Species Status Assessment (SSA) Report
For the
Cobblestone Tiger Beetle
(*Cicindela marginipennis*)
Version 1.1

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U.S. Fish and Wildlife Service
Northeast Region
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Species Status Assessment Report for the
Cobblestone Tiger Beetle (*Cicindela marginipennis*)

EXECUTIVE SUMMARY

This report summarizes the results of a species status assessment (SSA) conducted for the cobblestone tiger beetle (*Cicindela marginipennis* Dejean (1831)). This SSA was conducted to compile the best scientific and commercial data available regarding the species' biology and factors that influence the species' viability.

The decision whether to list a species is based not on a prediction of the most likely future for the species, but rather on an assessment of the species' risk of extinction. To inform this assessment of extinction risk, we describe the species' current biological status and assess how this status may change in the future under a range of scenarios to account for the uncertainty of the species' future. We evaluate the current biological status of the cobblestone tiger beetle (CTB) by assessing the primary factors negatively and positively affecting the species to describe its current condition in terms of resiliency, redundancy, and representation (3Rs). We then evaluate the future biological status of the CTB by describing three plausible future scenarios representing a range of conditions for the primary factors affecting the species and forecasting the most likely future condition for each scenario in terms of the 3Rs. These scenarios do not include all possible futures, but rather include specific plausible scenarios that represent examples from the continuous spectrum of possible futures. As our analytical unit (AU), we chose the USGS 10-digit Hydrologic Unit Code HUC (HUC10) watershed that comprises a river reach (part of a larger basin) and its tributaries for the United States CTB populations and the National Hydro Network (NHN) watershed units to represent the Canadian CTB populations. In 3 states we only had data to determine the county in which the CTB occurred and used these counties as AUs.

The historical range of the CTB has been recorded from New Brunswick, Canada into the United States with populations in Maine, New Hampshire, Vermont, Massachusetts, New York, New Jersey, Pennsylvania, West Virginia, Indiana, Ohio, Kentucky, Alabama, and Mississippi, in riverine habitats with cobble substrates. The exception is the Grand Lake, New Brunswick population that occurs along similar substrates on the lake's shoreline.

There are a total of 45 AUs throughout the range. Of these, 27 AUs (60 percent) are considered to be extant, including 2 AUs of unknown status, and 18 AUs (40 percent) are considered to be historical or extirpated. The 2 unknown AUs are still considered extant populations, but they are designated as "unknown" because it is not known if the lack of observations is due to population extirpation or low detectability. Historical presence has been recorded in 40 HUC10 watersheds and 3 counties in the United States and 2 NHN watersheds in Canada (a total of 45 analytical units). Current distribution records (last 20 years) show occupation of 24 of the 40 historical HUC10s, 1 of the 3 counties, and 2 NHN watersheds.

Survey data vary widely due to different monitoring objectives and the lack of a standardized survey protocol for the species. Extant population surveys have recorded CTB numbers ranging from 1 to 5 individuals to over 100 individuals. Most surveys have not provided a population estimate. In general, most populations are considered to be small and estimated to rarely exceed

60 individuals at a site with the exception of locations in Alabama, Maine, and Canada.

The CTB life history is not well known, but is described as being similar to other diurnal summer-active tiger beetle species. The species likely has a 2-year life cycle with the potential for a 3-year cycle in northern parts of its range. After mating, females most likely deposit fertilized eggs in mid-summer in open sandy areas between cobblestones. The CTB larvae dig burrows in the sand and overwinter in the burrows, where they complete multiple larval stages.

The CTB can be found on both shoreline cobble bars and cobble islands. The majority of occupied sites are on cobble bars associated with islands. In the U.S., the CTB occurs along rivers where the currents are strong enough to scour shorelines and mid-channel bars, creating and maintaining cobble bars. Periodic scouring by high flows also prevents the establishment of dense vegetation on the riverine cobble bars. The CTB occurs in similar habitat along the shorelines of Grand Lake in New Brunswick, Canada, a lake closely tied to hydrological effects from the St. John River. CTB habitat usually consists of cobblestones and coarse gravel with small patches of sand, as well as areas of loose, mixed-size cobbles. In general, vegetation observed at occupied sites is sparse and low growing with low species richness. One of the driving forces behind natural cobble habitat maintenance is the occurrence of seasonal flooding. Spring freshets, flooding, and/or ice scour are all thought to be beneficial to maintaining CTB habitat by removing encroaching vegetation and exposing cobble. Habitat along the shoreline of Grand Lake is maintained by wave action during spring flooding.

There is very little information on population demographics for the CTB. Many of the tiger beetle taxa demographics are based on a metapopulation structure, most likely due to the dynamic environments in which they are found. Because the CTB cobble bar habitat is found in hydrologic regimes that undergo periods of intense scouring or flooding that create, maintain, and occasionally destroy the habitat, we consider this species needs a metapopulation structure in order to persist.

The following conditions are needed to support self-sustaining populations:

Suitable Habitat: To provide for breeding, sheltering and feeding, the CTB needs riverine or riverine-like cobble bars associated with shorelines or islands that are sparsely vegetated with native shrubs and vegetation.

Maintenance of Hydrological Processes: Cobblestone tiger beetle habitat is created and maintained by natural hydrological disturbances, including ice scour, spring freshets and flooding. Vegetation density may be reduced by scour, and sand and suitable cobbles may be deposited during flood events.

Connectivity of Populations: Populations typically consist of site clusters -- multiple populations located within 500 meters or less -- suggesting a metapopulation structure. For CTB populations to be self-sustaining, suitable habitat must occur within the species' dispersal distance of 500 meters.

We evaluate the species' needs in terms of the resources and/or the circumstances that support the redundancy and representation of the species. Specific to the CTB, redundancy is evaluated by the presence of multiple, self-sustaining metapopulations distributed throughout its range. Therefore, we evaluate the redundancy of the CTB based on the number of populations within a metapopulation and whether the AUs consist of metapopulations or isolated populations. Specific to the CTB, representation is evaluated based on the presence of multiple metapopulations spread across the range.

Our analysis of the past, current, and future influences on what the CTB needs for long term viability revealed that there are 2 influences that pose the largest risk to the viability of the species. These risks are primarily related to changes in the natural hydrological regime and the effects of climate change. Other stressors we evaluated include water quality impacts, recreation, and collection. We also analyzed conservation efforts.

The riparian ecosystem in which CTB habitat occurs evolved in a natural system of seasonal floods, ice scour, erosion, and accretion. CTB habitat appears to be largely dependent upon the flow regimes that allow for spring flooding or ice scour and preclude prolonged inundation of adult or larval CTB habitat. Dams that alter the natural flow regime may reduce the size of metapopulations, resulting in isolated populations or extirpation.

Habitat loss may also result from changes in land use, particularly as forested or agricultural lands are converted to residential or commercial uses. The loss of vegetated buffers along the shoreline, sediment loading from construction, and run-off from impervious surfaces may alter cobble bars through siltation. The water quality stressors of primary concern are excess nutrients and silt deposits on CTB habitats which could enhance vegetative growth, Currently no AUs are listed by U.S. states as impaired by sedimentation. Water quality concerns may become more severe in the future in 4 AUs with the largest projected increase in urbanization.

Climate change is projected to result in increased annual temperatures throughout the range by mid- and late-century, using Representative Concentration Pathways (RCPs) 8.5 and 4.5. The projected increases in winter temperatures for the northern states could affect the timing of river and lake freeze-up and breakup. Higher water and air temperatures in the fall and spring could combine to delay the time of first ice-formation (fall) and advance the time of first ice break-up (spring). Thus, there are predictions for increased springtime flooding. In many northern states, the predictions are for a greater than 15 percent increase in winter precipitation by mid-century and a 20 to 30 percent increase by the end of the 21st century, largely as rain. More intense and extended summer drought is predicted throughout the range, especially in the midwest and south. Throughout, there will be a greater frequency of extreme precipitation events.

These climate changes are likely to affect CTB life stages and habitat in several ways. Summer extreme heat may approach the species' thermal tolerance limit for survival of larvae. Lessened ice scour could allow vegetation to become established to a level that is unsuitable for larval burrowing. Prolonged flooding could extend past the period that larvae can tolerate. In the summer, larval burrow habitat may become too dry because of more intense and extended drought.

Collection, disease, predation, and sand and gravel mining do not appear to be occurring at a level that affects the species overall. Recreational impacts (through ATV use) have been documented in 3 AUs; however, we do not have information to indicate that these impacts are currently affecting the CTB at a species level.

There are no species-specific actions or strategies dedicated to CTB conservation. The species benefits from general conservation strategies that are outlined in state wildlife action plans and when it occurs on conservation or public lands that are protectively managed for natural resources.

Resiliency describes the ability for a species to withstand environmental or demographic stochastic events. This is generally informed by looking at the health of each population throughout the range. We examined habitat and demographic metrics to analyze AU resiliency and assigned resiliency categories (high, moderate, and low) based on a scoring matrix. There are 13 AUs with a High resiliency category, 9 AUs with a Moderate resiliency category, 3 AUs with a Low resiliency category, and 2 AUs considered Status Unknown. Although the majority of the extant AUs received a designation of High, there was a loss of 40 percent of the historical AUs leading us to designate the overall current CTB resiliency as Moderate.

Redundancy describes a species' ability to withstand catastrophic events. This is usually informed by the number of resilient populations and their distribution throughout the range. Evidence suggests that CTB populations were once more broadly distributed throughout the species' historical range. Whereas the overall range of the CTB has not changed significantly, it has lost populations throughout its range. Since 40 percent of the AUs are historical or extirpated, the population distribution of the extant AUs has become more disjunct throughout the range. Despite the rangewide reduction in AUs, we found 16 extant metapopulations, most of which are located in the northern part of the range. The presence of metapopulations within the extant AUs indicates there is sufficient suitable habitat available to maintain multiple, closely situated populations, an important factor for this species as it is genetically adapted to colonize habitat patches.

Identifying and evaluating representative units that contribute to a species' adaptive potential are important components of assessing overall species' viability. Representation describes the ability of a species to adapt to changing environmental conditions over time and is characterized by the breadth of genetic and environmental diversity within and among populations. Representation for the CTB can be described in terms of variability among latitudes and physiographic provinces. Although overall the physiographic regions may differ with respect to ecosystem types, geomorphology and climate, the basic habitat requirements do not vary. The historical CTB range spans from New Brunswick, Canada to Alabama, representing 7 physiographic provinces. The current CTB range remains in 5 of the 7 physiographic provinces. Therefore, the species maintains some adaptive potential and variability amongst its populations against catastrophic events.

To capture the uncertainty associated with the degree and extent of potential future conditions and their impacts on the CTB, each of the 3Rs were assessed using three plausible future scenarios. The CTB faces risks from the operation and construction of dams, the effects of climate change, and loss or destruction of habitat (resulting from development, bank stabilization activities, recreational impacts, and invasive vegetation). These risks play a large role in the future viability of the CTB. If AUs lose resiliency, they are more vulnerable to extirpation, with resulting losses in representation and redundancy. We present 3 plausible scenarios to forecast future conditions for the forecast periods of 2050 and 2080. Scenario A is a continuation scenario in which the influencing factors are projected to change in a similar manner as in the present day. Climate change projections are based on RCP8.5, the higher emissions pathway. Scenario B is a scenario in which the influencing factors change on a trajectory that is different than the continuation scenario, largely due to conservation actions that may partially counteract some projected adverse effects. Climate change projections are based on RCP4.5. Scenario C is a scenario in which some of the influencing factors would change to a greater extent than under Scenario A, largely due to a lack of conservation actions.

Under Scenario A, the recent changes and trends affecting CTB habitat and populations extend with the same trajectory through the two forecast periods. Under Scenario A we expect the CTB's viability to be characterized by continued resiliency, representation, and redundancy. Through 2080, 7 of the 27 currently extant AUs remain in High condition, 14 AUs will be in Moderate condition, and 2 AUs will be in Low condition. We project that 4 AUs will go from either a Low or Unknown current condition to Extirpated by 2080.

With Scenario B, climate change would be forecast to proceed along a scenario that takes into a lower path of temperature change, where drought would be less severe and shorter than is projected under Scenario A. Under Scenario B we expect the CTB's viability to be characterized by continued resiliency, representation, and redundancy. Through 2080, 15 of the currently extant 27 AUs will be in High condition, 14 AUs will be in Moderate condition, and 5 AUs will be in Low condition. We project that all of the current AUs will persist. Seven AUs, that are currently considered extirpated, will be restored either by natural repopulation or translocation, and have an overall Moderate condition, resulting in a range expansion and increased redundancy, compared to the current condition.

With Scenario C, some changes are projected to occur that would be detrimental to CTB habitats and populations compared with Scenarios A and B. Under Scenario C we expect the CTB's viability to be characterized by a loss in resiliency, representation, and redundancy. Through 2080, 1 of the 27 currently extant AUs will remain in High condition, 18 AUs will be in Moderate condition, and 2 AUs will be in Low condition. We project that 6 AUs will go from either a Low, Moderate, or Unknown current condition to Extirpated by 2080.

3Rs	Needs	Current Condition	Future Condition	
Resiliency (Large populations able to withstand stochastic events)	● Sparsely vegetated island or shoreline cobble bars of 1,750 to 76,100 sf ● Naturally maintained ecosystem with seasonal flood or ice scour events to maintain sparse vegetation, generally less than 10% cover ● Lack of invasive non-native vegetation ● Unembedded cobble substrate with moist interstitial sand – 6 to 30 percent suitable sand component ● Minimal long-term inundation (less than 12 days)	● 18 Historical/Extirpated AUs ● AU Resiliency: ○ High - 13 ○ Moderate - 9 ○ Low – 3 ○ Unknown - 2	● Scenario A - 2050 ○ High - 10 ○ Moderate - 12 ○ Low – 2 ○ Historical/Extirpated -21 ● Scenario B - 2050 ○ High - 14 ○ Moderate - 8 ○ Low – 5 ○ Historical/Extirpated -18 ● Scenario C - 2050 ○ High - 4 ○ Moderate - 17 ○ Low – 1 ○ Historical/Extirpated -23	● Scenario A - 2080 ○ High - 7 ○ Moderate - 14 ○ Low – 2 ○ Historical/Extirpated -22 ● Scenario B - 2080 ○ High - 15 ○ Moderate - 14 ○ Low – 5 ○ Historical/Extirpated -11 ● Scenario C - 2080 ○ High - 1 ○ Moderate - 18 ○ Low – 2 ○ Historical/Extirpated -24
Redundancy (Number and distribution of populations to withstand catastrophic events)	● Multiple resilient populations with each AU ● At least metapopulation within each AU	● Current range more disjunct with loss of 18 AUs: ○ 19 AUs contain metapopulations ○ Four metapopulations span two AUs ○ One AU contains two metapopulations ● Majority of the metapopulations are found in the northern portion of the range	● Scenario A by 2080 ○ Loss of 2 metapopulations ○ Both metapopulations lost contained two populations and had a geographic range <1 mile ○ Both extirpations occur in the Northern portion of the range ● Scenario B by 2080 ○ No loss of metapopulations ○ Projected restoration of 9 AUs ○ Restored AUs located throughout the Northern, Central, and Southern portions of the range ● Scenario C by 2080 ○ Loss of 2 metapopulations ○ Extirpations occur in the Northern, Central, and Southern portion of the range	

3Rs	Needs	Current Condition	Future Condition
Representation (Genetic and ecological diversity to maintain adaptive potential)	● Ecological variation exists due to latitudinal variability	● Historical: Representation in 7 physiographic provinces ● Current: Representation is in 5 physiographic provinces ● One province (Piedmont) is lost from the current range ● One province (Valley and Ridge) has unknown status ● Majority of the extant AUs are found within the New England province	● Scenario A by 2080 ○ Four physiographic provinces will maintain representation ○ Loss of representation within the St. Lawrence Valley and Valley and Ridge provinces ● Scenario B by 2080 ○ Seven physiographic provinces will maintain representation ○ Both current and historical physiographic provinces will have representation ○ Increased representation in New England (two AUs), Piedmont (one AU), Appalachian Plateau (one AU), and Central Lowland (two AUs) ● Scenario C by 2080 ○ Four physiographic provinces will maintain representation ○ Decrease in representation of 3 physiographic provinces ▪ Coastal Plain (one AU) ▪ Appalachian Plateau (one AU) ▪ New England (one AU) ○ Loss of representation within the St. Lawrence Valley and Valley and Ridge provinces

Summary results for the Cobblestone Tiger Beetle Species Status Assessment

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Chapter 1 Introduction

1.1 Background

This report summarizes the results of a species status assessment (SSA) conducted for the cobblestone tiger beetle (*Cicindela marginipennis* Dejean (1831)). In 2010, we, the U.S. Fish and Wildlife Service (Service) received a petition to list 404 aquatic, riparian and wetland species, including the cobblestone tiger beetle (CTB), as endangered or threatened species under the Endangered Species Act of 1973, as amended (Act) (Center for Biological Diversity 2010, pp. 1–66, 243–245). In 2011, the Service made a substantial 90-day petition finding for 371 species, including the CTB, indicating that listing may be warranted (76 FR 59836 September 11, 2011). A subsequent complaint for not meeting the statutory petition finding deadlines was filed on August 5, 2016. Per a court approved settlement agreement, we agreed to send a 12-month petition finding for the CTB to the *Federal Register* by September 30, 2019. Thus, we conducted an SSA to compile the best scientific and commercial data available regarding the species' biology and factors that influence the species' viability (Smith *et al.* 2018 entire).

1.2 Analytical Framework

The SSA report, the product of conducting an SSA, is intended to be a concise review of the species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA report to be easily updated as new information becomes available, and to support all functions of the Endangered Species Program. 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 Act.

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

Using the SSA framework (Figure 1), we consider what a species needs to maintain viability by characterizing the biological status of the species in terms of its **resiliency**, **redundancy**, and **representation** (together, the 3 Rs) (Smith *et al.* 2018, entire). For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in natural ecosystems within a biologically meaningful timeframe: in this case, 30 to 60 years. We chose 30 to 60 years due to this timeframe representing multiple CTB generations (e.g., a 2-year cohort life history, see section 2.2) and because the available data allow us to reasonably predict the potential significant effects of stressors within the range of the CTB during this timeframe.

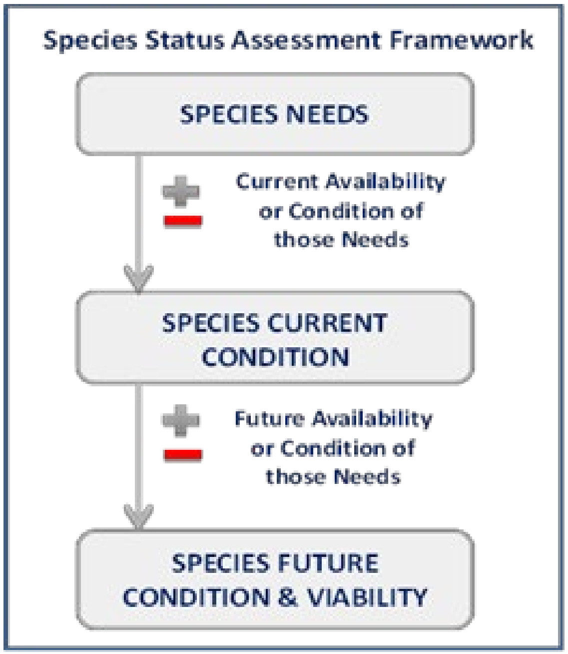

Figure 1. Species Status Assessment Framework

We define resiliency, redundancy, and representation as follows:

- **Resiliency** describes the ability of a species to withstand stochastic disturbance (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size, if that information exists. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of human activities.

