0.00	S	S	S	S	S
NE	ME_21	Low	0.15	0.84	0.00	0.73	2.21	0.5	2.31	0.00	0.00	S	S	S	S	S
NE	ME_22	Very Low	3.08	1.85	0.00	4.14	5.26	3.26	5.5	0.00	0.00	S	S/I	S/I	S/I	S/I
NE	ME_25	Very Low	2.42	1.15	0.00	5.43	5.91	4.07	6.22	0.00	0.00	S	S/I	S/I	S/I	S/I
NE	ME_26	Medium	0.60	0.95	0.00	2.27	4.03	1.6	4.24	0.00	0.00	S	S	S	S	S
NE	ME_29	Very Low	0.50	2.76	0.00	1.07	7.37	1.83	7.26	0.00	0.00	S	S/I	S/I	S/I	S/I
NE	ME_32	Very Low	6.49	5.09	0.00	6.81	10.86	6.98	10.86	0.00	0.00	S/I	I	I	I	I
NE	ME_35	Very Low	3.70	8.40	0.00	16.31	11.51	9.6	12.7	0.00	0.00	S/I	I	I	I	I
NE	ME_39	Very Low	1.89	11.95	0.00	8.21	18.65	4.28	19.87	0.00	0.00	I	I	I	I	I
NE	ME_40	Very Low	0.54	34.71	0.00	5.41	40.3	2.46	41.18	0.00	0.00	N	N	N	N	N
SE	NC_02	High	0.03	1.41	0.00	1.81	2.68	0.53	3.03	0.00	0.00	S	S	S	S	S
SE	NC_09	Low	0.30	25.97	0.00	17.43	33.63	2.71	35.68	0.00	0.00	N	N	N	N	N
NE	NH_10	Very	2.36	11.02	0.00	11.12	17.92	5.68	19.84	0.00	0.00	I	I	I	I	I

			Current Land Cover (%)			Future Land Cover (%): Scenario 1 (S1)		Future Land Cover (%): Scenario 2 (S2)		Future Energy Pr(development ≥ 0.9)		Stream quality (Schueler *et al.* 2009)				
RA	**AU**	**CC**	**Crops**	**Urban**	**Energy**	**Crops**	**Urban**	**Crops**	**Urban**	**High Impact (HI)**	**Low Impact (LI)**	**Current**	**S 1 (HI)**	**S 2 (HI)**	**S 1 (LI)**	**S 2 (LI)**
		Low														
NE	NH_11	Very Low	1.26	30.83	0.00	6.84	35.42	3.12	36.8	0.00	0.00	N	N	N	N	N
MA	NJ_03	Very Low	3.52	2.90	0.00	3.52	2.93	3.52	2.93	0.00	0.00	S	S	S	S	S
MA	NJ_05	Very Low	6.17	6.76	0.00	2.49	17.23	1.68	17.45	0.00	0.00	S/I	I	I	I	I
MA	NJ_06	Very Low	1.66	14.90	0.00	0.58	24.24	0.43	24.23	0.00	0.00	I	I/N	I/N	I/N	I/N
MA	NJ_08	Very Low	32.50	7.23	0.00	4.02	44.01	4.37	43.95	0.00	0.00	S/I	N	N	N	N
MA	NJ_09	Very Low	15.64	38.93	0.00	1.68	64.27	1.66	64.19	0.00	0.00	N	N/U	N/U	N/U	N/U
MA	NJ_10	Very Low	25.00	15.04	0.00	6.31	37.67	6.82	37.58	0.00	0.00	I	N	N	N	N
MA	NJ_11	Very Low	19.23	13.25	0.00	2.89	48.16	2.97	48.06	0.00	0.00	I	N	N	N	N
MA	NJ_12	Very Low	9.79	49.90	0.00	3.38	66.59	1.91	67.62	0.00	0.00	N	N/U	N/U	N/U	N/U
MA	NY_09	Low	1.02	51.40	0.00	4.51	56.46	2.91	56.73	6.56	0.33	N	N/U	N/U	N	N
MA	NY_10	Low	2.07	15.32	0.02	8.43	24.96	5.38	25.53	2.77	0.14	I	N	N	N	N
MA	PA_01	Very Low	3.58	6.39	0.05	15.96	14.33	7.2	17.77	0.00	0.00	S/I	I	I	I	I
MA	PA_02	Very Low	0.19	3.77	0.00	1.36	5.78	0.65	6.04	0.00	0.00	S	S/I	S/I	S/I	S/I
MA	PA_05	Low	1.12	2.09	0.43	2.57	4.32	1.34	4.82	44.10	2.21	S	N	N	S/I	S/I
MA	PA_07	High	23.18	9.54	0.00	13.02	16.07	8.42	19.65	0.00	0.00	S/I	I	I	I	I