- **Redundancy** describes the ability of a species to withstand catastrophic events. A catastrophic event is defined here as a rare, destructive event or episode involving multiple populations and occurring suddenly. Redundancy is about spreading the risk and can be measured through the duplication and distribution of populations across the range of the species. Generally, the greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.

- **Representation** describes the ability of the species to adapt to changing environmental conditions over time. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. Theoretically, the more representation the species has, the higher its potential of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics within the geographical range.

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

Analytical Units

As our analytical unit (AU), we chose the USGS 10-digit Hydrologic Unit Code HUC (HUC10) watershed that comprises a river reach (part of a larger basin) and its tributaries for the United States' CTB populations and the National Hydro Network (NHN) watershed units to represent the Canadian CTB populations. We determined that the HUC10 and NHN geographic level of analysis would be at an appropriate scale to map CTB populations without providing sufficient detail to pinpoint occupied locations, thus preventing unwanted collection of CTBs or habitat vandalism. HUC10 units were also small enough that we could identify site-specific stressors affecting CTB populations. In a few cases, the data provided for CTB occurrences were insufficient to determine the HUC unit in which the species was found (e.g. Kentucky, Mississippi). The AUs for those locations were assigned at the county level. The Canadian NHN units are larger than the HUC10 units, but there was no other equivalent geographic unit available for our analyses of Canadian populations. With respect to describing specific CTB sites, we use the words "site" and "location" interchangeably as the specific area where CTBs have been documented. If at least one CTB was found in a survey, it is defined as an occurrence.

Chapter 2 Species Information

2.1 Taxonomy and Species Description

The CTB is a member of the Order Coleoptera, Family Carabidae, and subfamily Cicindelinae. Adults are approximately 11 to 14 millimeters (mm) (0.4 to 0.6 inches (in)) in length and have large mandibles used to capture prey. The elytra (hardened forewings) are a dull olive with a cream-colored border. The abdomen is a bright red-orange that is exposed when the elytra are spread (Pearson *et al.* 2006, p. 133; Committee on the Status of Endangered Wildlife in Canada (COSEWIC) 2008, p. iv) (Figure 2). In the disjunct southern populations of Alabama, individuals tend to be larger and browner than those in the northeastern populations (Pearson *et al.* 2006, p. 133). This has led some to think these populations could represent a subspecies (Holt 2017; Knisley 2017). These relationships will be evaluated as part of a preliminary rangewide population genetic analysis, funded by the Service, which will be completed by the end of 2019 and will assess whether the Alabama populations are the same species or a subspecies. The study will investigate measures of intra-specific diversity, population structure, and geographic variation. Pending the results of the study and for the purposes of this assessment, we accept the current nomenclature of a single species (*Cicindela marginipennis*).

Figure 2. Adult cobblestone tiger beetle (USFWS photo)

2.2 Range and Distribution

The historical range of the CTB has been recorded from New Brunswick, Canada into the United States with populations in Maine, New Hampshire, Vermont, Massachusetts, New York, New Jersey, Pennsylvania, West Virginia, Indiana, Ohio, Kentucky, Alabama, and Mississippi (Figure 3; Table 1), in riverine habitats with cobble substrates. The exception is the Grand Lake, New Brunswick population that occurs along similar substrates on the lake's shoreline (COSEWIC 2008, p. 9).

There are a total of 45 AUs throughout the range, with 27 considered to be extant (including the 2 unknowns) and 18 considered to be historical or extirpated. Historical presence in the U.S. has been recorded in 40 HUC10 watersheds and 3 counties (Table 1). Current distribution records (last 20 years) show occupation of 24 of the 40 historical HUC10s and 1 of the 3 counties. There are extant populations in two NHN watersheds in Canada. Populations reported from Mississippi (two counties) and Massachusetts (one HUC10) are considered extirpated due to the documented loss of previously occupied habitats (Tennessee Valley Authority 2006, p. 30; MassWildlife 2017). Two AUs (Flat Brook-Delaware River and Raymondskill Creek-Delaware River) have zero beetle observations in the last 7 years, despite multiple surveys. These AUs are still considered extant populations, but they are designated as "unknown" because it is not known if the lack of observations is due to population extirpation or low detectability.

It is difficult to ascertain with certainty whether a population is extirpated or historical. We considered a time frame of approximately 10 generations equating to approximately 20 years (for a 2-year life cycle) for our frame of reference when determining whether a CTB site is extant, historical, or extirpated. If there were no CTB observations during surveys conducted over the past 20 years, we considered that there was little likelihood that the species was present. Accordingly, we considered the following rankings (in part following the NatureServe definitions (NatureServe 2018)):

- a population is considered to be <u>extant</u> if CTB were documented at least once within the last 20 years;
- a population is considered <u>unknown</u> if it is not known whether the lack of CTB observations in one or more surveys conducted within the last 20 years is due to population extirpation or low detectability;
- a population is considered to be <u>historical</u> (Possibly Extirpated per NatureServe definition) if its presence has not been verified in the past 20 years despite exhaustive searches; the only known occurrences were destroyed; or if it had been extensively and unsuccessfully looked for and not found; and
- a population is considered to be <u>extirpated</u> if it has not been located despite intensive searches of historical sites and other appropriate habitat, and there is virtually no likelihood that it will be rediscovered.

In the absence of consistent surveys and site-specific data for the CTB, it is difficult to distinguish whether a population should be considered extirpated or historical. Therefore, we combined these categories into extirpated/historical (Figures 3 – 5).

Survey data vary widely due to different monitoring objectives and methods since there is no standardized survey protocol for the species at this time. Extant population surveys have recorded CTB numbers ranging from 1 to 5 individuals to over 100 individuals. Most surveys have not provided a population estimate. In general, most populations are considered to be small and estimated to rarely exceed 60 individuals at a site with the exception of locations in Alabama (Holt 2018b), Maine (Mays and Ward 2013) and Canada (COSEWIC 2008).

Table 1. Presence/Absence Status of the CTB Analytical Units

State/ Province	Extant AUs	Historical/Extirpated AUs	Status Unknown AUs
Alabama	Mill Creek/Cahaba River, Upper Cahaba River, Soapstone Creek/Alabama River	Weoka Creek/Coosa River	
Indiana	Pipe Creek/Whitewater River	East Fork Whitewater River	
Indiana/Ohio	Whitewater River		
Kentucky	McCreary County		
Maine	Lower Carrabassett River, Middle Carrabassett River		
Massachusetts		Lower Deerfield River	
Mississippi		Clay County, Tombigbee River/ Lowndes County	
New Hampshire	Upper Pemigewasset River, Middle Pemigewasset River		
New Hampshire/Vermont	Mill Brook-Connecticut River, Vernon Dam- Connecticut River		
New Jersey/ Pennsylvania		Lower Delaware River Upper Delaware River	Raymondskill Creek/Delaware River, Flat Brook/Delaware River
New York	Outlet Silver Lake/Genesee River, Cold Creek/Genesee River, Caneadea Creek/Genesee River, Cattaraugus Creek, Headwaters Cattaraugus Creek	Saw Mill River/Hudson River	
New York/ Pennsylvania		Middle Delaware River	
Ohio	Taylor Creek/Great Miami River	Kinnikinnick Creek/Scioto River, Ralston Run/Paint Creek, Headwaters Todd Fork	
Ohio/West Virginia	French Creek/Ohio River	Little Sandy Creek/Ohio River Little Hocking River/Ohio River	
Pennsylvania	Allegheny River	Susquehanna River (0205030510), Susquehanna River (0205030617), Middle Schuylkill River	
Vermont	Winooski River, White River, Rock River - West River		
West Virginia		Upper Monongahela River	
New Brunswick, CA	01AO000 (Grand Lake) 01AJB00 (Saint John River)		

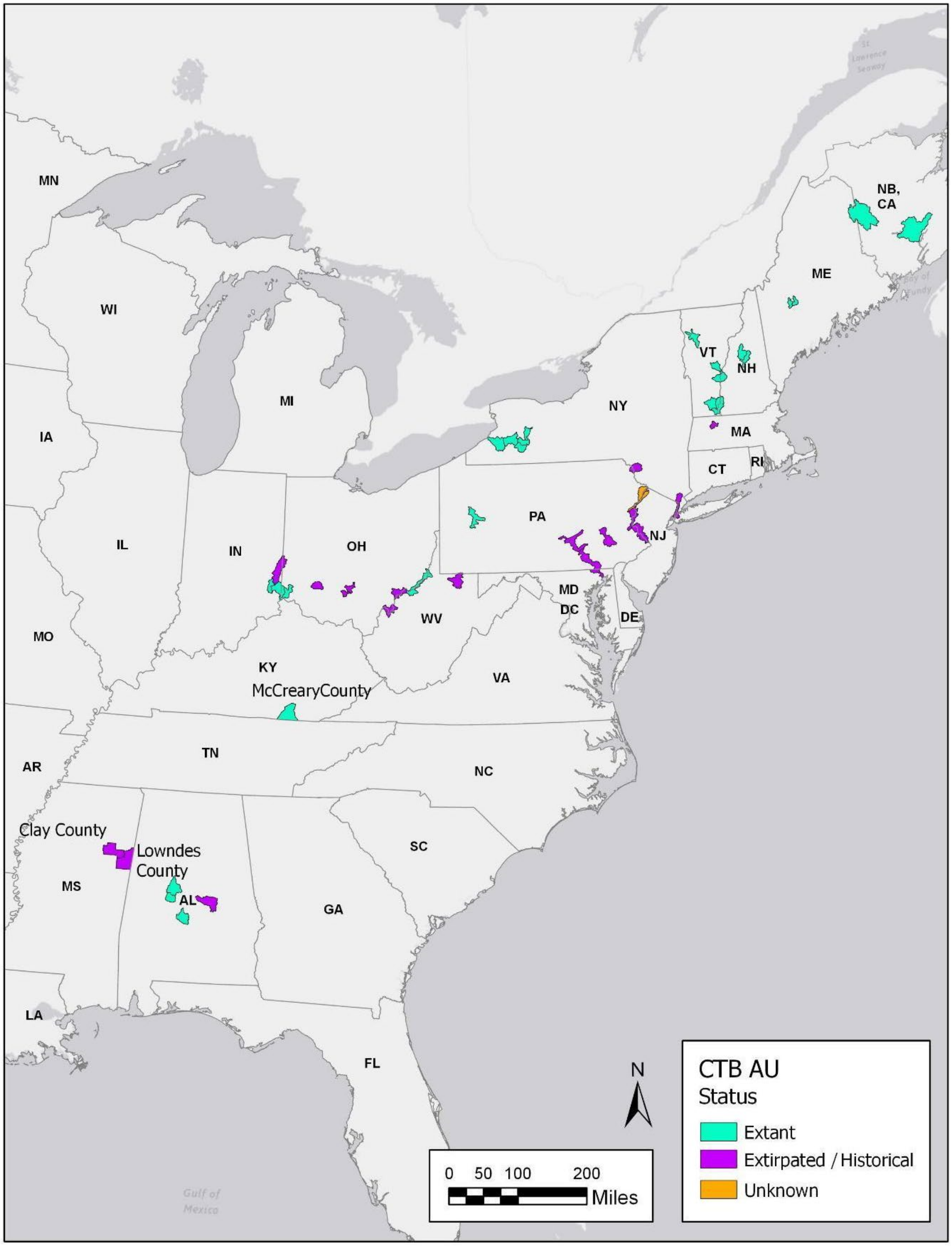

Figure 3. Extant and historical or extirpated CTB AUs: entire range

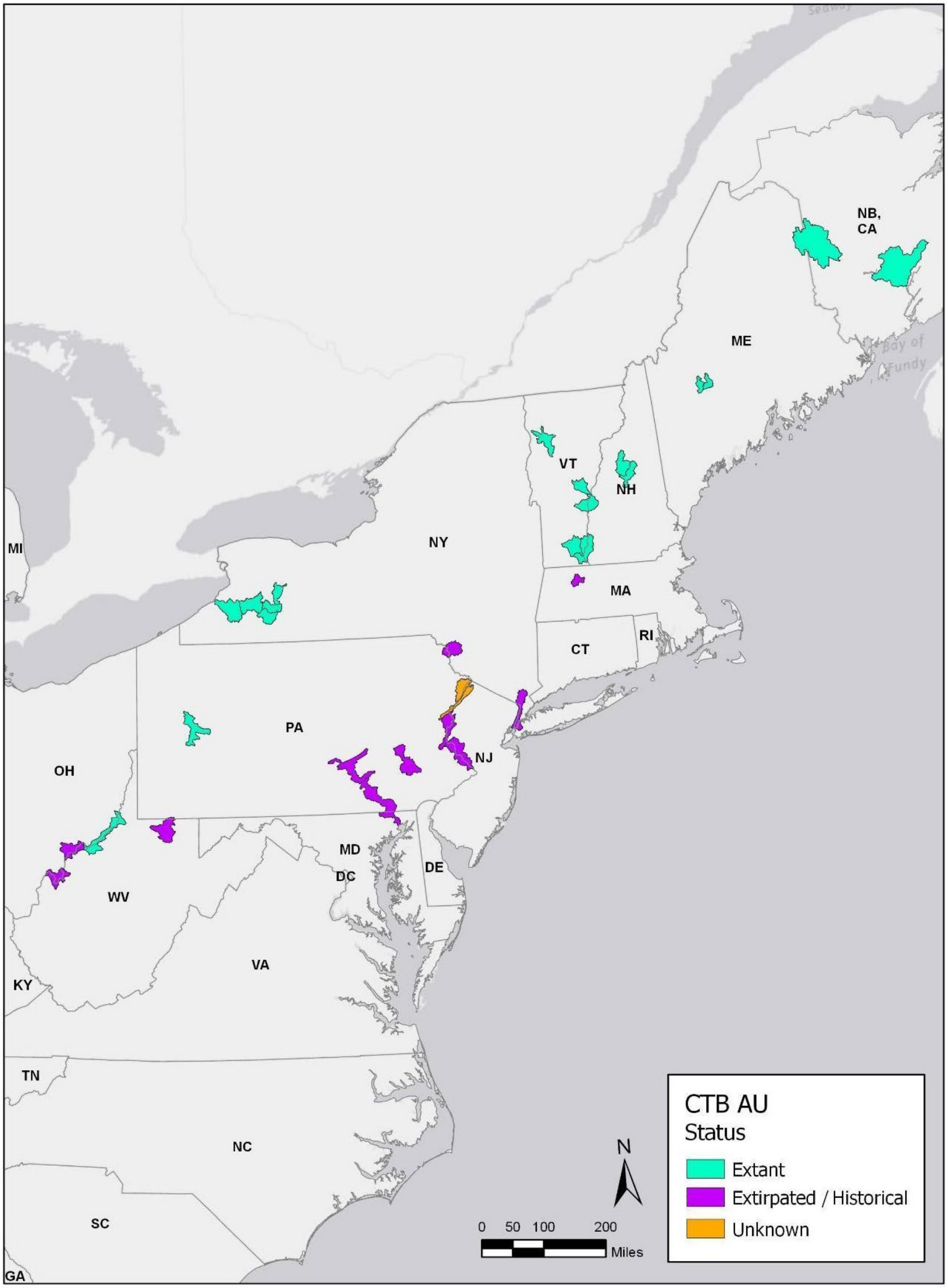

Figure 4. Extant and historical CTB AUs: Northern United States and New Brunswick, Canada

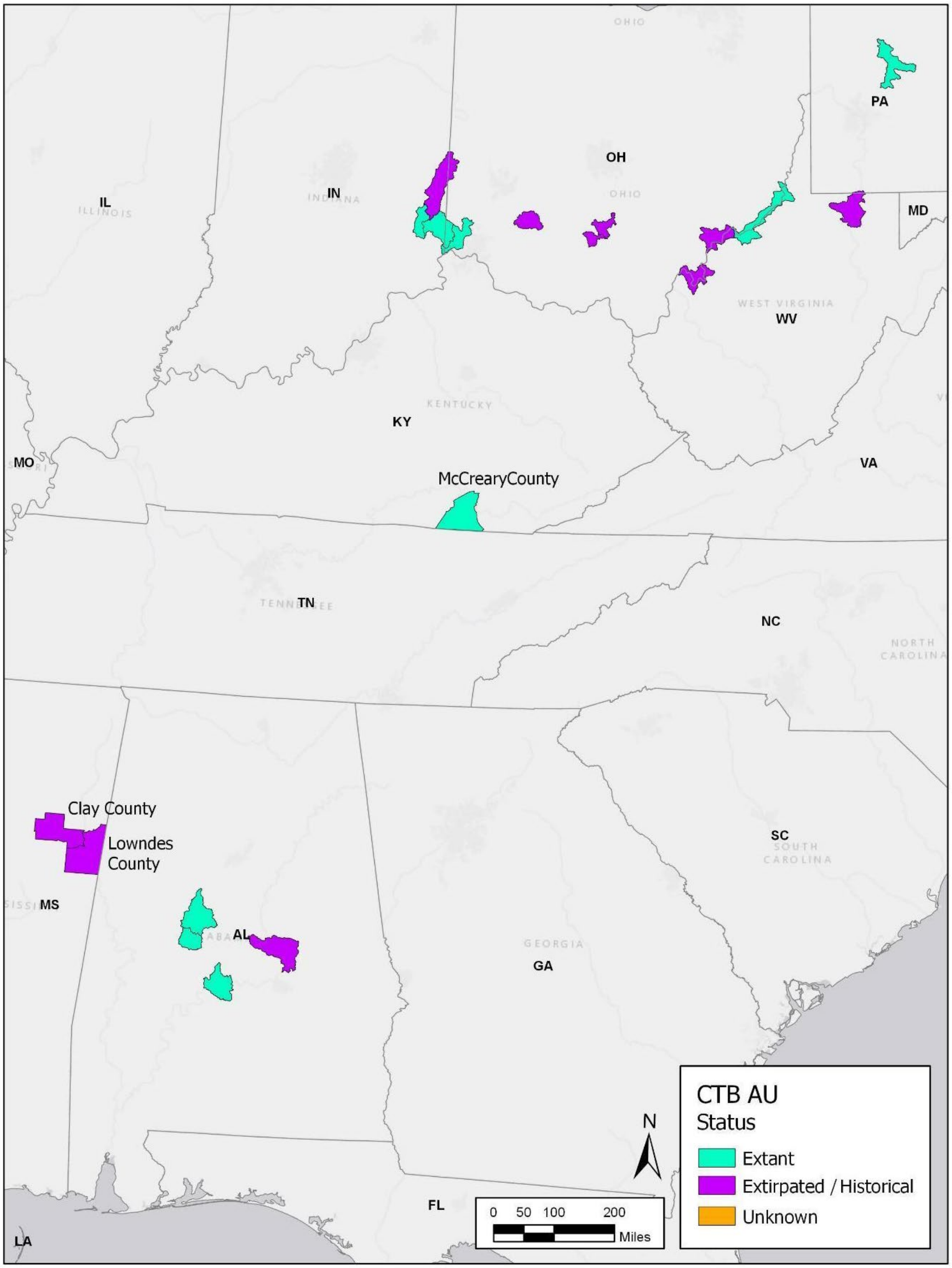

Figure 5. Extant and historical CTB AUs: Midwest and Southeastern United States

2.3 Life History

The CTB life history is not well known, but is described as being similar to other diurnal summer-active tiger beetle species. The species likely has a 2-year life cycle with the potential for a 3-year cycle in northern parts of its range (Knisley 2018a (see Figure 6)). Emergence of adults varies by location and temperature (Vermont Fish and Wildlife Department (VTFWD) 2011, p. 5), but generally occurs in late June with peak abundance in early to mid-July (Acciavatti 2001, p. 9). Adults then engage in mating and egg laying activities until early September (Allen and Acciavatti 2002, p. 26). Adults do not live past their first summer (Hudgins 2010, p. 68).