			Current Land Cover (%)			Future Land Cover (%): Scenario 1 (S1)		Future Land Cover (%): Scenario 2 (S2)		Future Energy Pr(development ≥ 0.9)		Stream quality (Schueler *et al.* 2009)				
RA	**AU**	**CC**	**Crops**	**Urban**	**Energy**	**Crops**	**Urban**	**Crops**	**Urban**	**High Impact (HI)**	**Low Impact (LI)**	**Current**	**S 1 (HI)**	**S 2 (HI)**	**S 1 (LI)**	**S 2 (LI)**
MA	PA_08	Very Low	17.69	9.23	0.00	9.21	15.56	6.3	18.3	0.00	0.00	S/I	I	I	I	I
MA	PA_10	Very Low	4.63	6.04	0.00	5.42	9.94	3.64	12.76	0.00	0.00	S/I	S/I	I	S/I	I
MA	PA_11	Very Low	4.07	4.72	0.00	3.89	8.51	1.92	9.77	0.00	0.00	S	S/I	S/I	S/I	S/I
MA	PA_12	Very Low	7.18	5.76	0.00	6.78	10.97	3.2	13.1	0.00	0.00	S/I	I	I	I	I
MA	PA_13	Very Low	5.84	4.34	0.00	6.87	8.36	2.8	10.64	0.00	0.00	S	S/I	I	S/I	I
MA	PA_15	Very Low	11.13	24.40	0.00	5.6	34.55	3.12	40.13	0.00	0.00	I/N	N	N	N	N
MA	PA_16	Very Low	13.51	13.56	0.00	8.82	19.45	5.1	24.65	0.00	0.00	I	I	I/N	I	I/N
MA	PA_18	Very Low	14.04	10.75	0.00	12.09	29.66	5.07	37.14	0.00	0.00	I	N	N	N	N
MA	PA_21	Very Low	21.61	2.60	0.00	13.09	22.9	6.29	27	0.00	0.00	S	I/N	N	I/N	N
MA	PA_24	Very Low	4.83	10.77	0.00	5.41	15.73	2.65	16.85	0.00	0.00	I	I	I	I	I
MA	PA_28	Very Low	5.19	11.65	0.00	4.14	15.12	3.89	15.33	0.00	0.00	I	I	I	I	I
MA	PA_29	Very Low	10.15	9.87	0.00	2.64	20.59	2.04	20.99	0.00	0.00	S/I	I/N	I/N	I/N	I/N
MA	PA_31	Medium	17.83	33.99	0.00	4.97	59.11	4.11	59.21	0.00	0.00	N	N	N	N	N
MA	PA_32	Very Low	34.60	12.31	0.00	11.42	37.09	5.42	44.28	0.00	0.00	I	N	N	N	N

RA	AU	CC	Current Land Cover (%)			Future Land Cover (%): Scenario 1 (S1)		Future Land Cover (%): Scenario 2 (S2)		Future Energy Pr(development ≥ 0.9)		Stream quality (Schueler *et al.* 2009)				
			Crops	Urban	Energy	Crops	Urban	Crops	Urban	High Impact (HI)	Low Impact (LI)	Current	S 1 (HI)	S 2 (HI)	S 1 (LI)	S 2 (LI)
MA	PA_35	Very Low	26.13	21.36	0.00	9.1	44.29	4.4	46.87	0.00	0.00	I/N	N	N	N	N
MA	PA_36	Very Low	11.41	50.14	0.00	5.71	65.77	3.31	67.35	0.00	0.00	N	N/U	N/U	N/U	N/U
SE	SC_01	High	0.20	2.54	0.00	1.19	3.66	0.39	3.75	0.00	0.00	S	S	S	S	S
MA	VA_01	Very Low	3.87	7.48	0.00	20.97	13.78	12.93	14.29	0.00	0.00	S/I	I	I	I	I
MA	VA_02	Very Low	2.06	10.43	0.00	18.79	15.85	10.08	16.43	0.00	0.00	I	I	I	I	I
MA	VA_03	Very Low	0.33	6.74	0.00	8.58	10.64	4.87	10.95	0.00	0.00	S/I	I	I	I	I
MA	VA_04	Very Low	0.39	10.42	0.00	9.55	15.04	5.35	15.4	0.00	0.00	I	I	I	I	I
MA	VA_07	Very Low	11.17	34.81	0.00	12.99	48.62	8	49.48	0.00	0.00	N	N	N	N	N
MA	VA_09	Very Low	7.15	9.62	0.00	35.65	15.43	17.57	16.78	0.00	0.00	S/I	I	I	I	I
MA	VA_10	Very Low	3.40	8.49	0.00	18.74	12.93	9.57	13.67	0.00	0.00	S/I	I	I	I	I
MA	VA_11	Very Low	3.20	10.89	0.00	20.05	14.08	9.27	15.14	0.00	0.00	I	I	I	I	I
MA	VA_12	Very Low	2.05	27.31	0.00	13.9	31.05	5.21	31.68	0.00	0.00	N	N	N	N	N
MA	VA_13	Very Low	4.26	10.67	0.00	19.95	15.21	7.56	16.09	0.00	0.00	I	I	I	I	I
MA	WV_02	Very Low	0.18	2.88	0.00	3.06	9.49	3.16	8.9	0.00	0.00	S	S/I	S/I	S/I	S/I

			Current Land Cover (%)			Future Land Cover (%): Scenario 1 (S1)		Future Land Cover (%): Scenario 2 (S2)		Future Energy Pr(development ≥ 0.9)		Stream quality (Schueler *et al.* 2009)				
RA	**AU**	**CC**	**Crops**	**Urban**	**Energy**	**Crops**	**Urban**	**Crops**	**Urban**	**High Impact (HI)**	**Low Impact (LI)**	**Current**	**S 1 (HI)**	**S 2 (HI)**	**S 1 (LI)**	**S 2 (LI)**
MA	WV_03	Very Low	0.05	1.83	0.00	2.1	6.02	1.88	5.83	0.00	0.00	S	S/I	S/I	S/I	S/I
MA	WV_06	Very Low	0.11	3.77	0.00	4.45	6.72	2.48	7.19	0.00	0.00	S	S/I	S/I	S/I	S/I
MA	WV_11	Very Low	2.60	3.68	0.00	6.24	12.35	5.04	12.09	0.00	0.00	S	I	I	I	I
MA	WV_12	Very Low	9.34	16.66	0.00	13.6	26.73	11.65	26	0.00	0.00	I	N	N	N	N
MA	WV_13	Very Low	1.71	11.30	0.00	9.18	19.55	6.15	20.46	0.00	0.00	I	I	I/N	I	I/N

Table F5. Summary of forecasts for future condition at mid-century. Forecasts were based on projections of development (agricultural, urban, and energy) within each Analysis Unit, estimates of stream quality and current population condition. A simple rule set (Table F3) was used to identify where expert judgement was needed. The likelihood point method was used to distribute 100 points across condition categories reflecting uncertainty in forecasts. Scenario 1 was based on economic conditions favorable to agriculture and Scenario 2 was based on economic conditions favorable to urban development (Lawler *et al.* 2014; Table X). Both scenarios included the high energy impact assumption as previously described.