The life cycle of the CTB is thought to be similar to other tiger beetle species (Pearson 1988, p. 129; Knisley 2018c). After mating, females most likely deposit fertilized eggs in mid-summer in open sandy areas between cobblestones (Hudgins 2010, p. 69) and likely deposit single eggs up to one centimeter below the surface of the soil. Based on the traits of other tiger beetle species, it is likely that the CTB can lay 10 to 20 eggs per day (COSEWIC 2008, p. 14). Most likely, the CTB larvae dig burrows in open stretches of moist sand in the upper beaches above the strand of cobble. There, the larva use ambush tactics to feed on small insects and spiders (COSEWIC 2008, p. 13). Larvae are known to anchor themselves to the walls of their burrows and wait for prey to come within striking distance, seizing the prey with sickle-shaped mandibles (Valenti and Gaimari 2000, p. 3).

Tiger beetles may have multiple larval stages (instars). Generally, the newly hatched larvae (first instars) transition to larger larvae (second instars) within the same season. For 2-year life cycles, the second instar will over winter the first year. The following summer, the second instar molts into a larger larvae (third instar). The third instar over winters (year 2), entering a pupal stage the following summer where it remains immobile in the pupal cell until emerging as an adult (Webster 2018) (Figure 6).

The CTB larval stages have not yet been taxonomically described (Normandeau Associates Inc. 2016, p. 18; Knisley 2018a). Some survey reports document two larval cohorts in the late spring before pupation, and suggest that the CTB has a 2-year life cycle (Acciavatti 2001 pp. 8-9). There is some uncertainty about this given that the larvae have not been described and observations could have been of larvae from another co-occurring species (e.g. the bronzed tiger beetle (*C. repanda*)). Should these observations be correct, we would assume the CTB has a 2-year life cycle as outlined in Figure 6, since the larvae will survive two winters before pupating and emerging as adults in the third summer of their life cycle. The Service funded a lab-based taxonomic study of the larvae, to be completed in 2019, to describe the three larval stages for field identification. This research will determine the duration of the life cycle and where CTB larval habitat occurs by locating and verifying CTB larvae in the field.

Larval development can be affected by limited food availability or the effects of severe weather, including unusually cold or hot temperatures or prolonged inundation.. Depending on the severity of these impacts, larval development could extend an additional year extending adult emergence into a fourth summer (Knisley 2018b).

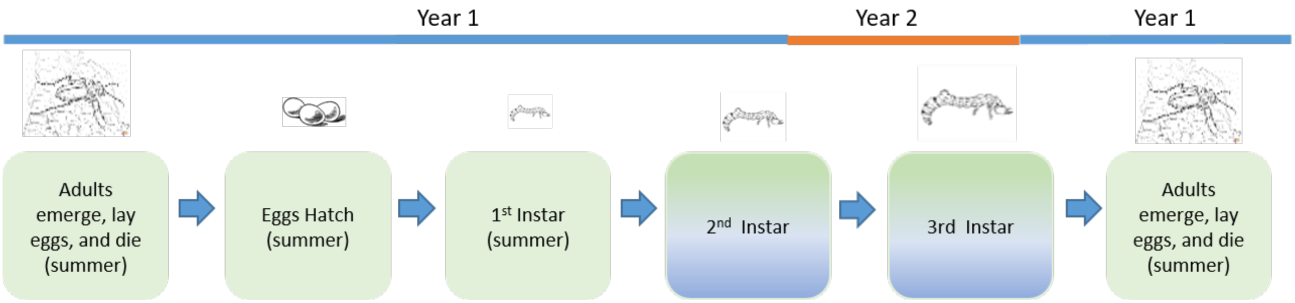

Figure 6. Theoretical 2-year life cycle for a tiger beetle species

2.4 Behavior

Tiger beetles are ectothermic (largely dependent on external temperatures to maintain internal temperature) and use behavioral adaptations and movement within their habitat to maintain their internal body temperatures in a range just below the lethal limit of 39°C (102.2°F). The high internal temperatures allow for maximum speed for running and flying to capture prey or elude predators (Person *et al*. 2006, p. 177-1780). However, air temperatures nearing the lethal limit can cause dehydration, reduce gamete production, and affect general metabolism (Pearson *et al.* 2006, pp. 177-178). Different species of tiger beetles have different levels of temperature tolerance, which may account for differences in habitat usage or activity period between sympatric species. The CTB is a diurnal species that likely regulates temperature by positioning the body towards the sun, or digging burrows in cooler substrates.

Tiger beetles are known to have excellent stereoscopic vision. However, certain behaviors suggest a reliance on alternate senses during feeding and night time activities (Riggins and Hoback 2005, p. 306). Temporary blindness in tiger beetle species has been recorded during pursuit of prey due to intense bursts of speed (Gilbert 1997, p. 217), suggesting that tiger beetles may rely on other senses that allow for activity without sight (Riggins and Hoback 2005, pp. 309-310; Zurek and Gilbert 2014, p. 6). Tiger beetles are known to catch live prey, but have also been recorded feeding on dead organisms, suggesting that tactile receptors play a role in feeding behaviors (Riggins and Hoback 2005, p. 306). Although primarily considered to be diurnal, tiger beetles have been collected near lights at night and have been observed to respond to bat echolocation. Successful nocturnal foraging requires senses such as chemoreception, hearing, and touch (Riggins and Hoback 2005, p. 306).

The excellent vision of tiger beetles also aids in anti-predator defenses. Adult tiger beetles are mostly predated by robber flies, lizards, and birds. To avoid predation, adult tiger beetles rely on their vision and quick escape flights and running as a primary method of defense. The CTB color patterns may serve as camouflage for adult tiger beetles by matching the cobble substrate, making the beetles difficult to detect when not moving. In addition to the camouflage, the CTB's bright orange abdomens are exposed during flight most likely to serve as a warning and keep aerial predators away (Pearson 1984, pp. 133-134; Pearson *et al*. 2006, p. 133). Much like the adults, larvae tend to detect danger largely through vision and may also use ground vibrations to detect larger predators (Pearson *et al.* 2006, p. 185). The primary anti-predatory defense of larvae is to retreat from the top of the burrow to hide, and use hooks to dig into the sides of the burrow, making it difficult for predators to grab and pull the larvae from the burrow. As a last resort, larvae have also been known to abandon a burrow and move across the soil surface to find a new area to be excavated (Pearson *et al.* 2006, p. 184).

2.5 Resource Needs

The CTB can be found on both shoreline cobble bars and cobble islands (Acciavatti 2001, p. 2). In the U.S. the CTB occurs along rivers where the currents are strong enough to scour shorelines and mid-channel bars, creating and maintaining cobble bars (Allen and Acciavatti 2002, p. 6). Periodic scouring by high flows also prevents the establishment of dense vegetation on the riverine cobble bars. (Figure 7). The CTB occurs in similar habitat along the shorelines of Grand Lake in New Brunswick (COSEWIC 2008, p. v).

The majority of occupied sites are on cobble bars associated with islands. CTB habitat usually consists of cobblestones and coarse gravel with small patches of sand (COSEWIC 2008, p. 8), as well as areas of loose, mixed-size cobbles (Hudgins *et al.* 2011, p. 315). CTB habitat surveys of sites on the Connecticut River reported a mean percentage of sand ranging from 6.1 percent for the island habitats to 28.8 percent in the shoreline habitats (Nothnagle 1995, p. 8). Although cobble is a crucial component of CTB habitat, cobble size itself does not have a significant relationship with occupancy (Kritsky *et al.* 2009, p. 141).

Figure 7. Cobble habitat of the CTB in New Hampshire (USFWS photo)

A significant difference exists between occupied and unoccupied cobble bars in area, perimeter to area ratio, and elevation relative to the overall cobble bar area (Hudgins *et al.* (2010, p. 23-25; 2011, p. 311). CTB adults were more likely to be found on cobble bars with larger interiors and greater elevational relief. The perimeter-to-area ratio was found to be smaller for occupied versus unoccupied cobble bars. The average cobble bar in New York was 3.3 ± 0.5 acres (1.4 ±0.2 hectare) (Hudgins 2010 p. 23). Another study in New Hampshire and Vermont found that occupied cobble bars typically consisted of small and medium sized cobble with areas ranging from 0.04 to 1.75 acres (0.02 to 0.71 hectare) with an average bar size of 0.62 acre (0.25 hectare) (Normandeau Associates Inc. 2016, p. 14).

Vegetation is an important component of CTB habitat, although plant species composition, structure, and density parameters will vary throughout the species' range. In general, vegetation observed at occupied sites was found to be sparse and low growing with low species richness (Ward and Mays 2011, p. 16; Environment Canada 2013, p. 11; Normandeau Associates Inc. 2016, p.16). Vegetation density from CTB sites in New York, Vermont and New Hampshire ranged from 1 percent to 51 percent on occupied sites (Nothnagle 1995, p. 8; Hudgins *et al.* 2011, p. 311; Normandeau Associates Inc. 2016, p. 16). In New York, cover for all vegetation types was generally less than 10 percent (Hudgins *et al.* 2011, p. 311) and cobble bars with dense vegetation and fewer open areas were less likely to be occupied by cobblestone tiger beetles (Hudgins *et al.* 2011, p. 311). In Vermont and New Hampshire, the mean vegetative cover was 26 percent (Normandeau Associates Inc. 2016, p. 16). The more common native plant species documented as occurring on occupied CTB sites include dogbane (*Apocynum cannabinum*), goldenrod (*Solidago spp.*), grasses, and low-growing shrub willows, such as sandbar willow (*Salix exigua ssp. interior*) (Acciavatti 2001, p. 10; Normandeau Associates Inc. 2016, p. 16). The non-native, invasive purple loosestrife (*Lythrum salicaria*) was observed at New Hampshire and Vermont CTB sites, but percent cover never exceeded 5 percent (Normandeau Associates Inc., 2016 p. 16). Japanese knotweed (*Polygonum cuspidatum*), another non-native invasive plant species has been observed encroaching on occupied CTB sites in Vermont (Nothnagle 1995, p. 11; Vermont Fish and Wildlife Department (VTDFW) 2016, p. 4) and is particularly difficult to remove once established. However, spring scours might control its spread (VTDFW 2016, p. 4).

Adult CTBs are usually found in sparsely vegetated, scoured shorelines, often close to the water's edge in areas of moist sand or silt (Hudgins *et al.* 2011, p. 315; Environment Canada 2013, p.11).The females of most tiger beetle species have species-specific requirements for soil moisture, temperature and substrate type for their egg laying habitats (Brust *et al*. 2006, p.252). Although the specific parameters for egg laying habitat are not known for the CTB, we recognize that there must be soil moisture, sand grain size and thermal limitations to their habitat requirements. Preferred habitat for larval burrows has not been identified because the larval stages have not been described taxonomically, and CTB burrows cannot be distinguished from other tiger beetle species at this time. Temperature and soil moisture are also critical components for larval habitat and may affect larval activity and survivorship (Pearson and Knisley 1984, pp. 468-469). Given that the larvae of many tiger beetles burrow in sand, we assume that the CTB larval burrows occur in the moist, sandy interstitial spaces between cobbles, above the mean high water mark.

One of the driving forces behind natural cobble habitat maintenance is the occurrence of seasonal flooding (Environment Canada 2013, p Mays and Ward 2013, p. 2). Spring freshets[1], flooding, and/or ice scour are all thought to be beneficial to maintaining the habitat by removing encroaching vegetation and exposing cobble (Environment Canada 2013, p. 11). Habitat along the shoreline of Grand Lake is maintained by wave action during spring flooding (COSEWIC 2008, p. 9). The CTB is known to be a flood tolerant species; however, immersion could potentially become an issue if the duration of inundation of occupied cobble bars exceeds the flood tolerance of the species. Larvae are susceptible to inundation because of their immobility within their burrows. The length of time CTB larvae can survive underwater is currently unknown (Normandeau and Associates Inc. 2016, p. 47). Inundated tiger beetle larvae are known to reduce their metabolism by as much as 90 percent in lab situations, and they may also be able to breathe air trapped in their closed tunnels (Pearson *et al.* 2006, p. 177). Some species such as the Eastern beach tiger beetle (*Cicindela dorsalis*) and white-cloaked tiger beetle (*Cicindela togata*) have been recorded to survive inundation for as long as 6 to 12 days (Pearson *et al.* 2006, p. 177).

2.5.1 Individual Needs

We evaluate the individual needs of the CTB in terms of the resource needs and/or the circumstances that are necessary to complete each stage of the life cycle, including eggs, larvae, and adults (Table 2). The life history of the CTB is closely tied to the cobble bars and riverine or lacustrine hydrology for all stages of the species' life cycle, including breeding, feeding, and sheltering. Despite their lacustrine environment, the populations on Grand Lake are affected by flows from the Saint John River including tidally influenced flows (Klymko 2018). Therefore, the cobble bars and associated flows of both the riverine and lacustrine habitats are a necessary and integral part of each stage of the life cycle.

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[1] Flooding of a stream or river caused by snow or ice melt.

Table 2. Life history and resource needs of the CTB

Life Stage	Resources and/or circumstances needed for individuals to complete each life stage	Resource Function*	Information Source
All life stages	● Sparsely vegetated island or shoreline cobble bars of 1,750 to 76,100 sf ● Naturally maintained ecosystem with seasonal flood or ice scour events to maintain sparse vegetation, generally less than 10% cover ● Lack of invasive non-native vegetation ● Unembedded cobble substrate with interstitial sand – 6 to 30 percent suitable sand component	B, F, S, D	Normandeau Associates Inc. 2016, p. 16 Environment Canada 2013, p. 11 Hudgins *et al.* 2011, p. 311 Nothnagle 1995, p 8
Fertilized eggs – early summer	● Sufficient soil moisture on substrate in which eggs are oviposited and for hatching	B	Normandeau Associates Inc. 2016, p. 16 Environment Canada 2013, p. 11 Hudgins *et al.* 2011, p. 311 Nothnagle 1995, p 8
Larvae (1st, 2nd and 3rd Instars) – summer/fall/ winter	● Minimal long-term inundation (less than 12 days) ● Adequate food availability	B, F, S	Pearson *et al.* 2006, p. 177
Pupae and Adults - summer	● Adequate food availability	B, F, S, D	Normandeau Associates Inc. 2016, p. 16 Environment Canada 2013, p. 11 Hudgins *et al.* 2011, p. 311 Nothnagle 1995, p 8

* B=breeding; F=feeding; S=sheltering; D=dispersal

2.5.2 Population Needs

We evaluate the population needs of the cobblestone tiger beetle in terms of what is required for self-sustaining populations. The measure of resiliency is based on a population's ability to withstand or recover from environmental or demographic stochastic events, such as changes in the hydrological regime (e.g. from natural flow to managed flow, or a change in the managed flows) or an increase in the intensity and severity of storms, that may increase the likelihood of prolonged inundation. We evaluate resiliency in terms of resources and/or the circumstances that are necessary to maintain population abundance, distribution, population growth rates, and reproduction (see section 4.3).

The small cobble bars on which the CTB are found may reflect the species' reliance on closely located suitable habitat patches. The small area of the occupied sites indicates small carrying capacities (Omland 2009, p. 6); however, if a number of habitat patches are closely situated (e.g. 500 meters or less), the overall population may be considerably larger. Movement between closely situated sites would facilitate recolonization if one site were to go extinct as a result of a localized catastrophic event. Because the cobble bars are created and maintained by dynamic hydrological processes (flood events or ice scour), suitable habitat may be fluid throughout a watershed.

There is very little information on population demographics for the CTB. Many of the tiger beetle taxa demographics are based on a metapopulation structure, most likely due to the dynamic environments in which they are found (river shorelines, high energy coastal beaches) (Omland 2009, NatureServe 2018). Because the CTB cobble bar habitat is found in hydrologic regimes that undergo periods of intense scouring or flooding that create, maintain, and occasionally destroy the habitat, we considered this species to need a metapopulation structure in order to persist. Metapopulations are "systems of local populations connected by dispersing individuals" (Hanski and Gilpin 1991, entire).

Based on dispersal distances of other tiger beetle species moving between populations or to suitable habitat, and a review of the distance between extant populations located linearly on the same waterbody (river or Grand Lake), we observed that most CTB populations were within a 5-mile Euclidean distance of one another. Discussions with cobblestone tiger beetle experts solidified our determination that populations within a 5-mile Euclidean distance should be considered members of a metapopulation (Frantz 2018).

Local extirpations and recolonizations of habitat patches should be considered normal within a functioning metapopulation (Knisley 2018). It is likely that the most resilient CTB populations function as a metapopulation, with more resilient metapopulations being spatially distributed so that a localized catastrophic event does not affect an entire metapopulation.

The following conditions are needed to support self-sustaining populations:

Suitable Habitat
To provide for breeding, sheltering and feeding, the CTB needs riverine[2] or riverine-like cobble bars associated with shorelines or islands that are sparsely vegetated with native shrubs and vegetation. CTB occupied cobble bars have been documented to range from 0.04 to 3.3 acres (0.02 to 1.35 hectare) in size and are maintained by seasonal flooding or ice scouring (Hudgens 2010, p. 23; Normandeau Associates Inc. 2016, p. 14-16). Vegetation is generally sparse, with average cover ranging from 10 percent to 26 percent of suitable cobble bar habitat (Nothnagle 1995, p. 8; Ward and Mays 2011, p. 16; Hudgins *et al.* 2011, p. 311; Environment Canada 2013, p. 11; Normandeau Associates Inc. 2016, p. 14-16). Cobble size may not be indicative of suitable habitat; however, a mix of unembedded cobble and sand is crucial to maintaining CTB populations (Boyd 1978, p. 225; Nothnagle 1995, p 8.; COSEWIC 2008. p 9; Hudgins *et al.* 2011, pp. 312-313; Environment Canada 2013, p. 11).