Region	**AUs**	**Current Condition**	**Future Condition: Scenario 1**				**Future Condition: Scenario 2**			
			HIGH	**MED**	**LOW**	**VERY LOW**	**HIGH**	**MED**	**LOW**	**VERY LOW**
MA	DE_01	Very Low	0	0	0	100	0	0	0	100
MA	MD_04	Very Low	0	0	0	100	0	0	0	100
MA	MD_05	Low	0	0	47	53	0	0	35	65
MA	MD_06	Very Low	0	0	0	100	0	0	0	100
MA	MD_10	Very Low	0	0	0	100	0	0	0	100
MA	MD_11	Very Low	0	0	0	100	0	0	0	100
MA	MD_12	Very Low	0	0	0	100	0	0	0	100
MA	MD_13	Very Low	0	0	0	100	0	0	0	100
MA	MD_14	Very Low	0	0	0	100	0	0	0	100
MA	MD_15	Very Low	0	0	0	100	0	0	0	100
MA	MD_16	Very Low	0	0	0	100	0	0	0	100
MA	MD_17	Low	0	0	50	50	0	0	50	50
MA	MD_18	Very Low	0	0	0	100	0	0	0	100
MA	MD_19	Very Low	0	0	0	100	0	0	0	100
MA	MD_20	Very Low	0	0	0	100	0	0	0	100
MA	NJ_03	Very Low	0	0	0	100	0	0	0	100
MA	NJ_05	Very Low	0	0	0	100	0	0	0	100
MA	NJ_06	Very Low	0	0	0	100	0	0	0	100
MA	NJ_08	Very Low	0	0	0	100	0	0	0	100
MA	NJ_09	Very Low	0	0	0	100	0	0	0	100
MA	NJ_10	Very Low	0	0	0	100	0	0	0	100

Region	AUs	Current Condition	Future Condition: Scenario 1				Future Condition: Scenario 2			
			HIGH	MED	LOW	VERY LOW	HIGH	MED	LOW	VERY LOW
MA	NJ_11	Very Low	0	0	0	100	0	0	0	100
MA	NJ_12	Very Low	0	0	0	100	0	0	0	100
MA	NY_01	Medium	0	48	39	13	0	53	36	12
MA	NY_05	Low	0	0	100	0	0	0	52	48
MA	NY_06	Low	0	0	100	0	0	0	52	48
MA	NY_08	Low	0	3	52	45	0	0	45	55
MA	NY_09	Low	0	0	50	50	0	0	46	54
MA	NY_10	Low	0	0	50	50	0	0	50	50
MA	NY_11	Low	0	0	53	47	0	0	42	58
MA	NY_12	Low	0	0	45	55	0	0	48	52
MA	NY_13	Low	0	0	53	47	0	0	44	56
MA	NY_16	Low	0	0	56	44	0	0	46	54
MA	NY_17	Medium	4	61	28	7	0	58	38	5
MA	NY_18	Medium	4	63	23	10	4	48	38	7
MA	NY_19	Medium	8	57	23	12	8	52	30	10
MA	NY_20	Low	0	0	62	38	0	0	51	49
MA	PA_01	Very Low	0	0	0	100	0	0	0	100
MA	PA_02	Very Low	0	0	0	100	0	0	0	100
MA	PA_03	Medium	0	72	18	10	0	62	24	14
MA	PA_04	High	31	31	24	14	8	4	44	44
MA	PA_05	Low	0	0	50	50	0	0	48	52
MA	PA_07	High	100	0	0	0	80	0	12	8
MA	PA_08	Very Low	0	0	0	100	0	0	0	100
MA	PA_10	Very Low	0	0	0	100	0	0	0	100
MA	PA_11	Very Low	0	0	0	100	0	0	0	100
MA	PA_12	Very Low	0	0	0	100	0	0	0	100
MA	PA_13	Very Low	0	0	0	100	0	0	0	100

Region	AUs	Current Condition	Future Condition: Scenario 1				Future Condition: Scenario 2			
			HIGH	MED	LOW	VERY LOW	HIGH	MED	LOW	VERY LOW
MA	PA_15	Very Low	0	0	0	100	0	0	0	100
MA	PA_16	Very Low	0	0	0	100	0	0	0	100
MA	PA_18	Very Low	0	0	0	100	0	0	0	100
MA	PA_21	Very Low	0	0	0	100	0	0	0	100
MA	PA_24	Very Low	0	0	0	100	0	0	0	100
MA	PA_28	Very Low	0	0	0	100	0	0	0	100
MA	PA_29	Very Low	0	0	0	100	0	0	0	100
MA	PA_30	Low	0	0	44	56	0	0	20	80
MA	PA_31	Medium	0	0	50	50	0	0	48	52
MA	PA_32	Very Low	0	0	0	100	0	0	0	100
MA	PA_35	Very Low	0	0	0	100	0	0	0	100
MA	PA_36	Very Low	0	0	0	100	0	0	0	100
MA	VA_01	Very Low	0	0	0	100	0	0	0	100
MA	VA_02	Very Low	0	0	0	100	0	0	0	100
MA	VA_03	Very Low	0	0	0	100	0	0	0	100
MA	VA_04	Very Low	0	0	0	100	0	0	0	100
MA	VA_07	Very Low	0	0	0	100	0	0	0	100
MA	VA_09	Very Low	0	0	0	100	0	0	0	100
MA	VA_10	Very Low	0	0	0	100	0	0	0	100
MA	VA_11	Very Low	0	0	0	100	0	0	0	100
MA	VA_12	Very Low	0	0	0	100	0	0	0	100
MA	VA_13	Very Low	0	0	0	100	0	0	0	100
MA	WV_01	Medium	0	69	31	0	0	57	41	2
MA	WV_02	Very Low	0	0	0	100	0	0	0	100
MA	WV_03	Very Low	0	0	0	100	0	0	0	100
MA	WV_05	High	62	36	2	0	54	40	6	0
MA	WV_06	Very Low	0	0	0	100	0	0	0	100

Region	AUs	Current Condition	Future Condition: Scenario 1				Future Condition: Scenario 2			
			HIGH	MED	LOW	VERY LOW	HIGH	MED	LOW	VERY LOW
MA	WV_07	Low	0	0	82	18	0	0	59	41
MA	WV_08	Medium	0	78	22	0	0	68	30	2
MA	WV_09	High	74	24	2	0	54	42	4	0
MA	WV_11	Very Low	0	0	0	100	0	0	0	100
MA	WV_12	Very Low	0	0	0	100	0	0	0	100
MA	WV_13	Very Low	0	0	0	100	0	0	0	100
NE	CT_02	Medium	0	92	8	0	0	54	34	12
NE	CT_03	Very Low	0	0	0	100	0	0	0	100
NE	CT_04	Very Low	0	0	0	100	0	0	0	100
NE	CT_05	Low	0	0	71	29	0	0	39	61
NE	CT_06	Very Low	0	0	0	100	0	0	0	100
NE	CT_07	Very Low	0	0	0	100	0	0	0	100
NE	CT_08	Very Low	0	0	0	100	0	0	0	100
NE	CT_09	Very Low	0	0	0	100	0	0	0	100
NE	CT_10	Very Low	0	0	0	100	0	0	0	100
NE	CT_11	Very Low	0	0	0	100	0	0	0	100
NE	MA_01	Medium	0	68	26	4	0	64	32	6
NE	MA_03	Low	0	0	92	8	0	0	54	46
NE	MA_04	Low	0	0	57	43	0	0	45	55
NE	MA_05	Very Low	0	0	0	100	0	0	0	100
NE	MA_06	Medium	0	0	50	50	0	0	48	52
NE	MA_13	Very Low	0	0	0	100	0	0	0	100
NE	ME_01	High	100	0	0	0	96	4	0	0
NE	ME_02	Medium	0	100	0	0	0	96	4	0
NE	ME_03	High	100	0	0	0	100	0	0	0
NE	ME_04	High	100	0	0	0	100	0	0	0
NE	ME_05	Medium	0	100	0	0	0	100	0	0