Maintenance of Hydrological Processes
Cobblestone tiger beetle habitat is created and maintained by natural hydrological disturbances, including ice scour, spring freshets and flooding. Vegetation density may be reduced by scour, and sand and suitable cobbles may be deposited during flood events. A number of populations occur in riverine systems that have not been affected by dams, or locks and canals. Those may be

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[2] With the exception of Grand Lake in New Brunswick, Canada.

maintained by the current flow regimes. Changes to existing hydrological regimes, including changes to flow velocity, timing of high water events, or timing or duration of habitat inundation as a result of regulatory requirements (e.g. relicensing, see section 3.1.1.4), could result in habitat degradation and loss of populations.

Connectivity of Populations
Populations typically consist of site clusters (multiple populations located within 500 meters (1,640 feet) or less), suggesting a metapopulation structure (Nothnagle 1995, p.15). For CTB populations to be self-sustaining, suitable habitat must occur within the species' dispersal distance.

Cobblestone tiger beetles have been documented to move up to 500 meters between cobble bars (Hudgins *et al.* 2011, p. 310). Occupied cobble bars within 500 meters of each other are considered to be one population (Environment Canada 2013, p. 11). Under certain circumstances such as strong prevailing winds or flooding,, CTBs may travel several miles (VTFWD 2011, p. 9; MassWildlife 2018). Suitable habitat at greater distances than normal flight distances (500 meters) could provide stepping stones for dispersal (Ward and Mays 2011, p. 8). Tiger beetle dispersal could be in response to a catastrophic loss of habitat (flooding) or as emigration events when new habitat is created (COSEWIC 2008, p. 14).

CTB habitat is subject to change under normal hydrological conditions. Cobble bars and islands may form, move, change in size, or disintegrate depending on the hydrological processes affecting the sites. As a result of the variability in habitat formation, maintenance, and loss, clusters of cobble bars either on islands or the shoreline provide the ability for the CTB to move between suitable and unsuitable cobble bars, or disperse to newly created habitat.

2.5.3. Species Needs

We evaluate the species' needs in terms of the resources and/or the circumstances that support the redundancy and representation of the species. Specific to the CTB, redundancy is evaluated by the presence of multiple, resilient populations distributed throughout its range. Therefore, we evaluate the redundancy of the CTB based on the number of populations within a metapopulation and whether our analytical units consist of metapopulations or isolated populations (see section 4.2.2).

Specific to the CTB, representation is evaluated based on the presence of multiple populations and metapopulations spread across the range (see section 4.2.3). Habitat conditions, in particular the influences of river flows and climate, vary throughout the range of the CTB, although the site-specific habitat requirements may not vary (e.g. loosely embedded cobble, moist sand of suitable grain size, low vegetation density). The range is wide, from the New England, Appalachian Plateau, Saint Lawrence Valley, and Central Lowland physiographic provinces (New Brunswick, Maine, New Hampshire, Vermont, and New York), to the Valley and Ridge, Central Lowland, and Interior Low Plateau provinces (Pennsylvania, Ohio, Indiana, and Kentucky) and to the Coastal Plain province (Alabama).

2.5.4. Uncertainty

The life cycle of the CTB is not fully understood. The assumption that the CTB has a 2-year life cycle is based on life cycles of tiger beetle species exhibiting similar life history characteristics (e.g. time of adult emergence, observations of potentially two different instar burrow sizes). The length of time that CTB larvae can withstand inundation has not been determined, although we may infer a range of time based on research of other tiger beetle species. The specific components of egg laying and larval habitat have not been identified. Many of the resource needs identified in Table 2 are based on other tiger beetle species' characteristics and resource needs. We lack site-specific information about individual population size and trends. Models to estimate population numbers have been developed for the Puritan (*Cicindela puritana*) and Northeastern beach tiger beetles (*Cicindela dorsalis dorsalis*) but have not been attempted for the CTB due to the above-mentioned data gaps. Therefore, there is uncertainty associated with CTB populations because our identification of extant CTB metapopulations is largely based on limited survey data.

Chapter 3 Factors Influencing the Species

In this chapter, we evaluate the past, current, and potential future influences that are affecting or could be affecting the current and future condition of the CTB throughout all or some of its range. These potentially influential factors include changes in hydrology (dams and riverbank stabilization), habitat loss and degradation (through development, sand and gravel mining, and recreation), water quality, small population size, and effects from climate change. Those risks that are not known, based on the best available information, to have effects on CTB populations, such as overutilization for commercial and scientific purposes, are not discussed in this SSA report.

3.1 Hydrology

Natural flood regimes benefit river, floodplain, and riparian ecosystems and provide and maintain habitats for fish, wildlife, and plants dependent on these ecosystems (Fitzhugh and Vogel 2010, p. 1). Sediment is moved through the river channel when flows are just below flood stage and may be deposited in floodplains or sand and gravel bars as the waters recede. Natural floods may also ameliorate the effects of low-flow conditions by: maintaining wetted habitat for species occurring in adjacent floodplains or at the river's edge; creating, enhancing or relocating habitat such as sandbars or cobble bars; and improving connectivity to upstream and downstream habitats (Fitzhugh and Vogel 2010, p. 1). The CTB is almost exclusively found on cobble bars in flowing, riverine environments with the exception of two metapopulations found on cobble shorelines at Grand Lake, New Brunswick. A natural hydrological regime maintains CTB habitat through seasonal flood events (e.g. spring freshets) by reducing vegetation, nourishing the substrate with suitable cobble, gravel and/or sand, preventing the establishment of invasive species, and providing suitable conditions for prey. The primary driving forces for river and lake hydrology effects to the CTB and its habitat are precipitation and for northern sites, ice formation (Figure 8).

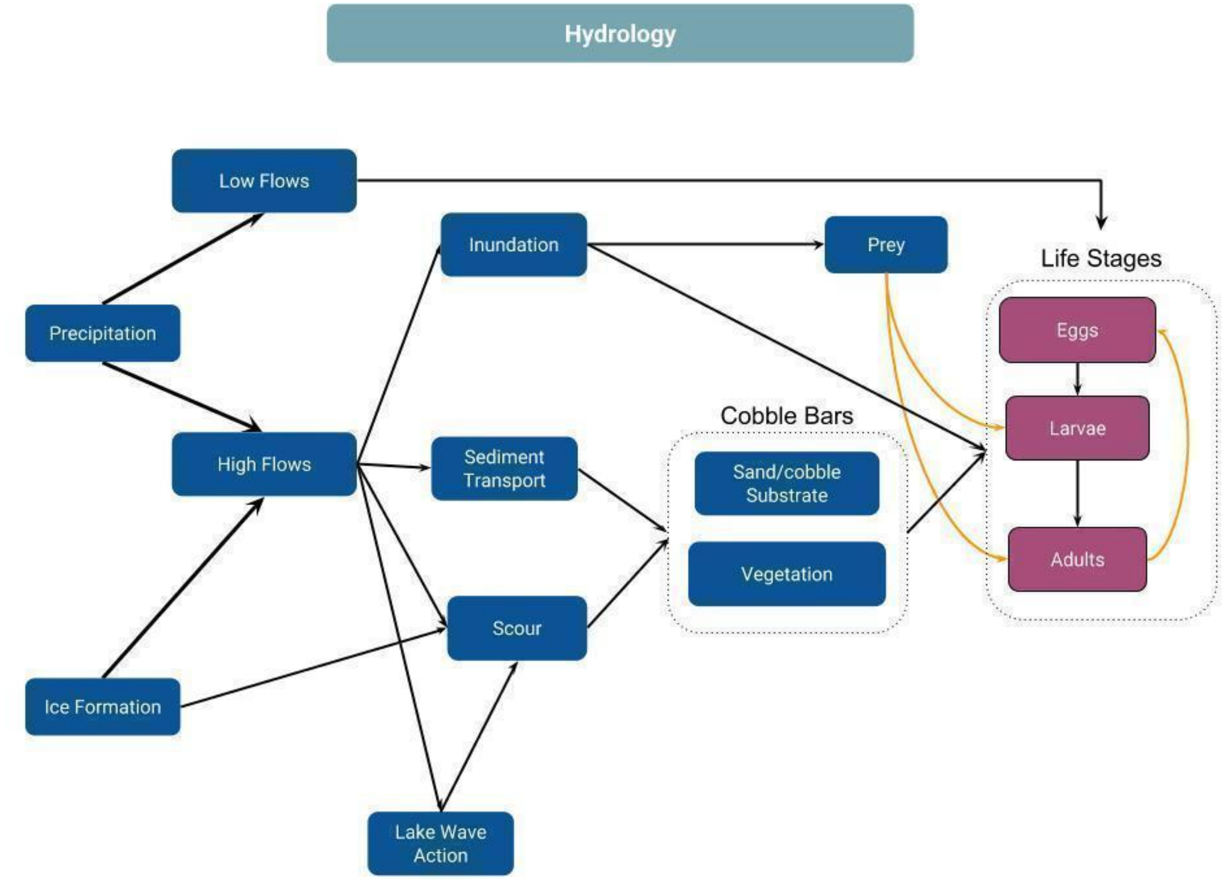

Figure 8. Hydrology Influence Diagram for CTB habitat and life stages

Spring scour, including ice scour, spring freshet and spring flooding may be necessary in maintaining suitable habitat by removing encroaching vegetation or preventing the establishment of invasive plant species (Environment Canada 2013, p. 11). Ice scour has been a common occurrence in the northern portion of the range (Nothnagle 1995, p. 16; COSEWIC 2008, p. 9; Mays and Ward 2013, p. 7). The Grand Lake shoreline habitat is maintained by wave action during spring flooding and a lack of summer flooding (COSEWIC 2008, p. 9).

Potential changes in these factors are discussed in Section 3.5. In addition to precipitation and ice formation, other factors (e.g., dams) influence hydrology of CTB sites and are discussed below.

3.1.1 Effects of Dam Operations

Alteration of the natural hydrological system through the construction and operation of dams may have serious consequences for the riparian ecosystem. Dams may range in size from small historical, non-functioning mill dams on streams to low-head hydropower dams on streams or rivers of varying sizes to huge, power generating facilities on large rivers. The impact of dams is dependent on the size and flow of the river as well as the flows released by a dam, the type and size of a dam, and if there are multiple dams on the river that have cumulative impacts to the riverine ecosystem (Foundation for Water and Energy Education (FWEE) 2018, p. 2). Ten of the

27 extant AUs in the United States (37 percent) and 1 Canadian AU are directly influenced by dams managed for hydropower (6), navigation (3), water supply (1), and flood control (1) (Table 3).

Table 3. CTB analytical units affected by managed flows

States	AU	Metapopulation	Flow Alteration Cause	Flow Management Purpose
AL	Soapstone Creek - Alabama River	No	Robert F. Henry Lock and Dam	Navigation; Hydropower; Flood control
NH/VT	Mill Brook-Connecticut River	Yes	Wilder Dam	Hydropower
NH/VT	Vernon Dam-Connecticut River	No	Bellows Falls Dam	Hydropower
NJ/PA	Raymondskill Creek-Delaware River	Unknown	Neversink River Reservoir	Water supply
NJ/PA	Flat Brook-Delaware River	Unknown	Neversink River Reservoir	Water supply
NY	Outlet Silver Lake-Genesee River	Yes	Mount Morris Dam	Flood Control
OH/WV	French Creek-Ohio River	Yes	Willow Island Lock and Dam	Navigation
PA	Allegheny River	No	Allegheny Lock and Dam 09	Navigation
VT	Winooski River	Yes	Bolton Falls Dam; Essex No. 19	Hydropower
VT	Rock River-West River	Yes	Townshend Dam	Flood control
Canada	01AJB00 (Saint John River)	Yes	Beechwood Dam	Hydropower

Peaking hydropower dams generate electricity by releasing more water during periods of high power demand, either daily (in the evening at the end of the workday) or seasonally (during the summer when air conditioners are running) (FWEE 2018, p. 3). These operations raise and lower water levels in dam impoundments and water levels in the river below the dam. Water levels will fluctuate to varying degrees depending on the electricity demands and/or the hydropower license prescription. These fluctuations have a number of effects: riverine habitats may be flooded or exposed for extended periods of time on a daily basis, riverbanks may experience increased erosion, natural sediment transport or deposition may be affected, and the potential establishment of invasive plant species may be increased (FWEE 2018, p 3; Magilligan and Nislow 2005, p. 2).

3.1.1.1 Inundation

If flow conditions result in extended periods of inundation at CTB sites, adults, pupae, and larvae (and their habitat) will be affected. The effects of such prolonged inundation of CTB habitat will vary depending on timing and duration. Habitat inundation that occurs during winter or spring high flows when the CTB larvae are senescent and adults are absent may have limited effects. CTB larvae might be able to withstand a few weeks of inundation during the winter but not during the summer.

During summer when CTB adults and larvae are active, inundation of 24 hours or more may reduce the time larvae and adults spend feeding or reduce the number/density of available prey. Prolonged inundation of habitat when larvae, pupae, and adults are present could delay larval development from one instar stage to another, decrease larval rate of survival, prevent pupae from emerging as adults, and increase competition for space and prey between the CTB and other tiger beetles that are present. Inundation on a daily basis or over a period of time during the beetle's active season, when larvae, pupae and adults are present, could limit the extent of habitat that is available to these life stages. This would make egg laying and larval habitat unsuitable due to elevated soil moisture levels and would restrict adults to a limited area, increasing intra- and interspecific competition for resources (e.g., habitat, food).

Limited exposure (one to several days) to inundation is unlikely to affect larvae, but they may experience mortality or indirect impacts from prolonged inundation during their active season (June through September) due to decreased oxygen levels when they are in their burrows. Increased water levels may cover the entire cobble bar or saturate the substrate reducing oxygen below larval tolerance levels. Laboratory research with larvae of the hairy-necked tiger beetle (*Cicindela hirticollis*) (another tiger beetle species found along riverine and coastal shorelines within the range of the CTB) demonstrated that these larvae abandoned their burrows after 96 hours of inundation and either relocated their burrows (if suitable habitat was present) or drowned. It is possible that larvae may float and land on dry, suitable habitat; however, if dry land is not encountered, then larvae will drown (Brust *et al.* 2006, pp. 257-261). It is not known whether these findings would apply to CTB.

If the entire CTB habitat is inundated when adults are present, they may be swept away (depending on water velocity), or temporarily forced into unsuitable habitat where they are unable to forage, mate or oviposit. Prolonged inundation of adult habitat may result in increased energy expenditure for adults as they seek suitable habitat or are restricted to unsuitable habitat, substantially delaying or preventing reproduction.

At least two CTB occurrences are known to have been impacted by a change in the flow regime of an upriver hydropower dam. In Massachusetts, the single CTB population located on the main stem of the Connecticut River was documented as being present through 2007. In the mid-2000s, the Turner's Falls hydropower dam immediately upriver of the population significantly increased the frequency and duration of water releases for power generation (MassWildlife

2017). As a result, summer flows submerged the entire cobble bar on an almost daily basis in late afternoons and evenings. Subsequent CTB surveys conducted in 2012, 2013, 2014, and 2017 failed to document any individuals (Nelson 2017). The habitat is considered to be unoccupied as a result of consistent flooding that completely inundated adult and larval habitat during critical life history periods (Nelson 2017). In addition to the Massachusetts population, the Winooski River population in Vermont is presumed to have been extirpated due to changes in the flow regime of a hydropower dam located approximately 7 miles upstream of that population (VTDFW 2011, p. 9).

There is evidence that other CTB populations were extirpated during the early part of the 20th century as dams were built throughout the northeast and mid-Atlantic states. In West Virginia, at least two populations are believed to have been extirpated due to the construction of locks and dams. A CTB population on the Monongahela River was lost once a series of locks were constructed after 1905 and habitat was inundated (Frantz 2018). A second possible occurrence may have been destroyed once Cheat Lake was created after a dam was built in 1926 (Frantz 2018). In the southeast, at least one population on the Coosa River in Alabama is believed to have been extirpated due to the construction of the dam at Jordan Lake (Holt 2018a).

We have no information to suggest additional dams will be built within the species' range, but hydrologic operations of existing dams may change in the future (see below). Some changes may be necessitated by alterations in flow regimes resulting at least in part from climate change (discussed in section 3.5).

3.1.1.2 Run-of-River Flows

Run-of-river dams allow water to pass at about the same rate as the river is flowing irrespective of their purpose (low-head hydropower or flood control). However, flood control dams will change run-of-river flows when flood control operations are implemented (FWEE 2018, p. 3). Flood control dams may be operated as run-of-river, may have recreational pools or impoundments and hold back water to maintain the pools, may have dry reservoirs, or may be managed as a flood control operation in combination with hydropower. During flood control operations, water may be stored prior to the storm event, dropping river water levels to unnatural lows for a period of time, and once released after the storm event is over, maintain artificially high water levels for a time.

The Beechwood Dam on the Saint John River in New Brunswick is categorized as "run-of-river" (New Brunswick Energy Institute 2018, p. 1). However, the downriver flows appear to have been affected by the dam's flow regime. The Tobique Dam (a dam located on a tributary upriver of the Beechwood Dam) and Beechwood Dam on the Saint John River upriver of the CTB populations (NHN 01AJB00) attenuate extreme low flows due to mandated minimum flows (Kidd et. al. 2011, p. 61). Moreover, flow studies below the Beechwood Dam document daily fluctuations of 1.5 meters exposing large portions of the river bottom (up to 50 percent) on a daily basis (Kidd et. al. 2011, p. 63). These fluctuations may limit available suitable CTB habitat through daily inundation and affect the prey base, as described in section 3.1.1.2.

3.1.1.3 Impoundments

Irrespective of the type of operations that are implemented at dams, the construction of dams most often results in impoundments or reservoirs behind the dams. The impoundments flood low lying habitat behind the dam causing the loss of suitable cobble or sand bars and floodplain habitat, trapping sediments and slowing the rate water is flowing downriver. The CTB was believed to have been more widespread on the Saint John River in New Brunswick prior to the construction of Mactaquac Dam, completed in 1967. It is estimated that the dam's impoundment submerged approximately 99 kilometers (61 miles) of the Saint John River (COSEWIC 2008, p. 8). The first CTB occurrence in this area was found in 2003; however, based on a review of historical aerial photography, 19 islands with potentially suitable habitat were inundated following dam construction, potentially significantly reducing the extent of CTBs within the Saint John River watershed (COSEWIC 2008, p. 12).

3.1.1.4 Dam Management Implications

The impacts of managed flows may change through time as a result of the implementation of regulations requiring the relicensing of hydropower dams (under the Federal Energy Regulatory Commission (FERC)) or water supply management programs. A number of CTB AUs may potentially be affected in the near future by these relicensing requirements.

The FERC regulates non-Federal hydropower projects that affect navigable waters, occupy United States lands using water or water power at a government dam, or affect the interests of interstate commerce. The FERC issues preliminary permits and project licenses, among other regulatory and oversight activities. During the license process, the FERC seeks input from the public, nongovernmental organizations, Indian tribes, and local, state, and Federal resource agencies in order to identify environmental issues regarding a proposed or existing project and determine what studies are needed in order to better understand these issues. Licenses are issued for a term of between 30 to 50 years, and exemptions are granted in perpetuity.

Presently, five hydropower projects on the mainstem Connecticut River (in Massachusetts, Vermont, and New Hampshire) are undergoing relicensing through the FERC. Four of the five projects affect all CTB populations on the Connecticut River mainstem (Mill Brook - Connecticut River and Vernon Dam - Connecticut River AUs). Pursuant to regulations promulgated under the Federal Power Act, consultation with resource agencies (including the Service) occurs as part of the relicensing process. The applicant for three of the projects is following a standard relicensing process at the present time, while the applicant for two of the projects is pursuing settlement negotiations with stakeholders. Each process presents the potential to minimize project-related effects to CTB habitat or improve habitat conditions within project-affected areas (von Oettingen 2018a).

During the FERC standard relicensing process for the upper Connecticut River dams, the applicant conducted surveys and studies for rare and aquatic species, including the cobblestone tiger beetle. The CTB study surveyed known occurrences, located 1 new occurrence, and identified habitat parameters that indicate suitable CTB habitat (Normandeau 2016, entire). Study results may be used to develop recommended changes to project operations to increase the amount of time and area that occupied CTB habitat is available on a daily basis during critical life history stages. Additional potentially suitable unoccupied habitat that is currently unavailable due to long periods of inundation could also become available depending on how peaking flows are managed. The second applicant and stakeholders are undergoing a different process, with negotiations focused on flow management that may take into consideration downriver impacts to CTB habitat. However, the outcome of the negotiations is not certain at this time (Grader 2018).

The Delaware River watershed, the primary water supply for New York City, is affected by the management of three reservoirs: Pepacton (East Branch Delaware River), Neversink (Neversink River) and Cannonsville (West Branch Delaware River) (Figure 9). The reservoir releases are managed to maintain flow targets at Montague, NJ and Trenton, NJ (Eyler 2018). Prior to 1977, flows were not required to consider conservation releases for the Pepacton and Neversink reservoirs (e.g., to maintain aquatic resources). The Cannonsville and Pepacton Reservoir releases would have directly impacted the Callicoon CTB site (Middle Delaware AU). All 3 reservoirs would have adversely impacted the remaining Delaware River populations in the Raymondskill Creek-Delaware River, Flat Brook-Delaware River, Upper Delaware and Lower Delaware River AUs (Eyler 2018). The Lower, Upper, and Middle Delaware River AUs are considered historical or extirpated whereas the status of the Raymondskill Creek and Flat-Brook Delaware AUs is unknown.

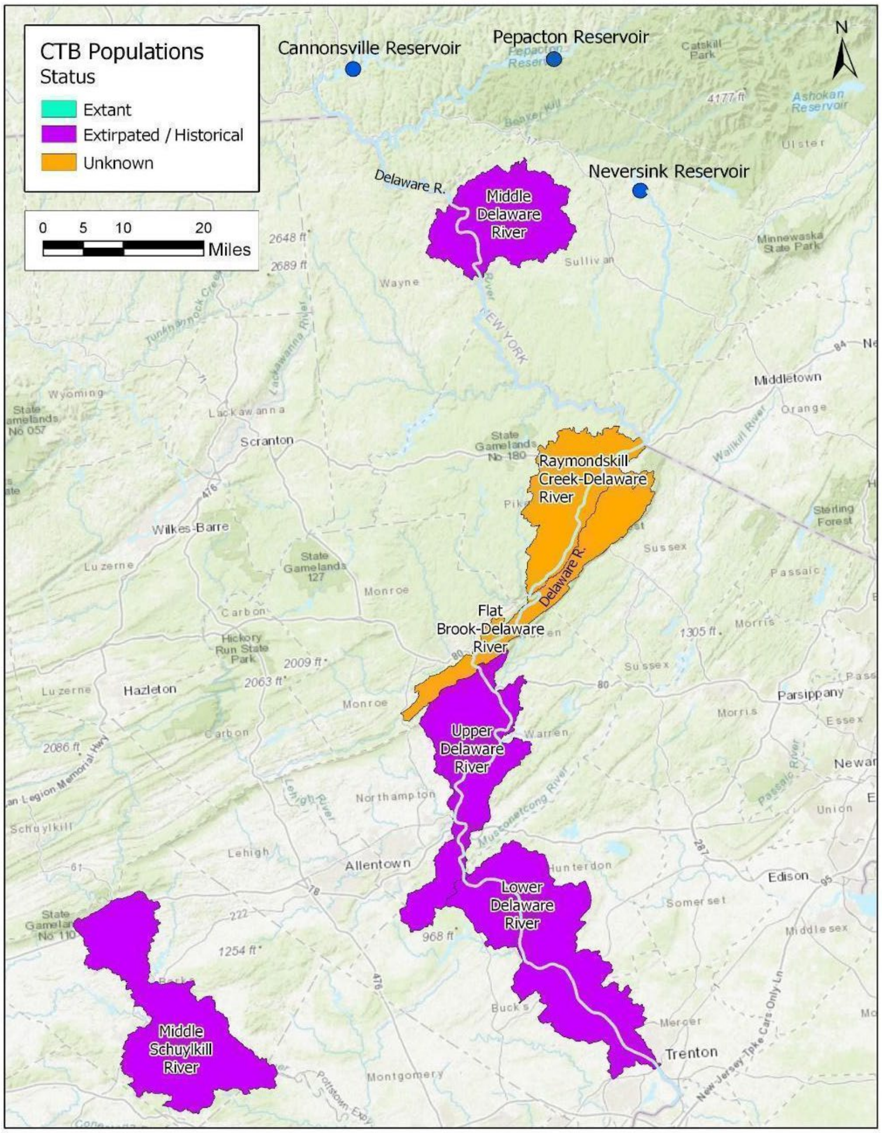

Figure 9. New York City Water Supply Reservoirs and associated CTB AUs

Currently, Delaware River flows are managed under a Flexible Flow Management Program that will be in place until 2027 (USGS 2018a). These flows are static, with prescribed, minimum flows. However, during droughts, flows may drop further in order to maintain prescribed water volumes in the reservoirs; during floods, flows will be elevated. What is uncertain is how these flows compare to flows that would occur under unmanaged flow conditions and whether or to what extent CTB habitat would be (or has been) impacted.

The typical impact of managed dams is to reduce the magnitude of peak flood flow that affects important riverine functions of sediment transport, habitat creation or enhancement, aquatic connectivity and disrupts aquatic life cycles. This change in median annual flooding is greatest in large and medium size rivers (Magilligan and Nislow 2005, p. 2; Fitzhugh and Vogel 2010, p. 9). Impacts may include major changes in flood frequency, flood duration and total area flooded. For example, the magnitude and type of hydrological impacts from Wilder Dam, a hydropower dam upriver of six extant CTB sites in the Connecticut River, varied with the elevation of the floodplain.

Additional impacts to CTB habitat from management of dam impoundments occur when water levels fluctuate significantly on a regular basis preventing the establishment of riverbank vegetation and increasing the impacts of bank erosion (FWEE 2018, pp. 2-3). As sediment is retained in the impounded area (FWEE 2018, p. 3), downriver habitat may become sediment starved, leading to a lack of replenishment of suitable sediments to be deposited onto the cobble bar habitats.

Flow alterations that reduce the area or number of point bars would affect tiger beetle metapopulations as the distance between occupied sites grows, preventing beetles from moving between locations in response to changing habitat conditions (Fenster and Knisley 2006, p. 882). Metapopulations could become isolated populations or extirpated entirely.

3.1.2 Riverbank Stabilization

Natural bank erosion, as stated above, is important for sediment transfer to create or enhance riparian habitat and may modulate changes in channel morphology and pattern (Florsheim *et al.* 2008, p. 520). Increased erosion from river flow management of dams or resulting from increased storm intensity can adversely impact the riparian system if large quantities of fine sediments are released or the river channel morphology is altered. Often, the anthropogenic response to erosion, whether significant or otherwise, is to stabilize banks with hard structures in order to limit land loss or protect infrastructure. Geomorphic and ecological effects to the riparian ecosystem from the impacts of channel bank infrastructure (riprap, gabions or concrete lining) may be considerable (Florsheim *et al.* 2008, pp. 523-524). Hard bank structures increase velocities along banks affecting riverbank vegetation, reducing channel complexity, and homogenization of near-bank flow velocity may occur. There may also be a loss of access to side channels, a loss of natural bank substrate, and limitation of geomorphic adjustments depending on the type and area of bank stabilization. Hard structures may ultimately lead to greater erosion events downriver or locally (Florsheim *et al.* 2008, p. 524). Ultimately the aquatic habitats associated with the river may be significantly degraded or lost altogether.

3.1.3 Uncertainty

Eleven AUs incorporating six metapopulations, three isolated populations, and two populations with unknown status occur on rivers affected by dam operations (Table 3). There are no data that describe the CTB status or extent of occupied habitat for these populations prior to the construction and management of the dams affecting their river reaches. Thus, there is uncertainty as to whether the metapopulations were impacted by the dam construction and operations through fragmentation or isolation and whether the extent of available habitat for populations was affected. It is unknown whether current managed flows are affecting populations by limiting available habitat or incurring prolonged inundation. Also uncertain is the extent to which the frequency and duration of inundation and scour events may change as a result of changing climate conditions (see section 3.5).

3.1.4 Summary

The riparian ecosystem in which CTB habitat occurs evolved in a natural system of seasonal floods, ice scour, erosion, and accretion. CTB habitat appears to be largely dependent upon the flow regimes that allow for spring flooding or ice scour and preclude prolonged inundation of adult or larval CTB habitat. Dams that alter the natural flow regime may reduce the size of metapopulations, resulting in isolated populations or extirpation. Anthropogenic activities including dams, impoundments, and channel bank infrastructure affect the balancing forces that maintain the river channel geomorphology, ultimately degrading or destroying sensitive riparian habitats.

3.2 Habitat Loss and Degradation

In addition to loss of habitat from changes to the hydrology of the riverine system in which the CTB occurs, habitat loss may also result from changes in land use, particularly as forested or agricultural lands are converted to residential or commercial uses or mineral extraction occurs near or in the river where the CTB occurs. The loss of vegetated buffers along the shoreline, increased sedimentation from construction, and run-off from impervious surfaces may alter the physical structure of cobble bars (for example, increased fine sediment, increased vegetation). Recreational impacts may cause direct changes to cobble bars or disrupt normal behavior patterns of feeding, breeding and resting.

3.2.1 Urbanization and Construction

Urbanization could affect CTB habitat through runoff of fine-grained sediments from the watershed (especially from construction sites) with deposition and accumulation on the cobble bars, especially those situated along the river banks (as opposed to island cobble bars). Increased sediment deposition would adversely impact egg laying and larval habitat by altering the suitable grain size and providing a substrate for vegetation, likely increasing vegetation density. Moreover, as infrastructure and development increase in the vicinity of riverbanks, the likelihood of bank stabilization affecting shoreline cobble bars increases (see section 3.1.2), although impacts to island cobble bars may be less likely.

Stream channels adjust to the changes in water and sediment supply resulting from urbanization and three phases of adjustment occur (Colosimo and Wilcock 2007, p. 499). Initially, the increased sediment supply associated with urban construction results in an aggraded phase in which fine sediments add to the margins of point bars. This deposition would apply to CTB habitat, both on islands and along the shoreline, and would be detrimental, depending on the amount of fine sediment. The other two phases are “early erosion,” which results in wider channels with smaller bars and a lack of fine grained sediment, and “late erosion,” which is characterized by channel enlargement and no bars with fine grained sediment (Colosimo and Wilcock 2007, p. 519).

Therefore, all phases of stream channel adjustment to urbanization can be detrimental to CTB through alteration of habitat, first through deposition of fine grained sediment and then through erosion. The changes discussed above resulting from urbanization can adversely affect CTB habitats and populations, with the degree of impact depending on the nature of the activity, the hydrology and sediment grain size characteristics of the system, and the proximity to the site.

To document changes in urbanization that have occurred since 1997, we used the U.S. Forest Service's Forest and Rangeland Renewable Resources Planning Act (RPA) Assessment (Wear 2011, p. entire and supporting data file). Land use data from 1997 were projected to 2020 (which we use as an estimate for current condition) and thereafter every ten years through 2060 (which we use for future condition). The analysis was conducted for all counties in the conterminous United States. For each AU, we used data from the county with the largest overlapping land. Land use categories consist of forest, urban, rangeland, cropland, and pasture and are restricted to non-Federal lands. Since rangeland is minimal through the CTB range, we omitted this land use category and combined cropland and pasture into one agricultural category. The modeling approach takes into account county-level population and personal income to simulate future urbanization. Climate change is integrated into the analysis based on the scenarios in the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment (IPCC 2007, p. 44). To be consistent with our use of Representative Climate Pathway (RCP 8.5) in section 3.5, we used the highest emissions scenario (A2) evaluated by Wear (2011, p. 10).

The general pattern in the counties (used as estimates for AUs) was consistent with the national forecast of an increase in urban land and a decrease in forest and agriculture (Wear 2011, p. 1). The projected increases in urban lands in these watersheds ranged from 0 to 3.4 percent with the exception of four watersheds: Soapstone Creek (AL), Whitewater River (IN), Raymondskill Creek–Delaware River (NJ/PA), and Flat Brook–Delaware River (NJ/PA) (Table 4). For these three land use categories, we present the percentages in 1997 and 2020. The totals are less than 100 percent because the analysis does not include lesser land use categories and federal land.

The most urbanizing AUs are the two NJ/PA HUC10s, which are projected to increase in urban land by about 4 to 5 percent between 1997 and 2020: from 17.5 percent in Raymondskill–Delaware River in 1997 to 22.0 percent in 2020 and from 19.8 percent in Flat Brook-Delaware River in 1997 to 24.0 percent in 2020 (Table 4). Increases of about 4 percent are projected for Soapstone Creek (4.4 percent in 1997 to 8.5 percent in 2020) and Whitewater River (6.7 percent in 1997 to 11.4 percent in 2020).

Table 4. AUs with the greatest predicted increase from 1997 to 2020 in land use from agricultural and forest to urban: (A)=agriculture (sum of pasture and cropland); (F)=forest; (U)=urban. (A2 Scenario, data from Wear 2011, excel spreadsheet)

State	**AU**	**1997 (%)**	**2020 (%)**
AL	Soapstone Creek	23.1 (A), 65.0 (F), 4.4 (U)[3]	21.8 (A), 62.2 (F), 8.5 (U)
IN	Whitewater River	44.2 (A), 43.4 (F), 6.7 (U)	41.0 (A) 41.1 (F), 11.4 (U)
NJ/PA	Raymondskill Creek–Delaware River	13.4 (A), 51.5 (F), 17.5 (U)	12.5 (A) 47.9 (F), 22.0 (U)
NJ/PA	Flat Brook–Delaware River	28.2 (A), 42.9 (F), 19.8 (U)	26.5 (A), 40.4 (F), 24.0 (U)

With urbanization, there is an increase in the total impervious area (TIA), consisting primarily of roads, parking lots, and rooftops within the watershed (O'Driscoll *et al.* 2010, p. 606). With increased TIA, there is reduced infiltration and surface storage of precipitation and thus greater runoff. This is demonstrated in studies that indicate that urban streams are flashier with greater extreme flow events (those that are 3 or more times the median flow, O'Driscoll *et al.* 2010, p. 612). In the Northeast region, greater and more erratic flow regimes are also predicted as a consequence of climate change (see section 3.5).

Local projections for the Pemigewasset River corridor (17,583 acres) (Middle and Upper Pemigewassett AUs) suggest potential impacts to CTB through land use changes as the population increases. Water quality impacts with increased development would occur from the increase in impervious surface and the decrease in vegetated buffers along tributaries or the mainstem (Pemigewasset River Local Advisory Committee 2013, pp 18 - 19). Although more than 30 percent of the land within the Pemigewasset River corridor is protected, between 2001 and 2010 wetland or natural vegetation acreage declined by 7 percent and residentially developed acreage increased by 46 percent (Pemigewasset River Local Advisory Committee 2013, p. 18). The population growth trend of the Pemigewassett in the vicinity of the CTB populations is projected to continue at the same level as the 2000 to 2010 growth rate of approximately 20 percent with concurrent impacts.

Urbanization is not a major issue in the Saint John River watershed in Canada. The major land use categories for the New Brunswick portion of the watershed are: forested--83 percent, agriculture--6 percent, wetlands--5 percent, and urban--2 percent, although areas along the river close to the CTB sites are about 25 percent agricultural (Kidd *et al.* 2011, p. 32). The Saint John River islands sites are unsuitable for residential development (COSEWIC 2008, p. 18). In

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[3] The sum is not 100% because the analysis does not include lesser land use categories and federal land.

addition, three of the sites are owned by a non-profit conservation organization (COSEWIC 2008, p. 13).

Along Grand Lake, New Brunswick, Canada, there has been an increase in beach front development (i,e., cottage construction) (COSEWIC 2008, p. 18). Most of the Grand Lake sites are privately owned and not protected (COSEWIC 2008, p. 13). Construction, which is not allowed below the high water mark, results in the clearing of higher beach areas of vegetation and levelling the ground. Such alterations create conditions that are unsuitable for CTBs and eliminate the natural cover for their prey species. An approximate calculation of the amount of "occupied" land around Grand Lake (within a 100 meter (328 feet) buffer) increased by approximately 4 percent from the early-mid 1980s to 2014-2015, based on aerial photo interpretation. The amount of forested area within the 100m buffer remained about the same (New Brunswick Department of Energy and Resource Development unpublished data provided by Toner (2018)). According to Toner (2018), there are no current predictions of the rate of future cottage construction along Grand Lake.

To analyze possible relationships between land use and the extirpated/historical populations, land use data from 1997 (Wear 2011, p. 1) were compiled for the 17 U.S. counties that overlapped with the 18 extirpated/historical CTB AUs (Table 1). The median and ranges for the three major land use categories were: agriculture--34.6 percent (0 to 76.5 percent), forested--36.5 percent (0 to 75.9 percent), and urban--9.8 percent (2.9 to 67.7 percent) (Appendix A, Table A-1). Classifying the 17 counties into ranges of urban land use: 8 are in the 0 to 10 percent range; 4 are in the 10 to 20 percent range, 2 are in the 20 to 30 percent range, 1 is in the 30 to 40 percent range, and 2 are in the 60 to 70 percent range. Thus, no consistent pattern of the percentage of urban land is apparent in the habitats of these extirpated/historical populations.

3.2.2 Sand and Gravel Mining

Sand and gravel mining is conducted in stream channels, stream terrace deposits, and on flood plains across the United States (Langer 2003, p. 5). Whether or not these operations result in adverse impacts on stream ecosystems and CTB habitat depends on the nature of the operation. Mining operations can remove suitable cobble and sand habitat at the species' location and change the hydrology of the riverine system, which can affect downstream locations.