Region	AUs	Current Condition	Future Condition: Scenario 1				Future Condition: Scenario 2			
			HIGH	MED	LOW	VERY LOW	HIGH	MED	LOW	VERY LOW
NE	ME_06	Medium	0	90	10	0	0	77	23	0
NE	ME_07	Low	0	0	100	0	0	0	100	0
NE	ME_08	High	100	0	0	0	100	0	0	0
NE	ME_09	High	100	0	0	0	100	0	0	0
NE	ME_10	Medium	0	98	2	0	0	78	22	0
NE	ME_11	High	84	16	0	0	70	24	6	0
NE	ME_12	High	94	6	0	0	47	35	16	6
NE	ME_13	Very Low	0	0	0	100	0	0	0	100
NE	ME_14	High	100	0	0	0	100	0	0	0
NE	ME_15	Low	0	0	79	21	0	0	77	23
NE	ME_16	Medium	0	100	0	0	0	88	12	0
NE	ME_17	Low	0	0	96	4	0	0	80	20
NE	ME_18	High	82	4	12	6	42	36	14	8
NE	ME_19	High	67	27	6	0	78	22	0	0
NE	ME_20	Low	0	0	100	0	0	0	100	0
NE	ME_21	Low	0	0	100	0	0	0	100	0
NE	ME_22	Very Low	0	0	0	100	0	0	0	100
NE	ME_23	Medium	0	79	19	2	0	75	21	4
NE	ME_25	Very Low	0	0	0	100	0	0	0	100
NE	ME_26	Medium	0	100	0	0	0	100	0	0
NE	ME_27	Medium	0	76	22	2	0	58	40	2
NE	ME_28	High	86	6	8	0	58	28	12	0
NE	ME_29	Very Low	0	0	0	100	0	0	0	100
NE	ME_30	Low	0	0	72	28	0	0	68	32
NE	ME_32	Very Low	0	0	0	100	0	0	0	100
NE	ME_33	High	94	6	0	0	73	25	2	0
NE	ME_34	High	77	23	0	0	65	33	2	0

Region	AUs	Current Condition	Future Condition: Scenario 1				Future Condition: Scenario 2			
			HIGH	MED	LOW	VERY LOW	HIGH	MED	LOW	VERY LOW
NE	ME_35	Very Low	0	0	0	100	0	0	0	100
NE	ME_36	High	79	21	0	0	73	25	2	0
NE	ME_37	Medium	0	100	0	0	0	72	28	0
NE	ME_38	High	83	17	0	0	67	33	0	0
NE	ME_39	Very Low	0	0	0	100	0	0	0	100
NE	ME_40	Very Low	0	0	0	100	0	0	0	100
NE	NH_02	Medium	0	96	4	0	0	67	25	8
NE	NH_03	Medium	0	100	0	0	0	70	30	0
NE	NH_04	High	98	2	0	0	63	29	6	2
NE	NH_05	Medium	0	94	8	0	0	44	48	8
NE	NH_06	High	100	0	0	0	64	18	12	6
NE	NH_07	Low	0	0	62	38	0	0	44	56
NE	NH_08	Medium	0	96	4	0	0	60	36	4
NE	NH_09	Low	0	0	72	28	0	0	48	52
NE	NH_10	Very Low	0	0	0	100	0	0	0	100
NE	NH_11	Very Low	0	0	0	100	0	0	0	100
NE	VT_02	Medium	0	94	6	0	0	61	37	2
SE	NC_01	Low	0	4	96	0	0	3	86	11
SE	NC_02	High	100	0	0	0	100	0	0	0
SE	NC_03	High	100	0	0	0	81	19	0	0
SE	NC_04	High	100	0	0	0	95	5	0	0
SE	NC_05	High	100	0	0	0	93	8	0	0
SE	NC_06	High	100	0	0	0	59	29	12	0
SE	NC_07	High	100	0	0	0	61	25	14	0
SE	NC_08	Low	0	0	100	0	0	0	59	41
SE	NC_09	Low	0	0	50	50	0	0	46	54
SE	NC_14	Medium	0	100	0	0	0	64	36	0

Region	AUs	Current Condition	Future Condition: Scenario 1				Future Condition: Scenario 2			
			HIGH	MED	LOW	VERY LOW	HIGH	MED	LOW	VERY LOW
SE	NC_15	High	98	2	0	0	83	17	0	0
SE	NC_16	Medium	0	98	2	0	0	72	28	0
SE	NC_20	High	100	0	0	0	60	34	6	0
SE	NC_21	Low	0	0	98	2	0	0	80	20
SE	NC_22	Low	0	0	100	0	0	0	92	8
SE	SC_01	High	100	0	0	0	100	0	0	0
SE	SC_02	Low	0	6	65	29	0	0	49	51
SE	SC_03	Medium	2	84	14	0	0	71	25	4
SE	SC_04	Medium	2	84	14	0	0	80	20	0