Although there are no known current in-stream sand and gravel mining operations occurring near extant CTB habitats, there is one historical case. The CTB in the Pemigewasset River may have experienced loss of habitat in the 1970s when extensive sand and gravel extractions in an 8-mile stretch of the river were undertaken during the construction of an adjacent interstate highway near Woodstock, NH. The extraction created a 30-acre pit area, a large and deep pond, and caused the river to jump its bank (known as an avulsion) and change its course. This reach of the Pemigewasset River became excessively shallow, wide, and unstable with continuous bank erosion, channel widening, and/or the development of multiple channels. This reach was ultimately assessed as non-supporting of aquatic life due to streambank destabilization and was classified by the New Hampshire Department of Environmental Services as impaired by a non-pollutant source (U.S. Environmental Protection Agency (EPA) 2012, p. 1).

A geomorphology-based stream restoration project to reconnect the river to its original channel, reduce impacts associated with floodplain loss, and restore the impacted river reach to a stable condition was initiated in 2006. A 2011 assessment of the affected river reach determined that the project was successful. The river reach now provides the physical conditions supportive of the aquatic life designated use (EPA 2012, pp. 1-2). All three extant CTB locations along the Pemigewasset River are located either within or downstream of the restored reach.

Quarry operations near streams can also result in destruction of CTB habitat. An extreme example occurred in a "runoff stream" near a gravel quarry east of Richmond, Indiana. CTBs were collected in 1976 and 1977 along the stream but on a visit in 2007 the surveyors noted that the stream was "destroyed by gravel operations" and no specimens were collected (Kritsky *et al.* 2009, p. 140).

We do not have any information to suggest that sand and gravel mining will increase in the future.

3.2.3 Recreation

Driving an All-Terrain Vehicle (ATV) through CTB habitat can directly affect the population by compacting cobble substrate, reducing or eliminating larval burrows, and crushing adults, pupae, and larvae. ATVs can indirectly affect CTB habitat quality through substrate disturbance, which can be a vector for the spread of invasive plants.

All-Terrain Vehicles were identified as a threat to one of the largest Grand Lake (New Brunswick) CTB sites, although evidence of impacts has varied over the years (COSEWIC 2008, p. 12). In 100-meter transect surveys conducted in 2004 and 2005, 26 and 31 CTB individuals were detected, respectively (COSEWIC 2008, p. 20). This area had no evidence of ATV use during those years. In July and August 2007, this same area was re-surveyed with only 9 and 3 CTB individuals observed respectively, and evidence of ATVs, i.e., tire tracks, ruts, soil compaction, and damaged plants, was documented (COSEWIC 2008, p. 12). At two other CTB sites in Grand Lake, which were visited in 2007 and did not have documentation of ATV use, CTB populations had not changed since previous surveys, which suggests that a decline was restricted to the site with ATV use. However, detectability during surveys could have affected count data making the overall significance of ATV impacts uncertain. Although there may be larval destruction resulting from ATV use, the colonizing nature of CTBs could allow for populations to recover quickly with the removal of ATVs if the habitat has not been seriously degraded.

Cobble bar habitat may also be disturbed by people walking on it, which can cause soil compaction and collapse of larval tunnels (COSEWIC 2008, p. 20). The extent to which this occurs depends on the accessibility of the sites, i.e., whether burrows are in locations where people walk and the intensity of the recreational use. River sites may be adversely impacted by recreational boating, as island sites are made more accessible for pedestrian recreation. For example, sections of the Genesee (New York) and Pemigewasset Rivers (New Hampshire) have become popular destinations for rafting, kayaking, and tubing (Hudgins *et al.* 2011, p. 315; von

Oettingen 2018b) due to their shallow nature, steady flows, and accessibility for stopping off at cobble bars.

On the Genesee River, a previously occupied CTB site has become a drop-off area for buses and it is possible that this increase in human traffic impacted suitable larval habitat. Intense pedestrian recreation use may also interrupt reproduction by preventing courtship, disrupting copulation, and for small populations, preventing adult tiger beetles from encountering each other as beetles are forced to constantly take flight when pedestrians walk through their habitat.

3.2.4 Uncertainty

Habitat loss and degradation may occur as a result of different activities including changes in land use, mineral extractions in or near the CTB riverine habitat, or recreational activities.

Uncertainty in the United States land use analysis arises through the application of county scale land use data to CTB AUs. The AUs often cross county lines so the analysis was done on the single county with the greatest overlap with the AU boundaries. Thus, there may be cases where the urban land use in the county either overestimates or underestimates the urban land use in the AU. Furthermore, all land use projections are estimates based on current data and inputs to two models, with model uncertainty described in Wear 2011 (p. 33-37). The adjustments within each stream section that is undergoing the effects of urbanization will vary across space and time. CTB habitat may receive additional sediment if the stream section is aggrading or suffer effects from erosion if the section is in an erosional phase. Thus, the impacts to CTB habitat may vary over time both in degree and direction of the change. Some changes may be positive and some negative in relation to CTB habitat.

Recreational activities with the potential to adversely affect CTBs have been documented in 3 AUs. We are uncertain whether these types of activities will remain the same, increase, or decrease in the future. Because of inconsistent surveys and no standardized method of estimating a population, we do not know how the activities have affected the AU populations.

3.3 Water Quality

Water quality stressors can adversely affect CTB populations through alteration of habitat or direct toxicity to CTBs or their prey. Of primary concern are excess nutrients and silt deposits on CTB habitats, which could enhance vegetative growth by fertilizing plants or providing more suitable substrate for plant growth (COSEWIC 2008, p. 19). Siltation from excess sediment loading could also alter the preferred mix of grain size and unembedded cobble (see section 2.4), making habitat unsuitable for the CTB. Sources of sediment include residential runoff, forestry and mining operations, agricultural practices, construction sites, stream bank erosion, and in-stream disturbances (EPA 2002).

To evaluate the threats to CTB habitats, we relied upon each state's Clean Water Act 303(d) list of impaired waters as a standard approach for gathering water quality data. The Clean Water Act Section 303(d) requires that total maximum daily loads (TMDLs) be developed for impaired water. A TMDL defines the "allowable" load of a specific pollutant that the waterbody can assimilate and still meet water quality standards. The allowable load (mass over time) is equal to the sum of the waste load allocation from point sources, the load from non-point sources and naturally occurring background sources, and a margin of safety which accounts for uncertainty (Wallace *et al.* 2018, p. 1). Sediments are commonly listed as a target for TMDLs, with allocations based on modeling or comparisons to reference watersheds, defined as non-impaired watersheds in the same physiographic province with similar land use (Wallace *et al.* 2018, p. 2).

We reviewed maps of the 303(d) listed water bodies in relation to the CTB AUs and river reaches. The 303(d) listings that overlap with the extant CTB AUs are summarized in Table 5. None of the identified listings are for nutrients and sediments, which as stated above, can directly alter CTB habitat. Other impairments are attributed to pH, dissolved oxygen saturation, E. coli or bacteria, and temperature. Of these, low dissolved oxygen and bacterial impairments may be related to nutrient and/or sediment inputs. Thus, low dissolved oxygen and bacteria may be connected to possible adverse effects on CTB habitat from nutrients and sediment loading. These low dissolved oxygen and bacteria listings occur in the Upper and Middle Pemigewasset River, Winooski River, White River, and French Creek - Ohio River AUs. It is uncertain whether impairments for pH or temperature (unless it was at or approaching a lethal level) would adversely impact CTB habitat.

Of the 303(d) listings, the following extant AUs have toxic chemical concerns: Upper and Middle Pemigewasset (NH), Vernon-Dam-Connecticut River (NH/VT), Raymondskill Creek–Delaware and Flat Brook–Delaware River (NJ/PA), Allegheny River (PA), French Creek-Ohio River (OH/WV), and Pipe Creek–Whitewater River (IN). Several of these AUs are listed for human health concerns from chemicals that bioaccumulate in fish, such as PCBs, dioxin, chlordane, and mercury. It is unlikely that these chemicals pose direct or indirect toxic threats to CTBs or their prey. It is uncertain whether the listings for metals, pH, aluminum, copper, and iron are based on conditions or concentrations that could be hazardous to CTBs or their prey.

Table 5. Water quality issues of extant CTB analytical units per 303(d) Listings

State	AU	Year	303(d) Listings	Additional Information from 303(d) listing
IN	Pipe Creek–Whitewater River	2016	PCBs (fish tissue)	Two reaches of the Whitewater River in Franklin County are listed for PCBs in fish tissue (Indiana Department of Environmental Management (2016; Appendix P, spreadsheet)
NH	Upper and Middle Pemigewassett	2016	pH, aluminum, dissolved oxygen saturation	Source of contaminants unknown (New Hampshire Department of Environmental Services (NH DES) 2017, Appendix 1)
NH/VT	Vernon Dam-Connecticut River	2016	aluminum, copper	Source of contaminants unknown (NH DES 2017, Appendix 1)
NJ/PA	Raymondskill Creek–Delaware River and Flat Brook–Delaware River	2014	chlordane, mercury, DDT, PCBs (all in fish tissue), pH	Included in Delaware River Reach 1C listings for fish tissue contamination and pH (New Jersey Department of Environmental Protection (2017, pp. 23-24)

OH	Taylor Creek– Great Miami River	2018	Unknown	This watershed was listed as unknown as far as attainment of water quality with a TMDL scheduled for 2020 (Ohio Environmental Protection Agency 2018, p. J-34); The Lower Great Miami River has evidence of nutrient over-enrichment with high chlorophyll a in benthic algae and seston (LimnoTech 2017, p. 109).
OH/WV	French Creek-Ohio River	2016	bacteria, dioxin, iron	Ohio River (Middle North reach) listed for bacteria, dioxin, and iron by West Virginia Department of Environmental Protection (2016, List p. 8)
PA	Allegheny River	2016	metals, pH	Sections of the Allegheny River in Clarion County near Brady and Madison are listed for metals and pH due to abandoned mine drainage (Pennsylvania Department of Environmental Protection 2016, pp. 989-990)
VT	Winooski River	2016	E. coli	Mouth to Winooski Dam; attributed to combined sewer outfalls in Burlington fishery (Vermont Department of Environmental Conservation (VT DEC) 2016, p. 5)
VT	White River	2016	E. coli	Three reaches with consistently elevated E. coli (VT DEC 2016, p. 6)
VT	Rock River -West River	2016	temperature	Temperature in West River from Ball Mtn. Dam to Townshend Dam adversely affects (VT DEC 2016, p. 7)

Canadian provinces do not have impaired waters lists analogous to the 303(d) listings. For rivers, a Water Quality Index is calculated based on comparisons of chemical contaminant concentrations, nutrients, and pH with Guidelines for Freshwater Aquatic Life (New Brunswick Department of Environment 2007, p. 1). The most recent Watershed Summary for the Saint John River is based on 2003-2006 Water Quality Index data and comparisons with guidance values for nutrients, pH, E. coli, and dissolved oxygen. None of the 30 water quality monitoring sites in the watershed exceeded the guidance value for nitrate (New Brunswick Department of Environment 2007, p. 1). No data were provided on suspended sediments or total suspended solids.

All Saint John River CTB sites are adjacent to agricultural areas that are largely potato farms with about 25 percent agricultural land use (Kidd *et al.* 2011, p. 32). Evidence of agricultural runoff at a CTB island site near Hartland, New Brunswick was documented during an August 2005 survey (COSEWIC 2008, p. 19). Cobblestones along the island shoreline and adjacent river bank were coated with a layer of organic material and the air smelled strongly of poultry manure. It was uncertain whether this was a chronic or acute problem, as there was less evidence of agricultural runoff at this site during the 2006 and 2007 surveys (COSEWIC 2008, p. 19).

No similar Watershed Summary was identified for Grand Lake, although nutrients of unknown origin appear to be a concern. A Public Health Advisory issued for Grand Lake on July 15, 2015 for blue-green algal blooms is still in place (Government of New Brunswick 2018a, p. 1). However, CTBs are extant in this area.

Water quality concerns may become more severe in the future in 4 AUs with the largest projected increase in urbanization (see section 3.2.1) and with the projected changes in climate throughout the CTB range (see section 3.5). The climate-related changes involve changes in flow extremes (see section 3.1) which could result in more 303(d) listings for sediment and nutrients.

3.3.1 Uncertainty

Because CTB habitat is only partially aquatic (i.e., on cobble bars rather than in the water column or bottom sediments), the relevance of water quality impairments due to contaminants is uncertain. The 303(d) lists are based on the best available monitoring data. Monitoring programs vary across states and watersheds in sampling design, the number of samples within streams, and the list of analytes. Thus, there is uncertainty as to how well-characterized the reaches are in terms of sediments and nutrients, which are the water quality stressors we assume have the greatest direct impacts to CTB habitat. Site-specific information is rarely available as to where excess sediments deposit and whether these areas overlap with CTB habitat. Some streams are listed for urban or agricultural runoff, but it is unclear whether these listings are related to sediments or nutrients. It is also uncertain whether listings for toxic contaminants could reflect adverse effects on CTBs or their prey. Water quality criteria are intended to be protective of 95 percent of aquatic species and the data used to develop the criteria may not include related taxa (other beetles with similar sensitivity to toxic chemicals) or prey species. Thus, there are uncertainties in assessing the effects of contaminants, nutrients, and sediments on the different life stages of the CTB or determining whether there will be indirect effects on CTB prey.

3.4 Effects of Small Population Size

A species may be considered rare because of a limited geographical range, specialized habitat, or small population size (Primack 1998, p. 194). Many naturally rare species have persisted for long periods within small geographic areas, and many naturally rare species exhibit traits that allow them to persist despite their small population sizes.

Small populations also can be vulnerable due to a lack of genetic diversity (Shaffer 1981, p. 133). Although there are no population estimates for the majority of CTB sites, surveys indicate that most populations are estimated to be small, rarely exceeding 60 individuals at a site with the exception of locations in Alabama, Maine and Canada (see section 2.2). Population estimates were completed for the two Canadian AUs using data from surveys completed in 2007 and 2008. A combined total of 488 beetles were estimated for two of three Grand Lake localities (01AO000), and 4,487 for the four Saint John River localities (01AJB00). These estimates were based on two or three day mark, release, and recapture studies using the Lincoln Index (COSEWIC 2008, p. 16).

3.4.1 Uncertainty

We lack information regarding genetic diversity of the CTB. According to Knisley (2017), the CTB is genetically adapted to colonize habitat patches, which could indicate that small population size is less of a concern, especially within metapopulations. Lack of biological and demographic data hinders our ability to understand small population effects, but we theorize that the impacts are limited in comparison to environmental stressors that affect habitat quality.

3.5 Effects of Climate Change

We evaluate the climatological indicators that would most affect CTB habitat and resource needs at each life stage (see section 2.4, Table 1). These are the projected changes in: winter and summer temperature; winter, spring and summer precipitation; the frequency and intensity of extreme precipitation events; the duration and intensity of spring and summer flooding; and the intensity and duration of drought. Increased temperatures may harm the CTB if its thermal limit is exceeded (see section 2.4) or indirectly through changes in precipitation patterns (e.g., rain vs snow) and extent and frequency of ice scour (see below). In addition, heat and drought in the summer could result in dessication of larvae. Information on many of these indicators was incomplete at the AU level. In some cases, we relied on mapped data that allowed interpretation of the predictions for the AUs; in other cases we report predictions at the state and province scale.

The primary sources of climate data and predictions were taken from the most recent U.S. Global Change Research Program (USGCRP) reports: Third National Climate Assessment (NCA3, Melillo *et al.* 2014, entire report), Climate Science Special Report (Wuebbles *et al.* 2017, pp. 12-35; Vose *et al.* 2017, pp 185-206; Easterling *et al.* 2017, pp. 207-230), and draft Fourth National Climate Assessment (NCA4; USGCRP 2018 entire). All of these reports used the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP5). Wuebbles *et al.* (2017) and NCA4 focused on two pathways: the highest radiative forcing pathway Representative Climate Pathway[4] (RCP)8.5 and the medium-low radiative forcing scenario, RCP4.5. For detailed descriptions of these scenarios, see Hayhoe *et al.* (2017, pp. 135-149), and refer to Brown and Caldeira (2017, p. 47) for updated (and increased) temperature projections for each pathway. As part of NCA4, state summaries were prepared by the National Oceanic and Atmospheric Administration (Kunkel *et al.* 2017, p. entire) with maps of the projections using the RCP8.5 path. For New Brunswick, we used Environment Canada (2016, pp. 11-26) in which projections are based on RCP8.5.

We primarily use RCP8.5 based on data on current trends in global emissions (Jackson *et al.* 2017, p. entire) and the long-lasting influence of greenhouse gases already in the atmosphere (Collins *et al.* 2013, p. 1102-1105). The U.S. Global Change Research Program stated with very high confidence that the observed increase in global carbon emissions over the past 15-20 years has been consistent with higher scenarios such as RCP8.5 (Wuebbles *et al.* 2017, p. 31). It is therefore reasonable to conclude that changes from now through mid-century will also be closer to RCP8.5 than to RCP4.5. We did, however, use RCP4.5 in one of our future scenarios (see section 5.2).

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[4] Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. The different trajectories describe different climate futures, depending on how much greenhouse gases are emitted.

3.5.1 Temperature and Precipitation Projections

According to Vose (2017, p. 197), “Daily extreme temperatures are projected to increase substantially in the contiguous United States, particularly under the higher scenario (RCP8.5). For instance, the coldest and warmest daily temperatures of the year are expected to increase at least 5°F (2.8°C) in most areas by mid-century, rising to 10°F (5.5°C) or more by late-century. In general, there will be larger increases in the coldest temperatures of the year, especially in the northern half of the Nation, whereas the warmest temperatures will exhibit somewhat more uniform changes…”

Under both RCP4.5 and RCP8.5, average annual temperatures are projected to increase across all U.S. states with CTB AUs (Vose *et al.* 2017, p. 196). The following discussions refer to RCP 8.5. For the U.S. northeast states, the average increase is projected at 2.83°C (5.09°F) by the mid-century (2036-2065) and 5.06°C (9.11°F) by the late century (2070-2099) (Vose *et al.* 2017, p. 197). Similar changes are projected for the midwest U.S. states, with slightly lower projections for the southeast states (2.39°C (4.30 °F, mid-century) and 4.29 °C (7.72°F, late-century)). The temperature changes predicted for New Brunswick using RCP8.5 for 2046-2065 and 2081-2100, relative to 1986-2005 (Environment Canada 2016, pp. 14-15), are similar to the predictions for the Northeast U.S. In the winter, the average temperature is predicted to increase by 3.6°C (6.5°F) by mid-century and by 6.4°C (11.5°F) by late century. In the summer the predicted temperature increases are 3.0°C (5.4°F) and 5.4°C (9.7°F), respectively.

A study of the impact of climate change on northern New Hampshire (which encompasses a number of CTB AUs) mirrors Vose’s projections (Wake *et al*. 2014 entire). The authors conclude that for northern New Hampshire the frequency of extreme heat days is projected to increase dramatically, and the hottest days will be hotter. Moreover, extreme cold temperatures are projected to occur less frequently, and extreme cold days will be warmer than in the past (Wake *et al*. 2014 entire). For example, the town of Plymouth, NH (located due south of the Pemigewasset AUs) is anticipated to experience an annual increase in the minimum temperature of 1.0 to 1.1°C (1.8 to 2.0°F) (Low emission scenario to High emission scenario) by 2039 and an annual increase in temperature of 1.6 to 2.8°C (2.9 to 5.1°F) by 2069 and an annual increase in maximum temperatures of 1.0°C (1.8°F) by 2039 and an annual increase in temperature of 1.7 to 2.7°C (3.1 to 4.9°F) by 2069 (Wake *et al*. 2014, p.64). Both AUs in this region would experience these projected temperature increases.

The frequency of extreme precipitation events is expected to increase based on RCP8.5 across the CTB U.S. range (Janssen et al. 2014, p. 110-111; Kunkel et al. 2017, relevant state summaries) and New Brunswick (Environment Canada 2016, p. 24). The seasonality of these events has been projected to change from the base period 1901 to 2005 to the projected period of 2006 to 2100 (Janssen et al. 2016, pp. 5387-5388). In general, the fraction projected to occur in the winter, spring, and fall will increase and the fraction projected to occur in summer will decrease (Janssen et al. 2016, pp. 5387-5391).

By mid-century, winter precipitation in CTB locations in New York, New Hampshire, Vermont, and Maine were projected to increase by greater than 15 percent, with most as rain rather than snow (Frankson *et al.* 2017a, p. 5; Runkle *et al.* 2017a, p. 4; Runkle *et al.* 2017b, p. 4; Runkle *et* *al.* 2017c, p. 4) (Table 6). For Pennsylvania, the projection is for 10 to 15 percent increase in winter precipitation but the summary does not state whether there will be more rain than snow (Frankson *et al.* 2017b, p. 4). Predictions for 2070-2099 are also provided in Table 6, with increases as high as 20 to 30 percent for winter precipitation (Easterling *et al.* 2017, p. 217). For New Brunswick, the 50th percentile prediction was for a 3.6°C (6.5°F) increase in winter temperature for 2046-2065 and a 6.4°C (11.5°F) increase for 2081-2100 (Environment Canada (2016, p. 14). Winter precipitation was projected to increase 11.4 percent in 2046-2085 and 19.0 percent in 2081-2100. Coupled with the temperature projection, this would occur more often as rain. The New Brunswick Climate Change Action Plan (New Brunswick Department of Environment 2018, p. 9) noted a 50 percent decrease in snow pack over the past 30 years and the New Brunswick Summary of Predicted Impacts (Government of New Brunswick, 2018b, p. 1-2) predicted that spring peak flows will occur earlier and be reduced in duration.

For Ohio and Indiana CTB habitats, the projection is for 10 to 15 percent increase in winter precipitation by mid-century but the summaries do not state whether there will be more rain than snow (Frankson *et al.* 2017c, d; p. entire). CTB habitat in Kentucky is mapped as having a 5 to 10 percent projected increase in winter precipitation and those in Alabama a 0 to 5 percent increase in winter precipitation (Frankson *et al.* 2017b, p. 4).

Spring precipitation in the northern states is projected to increase by 10 to 15 percent (Kunkel *et al.* 2017; relevant state summaries). Predictions for 2070-2099 (Table 6) have increases of 10 to 20 percent for spring precipitation for the northeast U.S. (Easterling *et al.* 2017, p. 217). No predictions of spring precipitation were listed in Environment Canada (2016, p. entire). An earlier spring snowmelt (Horton *et al.* 2014, p. 374) with higher winter and spring rain is predicted to cause greater winter/spring flooding (Table 6). In addition, the projected increases in winter temperatures could affect the timing of river and lake freeze-up and breakup. Higher water and air temperatures in the fall and spring could combine to delay the time of first ice-formation (fall) and advance the time of first ice break-up (spring). In combination with increased flows, depending on the time of year, there could be an increase in the severity of ice jams, especially where flows are enhanced by regulated flows (dams) (Beltaos and Prowse 2009, p. 135). Ice jam floods can produce much deeper and faster flooding than open water floods, affecting erosion and sedimentation processes, destabilizing banks, and affecting channel morphology as well as aquatic habitat and water quality (Beltaos and Prowse 2009, p. 139). If ice breakup severity remains the same, increases in river sediment loads are still likely to result from possible increases in the frequency of freeze-thaw cycles (Beltaos and Prowse 2009, p. 140).

Spring precipitation in Ohio and Indiana is projected to increase by 10 to 15 percent (Frankson *et al.* 2017c, p. 5). Spring precipitation in CTB habitats in Kentucky is projected to increase by 5 to 10 percent and those in Alabama by 0 to 5 percent (Frankson *et al.* 2017c, p. 5). Increases in 2070-2099 are projected to be about 5 percent higher than those for 2036-2065 (Easterling *et al.* 2017, p. 217; Table 6).

Because summer precipitation projections were not addressed in the state climate summaries, we relied on Lynch *et al.* (2016, pp. 358-363) who analyzed monthly projections for precipitation from multiple models. For the AUs ranging from Ohio to Maine, the prediction is for no measurable change in summer precipitation in 2071-2100 compared with 1971-2000.

In the Northeast, the increased summer temperatures will lead to greater evaporation such that there will be heavier rain events interspersed with periods of summer drought (Horton *et al.* 2014, p. 374). In New Brunswick, summer precipitation is projected to increase by 4.2 percent in 2046-2065 and 7.8 percent in 2081-2100, with an increased frequency of thunderstorms. Warmer temperatures (3.6°C (6.5°F) higher in 2046-2065, 6.4°C (11.5°F) higher in 2081-2100; Environment Canada 2016, p. 15) would result in increased frequency, duration, and severity of drought in New Brunswick in between these storms (New Brunswick Department of Environment 2018, p. 2).

For summer precipitation, Staudinger *et al.* (2015, Chapter 1, p. 17), indicated about a 0 to 5 percent decrease in summer precipitation for the Ohio, Indiana, and Ohio River locations and a 5 to 10 percent decrease in Kentucky by mid-century. Projections under RCP 8.5 for 2070-2099 for summer precipitation are provided in Easterling *et al.* (2017, p. 217). For the AUs in Kentucky and Alabama, summer precipitation was projected to increase by 0 to 10 percent. For Indiana and Ohio, the projection was for a 10 to 20 percent decrease. Coupled with the increased summer temperatures, it is likely that there will be prolonged summer droughts in Ohio (Frankson *et al.* 2017c, p. 5), Indiana (Frankson *et al.* 2017d, p. 4) and the Southeast (Carter *et al.*, 2014, p. 404) interrupted by heavy storms.

Table 6. Precipitation projections and predicted effects on flooding and drought for states with CTB AUs.

State	Fall/Winter Precipitation (2036-2065; 2070-2099)	Spring/Summer Precipitation (2036-2065; 2070-2099)	Predicted Climate Change Effects[a]
AL	+0-5% + 0-10%	+0-5% + 0-10%	Increased intensity of droughts
IN	+ 10-15%[b] + 10-20%[c]	+ 10-15%[b] + 10-20%[c]	Increased frequency and intensity of floods, especially in spring; increased intensity of summer droughts
KY	+5-10% + 10-20%	+5-10% + 10-20%	Changes in summer and fall precipitation are uncertain; floods and droughts more intense
ME	+ > 15%[b,d] + 20-30%[b]	+ 10-15% + 10-20%[c]	Increased risk of springtime flooding;
NH	+ >15%[b,,d] + 20-30%[,c]	+ 10-15%[b] + 10-20%[c]	Earlier ice out dates; increased frequency and intensity of floods
NY	+ >15%[b,d] + 20-30%[c]	+ 10-15%[b] + 10-20%[c]	Increased frequency and intensity of floods, especially in spring

OH	+ 10-15%[b] + 10-20%[c]	+ 10-15%[b] + 10-20%[c]	More frequent and intense flooding, especially in spring; more intense drought
PA	+ 10-15%[b] + 10-20%[c]	+ 10-15%[b] + 10-20%[c]	Increased risk of springtime flooding due to earlier snowmelt
VT	+ >15%[b,d] + 20-30%[c]	+ 10-15%[b] + 10-20%[c]	Increased frequency and intensity of floods

[a] Effects listed are from Kunkel *et al.* (2017, relevant state climate summaries)
[b] Listed as statistically significant in most models according to Kunkel *et al.* (2017, state summaries)
[c] Listed as "large compared to natural variation" (Easterling *et al.* 2017, p. 217)
[d] More in the form of rain than snow (Kunkel *et al.* 2017, state summaries)

3.5.2 Climate Effects on AUs Affected by Managed Flows

The climate-driven changes in flow will result in a greater imbalance in water availability in wet vs. dry months. Such factors may affect operations of dams in the 10 AUs (Table 3) affected by managed flows. In general, the dams will need to retain more water in the wet season and release a larger portion of their storage in the dry season (Ehsani *et al.* 2017, p. 444). These climate-driven factors should be included in relicensing evaluations (see section 3.1.1.4) that need to consider the impacts of dam operations on threatened and endangered species.

3.5.3 Climate Change Vulnerability Analyses for the CTB

Climate change vulnerability analyses for the northeast and midwest states was compiled and reviewed by Staudinger *et al.* 2015, Ch, 2 and 3. Three state reports (New York, West Virginia, and Pennsylvania) were available regarding the potential impact of climate change on at-risk species, all based on the NatureServe Climate Change Vulnerability Index (CCVI). The CCVI methodology is based on the following factors: direct and indirect exposure, sensitivity, documented response, and modeled response, with details provided in Byers and Norris (2011, p. 4) and Schlesinger *et al.* 2011, p. 3-4).

For New York State, the CTB was categorized as "not vulnerable/presumed stable" in terms of its vulnerability to climate change up to the year 2050 (Schlesinger *et al.* 2011, p. 3, 19). This means that, "Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change." Confidence for the category was rated as very high (Schlesinger *et al.* 2011, p. 41). The CTB was ranked as moderately vulnerable (abundance and/or range extent within geographical area likely to decrease by 2050) in West Virginia (Byers and Norris 2011, p. 15) and Pennsylvania (Furedi *et al.* 2011, p. 10). In West Virginia, the authors stated that the moderate ranking was due to "their physical habitat specificity and presumed genetic bottlenecks, but they gain resilience from their tolerance of varying disturbance regimes, somewhat broad temperature tolerance, and relatively good dispersal ability" (Byers and Norris

2011, p. 15). In Pennsylvania, this ranking was attributed to their "habitat specificity, negative consequences as a result of increased flooding events, and evidence of genetic bottlenecks" (Furedi *et al.* 2011, p. 10).

In addition to the climate change vulnerability analyses conducted for West Virginia, New York and Pennsylvania, a climate change vulnerability assessment was conducted for Maine's wildlife Species of Greatest Conservation Need, state-listed plant species, and key habitats of the Maine Comprehensive Wildlife Conservation Strategy (Whitman et al. 2013, p. 1 – 5). The assessment included 142 species, including the CTB. The CTB was ranked as medium vulnerability to the effects of climate change, meaning that climate change is likely to have an intermediate impact on the species' range and/or population size in Maine within the next 50 to 100 years. The reviewers' confidence in the rating was low because of the limited distribution of the species in Maine, and the uncertainty regarding hydrology needs and threats (Whitman et al. 2018, p. 58).

We are unaware of climate change vulnerability analyses for other states with extant CTB populations or for New Brunswick.

3.5.4 Impacts on Resource Needs

In the winter and spring, the altered hydrology would affect the maintenance of cobble habitat (unembedded substrate with 6 to 30 percent sand and sparse vegetation (Table 1)). Changes in channel morphology as a result of flooding and sedimentation processes may cause CTB habitat degradation by altering or eliminating cobble bars or changing the cobble bar structure (size of cobble, interstitial sand). The projected decrease in ice scour in the northern portion of the CTB range, one factor that maintains sparse vegetation, could result in more vegetation taking hold and decrease the suitability of the habitat for larvae. Extended spring flooding with prolonged inundation could also be detrimental to larval survival (see section 2.5.1, Table 2).

Prolonged extreme heat, particularly in the southern portion of the CTB range, could approach the thermal tolerance limit for the CTB potentially resulting in reduced productivity, increased susceptibility to predation or mortality of larvae or pupae. Prolonged and more intense drought would adversely affect the CTB at several life stages. Laboratory research with hairy-necked tiger beetle (*Cicindela hirticollis*) larvae (another tiger beetle species found along riverine and coastal shorelines) demonstrated that these larvae select soils with surface moisture levels of 7 percent to 50 percent saturation to dig new burrows and avoided digging burrows in soils with lesser moisture content (Brust *et al.* 2006, p. 251, 256). Soil desiccation could prevent larvae from burrowing or adults from ovipositing. In addition, larvae may be unable to avoid desiccation during the drought periods.

The extent to which extreme storms will result in floods that will harm CTB habitat through prolonged inundation is uncertain (see section 3.3.1.1). These storms are projected to occur in areas that are also projected to undergo drought. The rapid changes in water levels may result in more movement of bed and bank sediment that could be disruptive to cobble bar habitats.

3.5.5 Uncertainty

Projections of climate change and its effects may be affected by a range of uncertainties, especially when evaluating downscaled models. The spatial scales of precipitation changes are more local than those for temperature. Storm events can be highly localized such that even weather predictions can be inaccurate. Thus, there is uncertainty regarding precipitation-driven flooding and whether floods will occur at times that are beneficial (early spring, if not prolonged) or harmful (prolonged summer flooding) to the CTB. Finally, it is unknown precisely how each habitat is maintained with a low (<10 percent) vegetation density. Thus, the impacts of decreased ice scour or spring floods on vegetation density are difficult to predict.

3.5.6 Summary

Under both RCP4.5 and RCP8.5, average annual temperatures are projected to increase across all U.S. states with CTB AUs (Vose et al. 2017, p. 196). In the northern and midwestern U.S. states and New Brunswick, Canada, annual temperatures are projected to increase by mid- and late century. The projected increases in winter temperatures for the northern states could affect the timing of river and lake freeze-up and breakup. Higher water and air temperatures in the fall and spring could combine to delay the time of first ice-formation (fall) and advance the time of first ice break-up (spring). Thus, there are predictions for increased springtime flooding. In the south, there will also be increases in annual temperature, but slightly less in magnitude than in the midwest and northeast. More intense and extended summer drought is predicted throughout the range, with the most extreme conditions in the midwest and south.

We summarized the NCA4 state summaries (Kunkel et al. 2017, pages for relevant states) for mid-century (2036 - 2065) precipitation projections and used Easterling et al. (2017, p. 217) (Table 6) for 2070-2099 precipitation projections. Precipitation is projected to increase in the winter, largely in the form of rain rather than snow. In many northern states, the predictions are for a greater than 15 percent increase in winter precipitation by mid-century and a 20 to 30 percent increase by the end of the 21st century. Summer precipitation predictions for the northeastern states are for little change. Throughout the CTB's range, there will be a greater frequency of extreme precipitation events. For the AUs in Kentucky and Alabama, summer precipitation was projected to increase by 0 to 10 percent. For Indiana and Ohio, the projection was for a 10 to 20 percent decrease.

Changes in these indicators are likely to affect CTB life stages and habitat in several ways. Summer extreme heat may approach the species' thermal tolerance limit for survival of larvae, which are less mobile than adults. Other changes could be detrimental to CTB habitat through alteration of the extent of erosion and sedimentation in all seasons. In the winter, reduced ice scour could allow vegetation to become established to a level that is unsuitable for larval burrowing. Prolonged flooding could extend past the period that larvae can tolerate. In the summer, the predictions of more extreme precipitation could lead to more movement of sediment; however, the more likely impact is predicted to occur from drying of larval burrow habitat because of more intense and extended drought. Soil desiccation could prevent larvae from burrowing or adults from ovipositing. In addition, larvae may be unable to avoid desiccation during the drought periods.

3.6 Collection

Tiger beetles are charismatic beetles that are attractive to many collectors and as such have generated a considerable worldwide following of amateur and professional entomologists focused on collecting them for scientific research, educational purposes, and personal collections. Global interest in tiger beetles is exemplified by the journal *Cicindela*, which is focused exclusively on tiger beetle genera, including the Cicindela genus (to which the CTB belongs). *Cicindela* (now in its 42nd year), presents articles on the taxonomy, biology, and conservation of tiger beetles.

Tiger beetle collecting for research, genetic or taxonomic considerations, or delineating the distribution of species is important to understanding the life history, trends, and status of a species (Knisley 2017; MacRae 2018). Collection of this species for scientific research (e.g. overutilization) has not been documented as evidenced by the lack of research and publications on the species. However, given the widespread interest as collectable items, tiger beetles, including the CTB, may be vulnerable to over- or illegal collection by a minority of tiger beetle collectors who are interested in having representative specimens from all known locations. Collection has been documented as a potential threat of varying degrees for some tiger beetle species including the federally endangered Ohlone tiger beetle (*Cicindela ohlone*, USFWS 2001, p. 50346-50347), the federally endangered Miami tiger beetle (*Cicindelidia floridana*, USFWS 2016, p. 68996-68997), and the non-listed Highlands tiger beetle[5] (*Cicindelidia highlandensis,* USFWS 2009, p. 20). It is uncertain to what extent collecting may impact the CTB as a species, but it is possible that recently discovered new sites may be vulnerable to collection due to the rarity of the species (MEDIFW 2016. p 2). The CTB is afforded protection from collecting without a state permit for the seven states in which it is state listed as endangered or threatened (see section 3.8.1 Table 7). However, enforcement of these laws is often lacking or ineffectual. Newly discovered sites may be more vulnerable to collection than sites that have been previously reported since private collectors desire representative specimens from as many sites as possible (similar to legitimate museum collections). Our AUs are large enough to preclude pinpointing CTB locations, especially new sites, and should provide some protection against collection pressure.

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[5] Specimens of this species are currently for sale on The Bugmaniac website: (http://www.thebugmaniac.com/index.cfm/page:shop/shopaction:search?query=cicindela accessed February 28, 2018)

Table 7. State Wildlife Action Plan conservation measure summaries

State	State Status	Rarity Ranks according to NatureServe[6]	State Wildlife Action Plan
Alabama	Not listed[7]	S1[8]	Imperiled, but not presently considered as SGCN
Indiana	Endangered	S2[9]	No mention
Kentucky	Not listed	S1	No mention
Maine	Endangered	S1	Listed as SGCN, provides information specific to CTB, stressors, conservation actions
Massachusetts	Endangered	Not ranked/Under review	Listed as SGCN, associated fact sheet provides information on status, threats
Mississippi	Not listed	SX[10]	No mention/status uncertain
New Hampshire	Endangered	S1	Listed as SGCN, Conservation Measures Identified
New Jersey	Not listed	S1	Noted as SGCN, General Conservation measures, no specifics for CTB
New York	Not listed	S1	Noted as SGCN, status and threats synopsis
Ohio	Threatened	S2	General Conservation measures, no specifics for CTB
Pennsylvania	Not listed	S1	General Conservation measures, no specifics for CTB
Vermont	Threatened	S1	Addresses Tiger Beetle Group, identifies threats, research and monitoring needs
West Virginia	Not listed	S1	General Conservation measures, no specifics for CTB
New Brunswick Canada	Endangered	S1	Specific recovery strategy (Environment Canada 2013)

The greatest impact to the species from unregulated or unauthorized collecting would occur at sites with low numbers of adults or if reproductive adults are removed early in the flight season or prior to oviposition (USFWS 2016, p. 68996), potentially causing extirpation at the local level. Single visit surveys generally document between 1 and 20 individuals per survey.

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[6] Conservation status is summarized as a series of ranks derived at global, national, or subnational (state/provincial) levels on a five-point scale from critically imperiled (G1, N1, S1) to secure (G5/N5/S5). (NatureServe 2018b).

[7] Species with state ranks of S1, S2, or S3 are tracked by the State but not listed officially under state law.

[8] Critically Imperiled— At very high risk of extirpation in the jurisdiction due to very restricted range, very few populations or occurrences, very steep declines, severe threats, or other factors.

[9] Imperiled— At high risk of extirpation in the jurisdiction due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors.

[10] Presumed Extirpated—Species or ecosystem is believed to be extirpated from the jurisdiction (i.e., nation, or state/province). Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered. [equivalent to "Regionally Extinct" in IUCN Red List terminology]

Removing adults prior to reproduction from these small sites, especially if they are isolated, could place these populations at risk of extirpation since they may not be able to withstand additional losses. Collectors may be unable to recognize when they are depleting occurrences below the thresholds of survival or recovery if they are not familiar with the site and tiger beetle density (USFWS 2016, p. 68996-68997).

3.6.1 Summary

To date, there has been no documentation of CTB sites becoming extirpated due to over collection. Although there is still widespread interest in maintaining private collections of tiger beetles, some enthusiasts are now documenting species through photography or are focusing efforts on the more diverse western species (Knisley 2017). The CTB range is widespread and consists of multiple metapopulations. The transient nature of some of the smaller sites within these metapopulations, where adults may disperse and establish for a short time period and then disappear, may minimize the likelihood of collecting if these sites are not geospatially identified or consistently occupied.

3.7 Disease and Predation

Currently there is no evidence of diseases that impact CTB populations. Known predators of the CTB include robber flies, lizards, ants, parasitoid insects, and birds. Larval tiger beetles are generally consumed by ground-foraging woodpeckers and ants, but are most vulnerable to mortality by parasitoid wasps (*Methocha* spp.) and flies (*Anthrax* spp.). Anti-predator mechanisms used by adult tiger beetles include flight, running, camouflage, chemical defenses, and excellent vision that help mitigate predation impacts (Pearson 1984, pp. 133-135). There is no evidence that predation is having a population or species level effect on the CTB, although further studies are needed to corroborate this assumption.

3.8 Conservation Efforts

A variety of techniques can be used to protect at-risk, threatened, and endangered species depending on the stressors limiting the species' ability to maintain viable populations or resiliency. Land conservation, regulatory mechanisms to protect habitat or individuals, population augmentation or introductions, and life history research are a few of the tools available to species' managers.

For species nearing extinction, keeping individuals in ex situ refugia, and/or implementing captive propagation (breeding) programs can be developed to keep a species in existence while other actions such as habitat protection are applied. Captive propagation has not been applied to the CTB. However, captive propagation was successfully achieved with the Puritan tiger beetle and could be developed for the CTB (Gwiazdowski 2018). Translocating individuals from robust populations to supplement smaller populations or establish new populations has been successfully used on a number of declining tiger beetle species including the Northeastern beach tiger beetle (Davis 2007, entire) and the Puritan tiger beetle (Davis 2006, entire).

3.8.1 State Wildlife Action Plans

The CTB is designated a Species of Greatest Conservation Need (SGCN) (USGS 2018b) based on information provided in State Wildlife Action Plans (SWAPs). Many states and Canada have listed the CTB and afford the species varying degrees of protection under state endangered species acts (Table 7). Some states track the species based on the NatureServe rankings despite not being listed under state endangered species laws (e.g. WV and AL). The NatureServe rankings are described on a five-point scale from critically imperiled (S1) to secure (S5) (NatureServe 2018).

No SWAPs have identified site-specific conservation measures for CTB populations; however, there are common threads in most SWAPs that provide general conservation measures for listed species that are applicable to CTB conservation (Table 7). These recommendations include: increase surveys, monitoring, and research to fill population and life history data gaps (most SWAPs); maintenance or restoration of natural riparian processes such as bank dynamics, channel meanders and flood regimes (AL, VT); prevention of substrate compaction from vehicular or recreational traffic (AL, NH, VT); minimization of point and non-point source (e.g. agricultural) pollution; avoidance of hard structures for bank stabilization; development of management plans to improve land-use practices (OH); site conservation through acquisition and/or easements (MA, VT); maintenance of riparian system connectivity (PA); and implementation or enforcement of applicable laws and regulations protecting the CTB habitat (MA, PA).

The Northeast Association of Fish and Wildlife Agencies recognizes the species as a Northeast Regional Species of Greatest Conservation Need for those states in which it occurs. The regional designation highlights the imperiled status of the species and promotes the design and implementation of regional conservation strategies for the species. To date, no state or regional conservation plan addressing the CTB has been prepared; state-specific actions are described above and in Table 7.

3.8.2 Protected Lands

Occupied CTB sites in six states have some form of land protection that either includes CTB extant populations or are adjacent to the cobble bars on which the species occurs. There may be some protected lands in Canada associated with the two Grand Lake CTB metapopulations (further confirmation is needed). In the United States, most sites are primarily in public ownership, although a few are under easement to a non-governmental organization. Management of protected lands varies across locations (Table 8). This includes sites that are specifically managed for biodiversity (AL, NH, VT, WV; four locations in total) or managed for multiple purposes that could include extractive activities such as mining or logging (AL, NH, NJ, NY, VT; eight locations). The remaining populations are not managed under any particular mandate (AL and NY; two locations). None of these sites are specifically managed to maintain or enhance CTB populations at this time. Opportunities may exist for coordinating with the landowners to identify conservation measures to protect existing populations. These measures could include vegetation and recreational management, prohibiting extraction activities that could degrade or destroy habitat, or increasing protective buffers around existing populations through additional land conservation.

The public's access to CTB inhabited protected areas also varies (Table 8). “Open” access has no special requirements for public access to the property. “Restricted” access describes the authorization needed to access the property (special permits from the owner, a registration permit on public land) or has highly variable times when open to use. Public access is prohibited in “closed” areas.

Table 8. Protected lands within CTB AUs

State	HUC10 Unit	Land Manager/Owner	Public Access	Management
AL	Soapstone Creek	Army Corps of Engineers Mobile District	Open Access	No known mandate for protection
AL	Mill Creek- Cahaba River	The Nature Conservancy	Closed	Managed for biodiversity
AL	Mill Creek- Cahaba River; Upper Cahaba River; Soapstone Creek	AL Department of Natural Resources	Open Access	Managed for multiple uses
NH	Mill Brook - Connecticut River	Town of Plainfield	Open Access	Managed for multiple uses
NH	Upper Pemigewassett River	Town of Plymouth	Open Access	Managed for multiple uses
NH	Middle Pemigewassett River	NH Department of Resources & Economic Development	Open Access	Managed for multiple uses
NH/VT	Mill Brook - Connecticut River	NH Fish & Game Department	Restricted Access	Managed for multiple uses
NH/VT	Mill Brook - Connecticut River	The Nature Conservancy	Closed	Managed for biodiversity
NJ/PA	Flat Brook- Delaware River; Raymondskill Creek- Delaware River	National Park Service	Open Access	Managed for multiple uses
NY	Outlet Silver Lake- Genesee River	Army Corps of Engineers, Buffalo District	Open Access	No known mandate for protection
NY	Outlet Silver Lake- Genesee River	NY State Office of Parks, Recreation and Historic Preservation	Open Access	Managed for multiple uses
OH/WV	French Creek- Ohio River	U.S. Fish and Wildlife Service	Restricted Access	Managed for biodiversity
VT	Winooski River	The Nature Conservancy	Closed	Managed for biodiversity

VT	White River	VT Agency of Natural Resources - Department of Fish and Wildlife	Restricted Access	Managed for multiple uses

3.8.3 Outreach

Little outreach has been expended specifically for the cobblestone tiger beetle at the state level. The Massachusetts Natural Heritage and Endangered Species Program has a fact sheet on the CTB (MassWildlife 2015) and some state wildlife action plans include species profiles (e.g. NH and MA wildlife action plans). Occasionally, the rarity and uniqueness of the species is recognized locally as happened in the town of Plainfield, New Hampshire in 1986 when the species was elected Plainfield Town Insect and its image was emblazoned on T-shirts and posters (M. Caduto 2004). The resultant media interest briefly highlighted the species, its habitat on the Connecticut River, and conservation needs.

3.8.4 Summary

There are no species-specific actions or strategies dedicated to CTB conservation. The species benefits from general conservation strategies that are outlined in state wildlife action plans and when it occurs on conservation or public lands that are protectively managed for natural resources.

3.9 Summary of Influencing Factors

Our analysis of the past, current, and future influences on what the CTB needs for long term viability revealed that there are two influences that pose the largest risk to the viability of the species. These risks are primarily related to changes in the natural hydrological regime and the effects of climate change. Our review of the 303(d) impaired waters list revealed that none of the identified listings are for nutrients and sediments, which can directly alter CTB habitat. Collection of CTBs has not been documented as being a concern for most of the populations and we have no evidence that it has led to a decline or extirpation of any of the sites. Recreational impacts (through ATV use) have been documented in 3 AUs; however, we do not have information to indicate that these impacts are currently affecting the CTB at a species level. Disease, predation, and sand and gravel mining do not appear to be occurring at a level that affects the species overall.

Chapter 4 Current Condition

4.1 Methods

To assess the biological status of the CTB across its range, we used the best available information, including peer reviewed scientific literature and survey data provided by state and federal agencies. Additionally, we consulted with several species experts who provided important information and comments on CTB life history, stressors, and habitat. Fundamental to our analysis of the CTB status was the determination of scientifically sound analytical units at a scale useful for assessing the species (e.g. HUC10 or NHN watersheds). We chose to assess CTB resiliency using a combination of habitat and demographic metrics that are most relevant to the species' biology and influencing factors, and for which we had available information to consider. Habitat metrics consisted of substrate/sedimentation, suitable scour/vegetation density, and managed flows. These metrics were categorized based on best available data and weighted based on ecological significance in order to determine the overall habitat metric designation (Table 9 and Table 10).

Table 9. Habitat metrics and weights.

Habitat Metric	Weight
Substrate/sedimentation	0.5
Suitable scour/vegetation density	1
Flow regime	2
Overall habitat score	1.5

Table 10. Demographic metrics and weights.

Demographic Metric	Weight
AU population status	1
Metapopulation status	2
Overall demographic score	1

Demographic metrics included AU population category and metapopulation category. Like the habitat metrics, the overall demographic score designation was determined by categorizing each AU according to the best available information on that metric and weighting it according to ecological significance. Both the overall habitat scores and overall demographic scores were used to determine the overall resiliency score of each AU.

4.1.1. Habitat Metric Analysis and Assumptions

As discussed in Chapter 3, many stressors are closely linked to the ability of the hydrological regime to maintain the cobble bar community. Sedimentation, vegetation density, and river flow all greatly impact the cobble bar presence and quality that is necessary for CTB populations. Fine sediment deposition allows for increased growth of vegetation, which reduces the availability of interstitial spaces used by the CTB for their multiple life cycle stages. River flow is especially important as it can greatly impact sediment deposition and transport as well as vegetation growth. Dams and locks are the most notable impacts on river flows that may negatively affect CTB habitat. Three examples of extirpated populations, Massachusetts, Alabama (Coosa River), and New York (Delaware River), and the hypothetical loss of populations in New Brunswick (an area of the Saint John River that was not surveyed for CTBs prior to the dam being constructed), highlight the significant impact that construction and operation of dams and locks may have on natural river flows (these effects are further explored in section 3.1.1). In order to assess dam impacts, we identified the presence and type of flow management (generally related to the dams' purpose) for each dam. The different managed flow regimes can have minor to major effects on up and downstream river hydrology.

Substrate/Sedimentation: The CTB needs cobble bars containing 20 percent to 30 percent sand of a suitable grain size for egg laying and larvae development and unembedded cobble (Hudgins *et al.* 2011, p. 311; Normandeau 2016, pp 14 - 16). Excessive sedimentation with fine substrates fills interstitial spaces and renders them unsuitable for the CTB. Sediment is transported to sites via moving water (river or lake). Although we do not have data to measure the amount of sedimentation at each site or to indicate the precise amount of sediment transported each year, we do have water quality data from state 303(d) list indicating which rivers are considered impaired due to excessive sedimentation. Therefore, we used the 303(d) data as a surrogate to indicate whether the extant CTB AUs are or are likely to remain suitable; waters listed as impaired are classified as Low and waters not identified as impaired are classified as High.

Suitable Scour/Vegetation Density: The CTB needs cobble bars with limited vegetation. Occupied CTB cobble bar habitats may range from 1 percent to 50 percent ± with a mean percent vegetative cover of approximately 20 percent to 26 percent (Nothnagle 1995, p. 8; Normandeau 2016, p 16). Vegetation is controlled by scouring from ice flows during spring runoff or spring flood events in rivers and by wave action in lakes (Allen and Acciavatti 2002, p. 6; Hudgins 2010, p. 17; Environment Canada 2013, p. 11). In the absence of survey reports, we classified sites as High (>10 year persistence), Moderate (6-10 year persistence), or Low (1-5 year persistence) based on the years of CTB persistence within the analytical unit. We assumed that if the CTB was persisting over time, that the percent of vegetative cover was suitable and being maintained at low density as a result of scour and/or spring floods.

Flow Regime: A natural hydrological regime maintains CTB habitat through seasonal flood events by reducing vegetation, nourishing the substrate with suitable cobble, gravel and/or sand, preventing the establishment of invasive species, and providing suitable conditions for prey. Alteration of the natural hydrological system through the construction and operation of dams may have serious consequences for the riparian ecosystem depending upon the flow prescriptions (peaking, seasonality of minimal/maximum flows). We assumed that natural flows or managed flows that closely mimic natural flows will provide long-term optimal conditions for CTBs. Therefore, we designated hydrological regimes that were not dammed or were managed for natural flow conditions as High; regimes with dams that are managed for natural flows with modifications were designated as Moderate; and regimes with dams that alter seasonal flow conditions, create unnatural, prolonged habitat inundation, and/or cause highly variable flow conditions were designated as Low.

Overall Habitat Score: The overall habitat score is based on characteristics that make up CTB habitat. We used sediment, vegetation density, and flow management to inform our habitat quality. Each characteristic is weighted based on importance and data availability. High, Moderate, and Low were designated for each category based on information we were able to collect on each AU. Each category corresponds with a value (High = 3, Moderate = 2, Low = 1) that was then weighted based on the metric, with managed flows receiving the greatest weight (see Appendix A for additional details).

4.1.2 Demographic Metrics and Assumptions

Two population scales were used for this analysis. The largest scale was a metapopulation that consisted of smaller populations. Populations that are within a 5-mile Euclidean distance of one another are considered to be members of a metapopulation (Frantz 2018). The populations themselves are sites at which the CTB was observed. The presence of metapopulations is an indicator of habitat availability within the AU and can help to inform dispersal distances. Cobble bars are regularly changing, and the ability for CTBs to travel between populations or find available habitat could prove to be important during dispersal periods. Geographic range within an AU was also factored into the metapopulation analysis. Metapopulations that contain more populations and have populations that are spread farther apart would be less susceptible to localized catastrophic events.

We determined AU population health based on each individual CTB population within an AU. Data collected from observations and surveys were not consistent throughout the CTB range so we used a combination of count and persistence data to inform overall AU population health. Many counts are the result of incidental observations rather than standardized survey methods. We took this into consideration when assigning population categories by incorporating persistence data to help better inform population health. Many of our data for the populations consisted of presence/absence designations. Presence data collected over many years could effectively demonstrate population health and the CTB's ability to persist in the presence of known stressors.

Analytical Unit Population Status: We determined AU population status using a combination of CTB count data and persistence data throughout each watershed. Count data consist of the number of individuals located at a site (i.e., population) in the most recent year surveyed. We added the most recent counts from each site within one AU to determine the total AU population. Because of the varying survey efforts across the range, population counts are not necessarily from the same year. We used the best available and most recent data from each population to determine AU population counts.

We assigned condition categories to classify AUs using count and persistence metrics that were combined. AUs with a count of zero that could potentially be extirpated were designated as Status Unknown. CTB counts of 1 to 20 beetles and/or a known persistence of 1 to 5 years were assigned to the Low category. CTB counts of 21 to 50 individuals and/or a known persistence of 6 to 10 years were assigned to the Moderate category, and CTB counts greater than 50 individuals and/or a known persistence of greater than 10 years were assigned to the High category. AUs that are considered to be historical or extirpated received a category of Extirpated.

If counts were Low but persistence was considered Moderate (6 to 10 years), persistence was weighted more and the overall AU was designated as Moderate. In instances where an AU was only recently surveyed and counts were High, the AU was designated as High.

Metapopulation Determination: A single population was considered a component of a metapopulation if it was within 5 miles Euclidean distance from another population. Populations within a metapopulation are referred to as populations.

Metapopulation Category: Metapopulation categories were determined using the number of populations contained within a metapopulation combined with the geographic range of the metapopulation. In a localized catastrophic event, populations with a higher number of populations that span a larger area are more likely to survive the impacts. Geographic range measures the distance between the most upriver population and the most downriver population within a metapopulation. The further the distance between extant populations leads to a higher chance of survival of the metapopulation if a localized catastrophic event occurs.

The metapopulation categories are Extirpated, Low, Moderate, and High. Analytical units that are considered Low indicate one to two populations with a geographic range of < 3 miles, Moderate consists of three to four populations with a geographic range of 3 to 7 miles, and High consists of five + populations with a geographic range of >7 miles. The distances are based on the likelihood of intermittent habitat patches to facilitate dispersal and potentially be sites for colonization or recolonization. Metapopulation metrics were not evaluated for AUs that received a population category of Status Unknown. Thus, these AUs were designated as Status Unknown for the metapopulation category. If there were a large number of populations within a shorter distance, we weighted the number of populations more heavily than the geographic range and the higher category was given.

Overall Demographic Score: The overall demographic score was determined using the AU population category and the metapopulation category metrics. Each metric was assigned a category corresponding with a score (see overall habitat score section) that was then weighted. These scores were then assigned to the appropriate category of High, Moderate, Low, or Extirpated.

Overall Resiliency Score: The overall resiliency score is similar to the overall habitat and overall demographic score in that each category has a corresponding score that is then weighted. Because of the CTB's ability to recolonize suitable habitat and the amount of uncertainty associated with the demographic metrics, we weighted the overall habitat metric (1.5) more heavily than the overall demographic metric (1). These scores were then added and divided by 2.5 to determine the overall resiliency score (rounding non-whole numbers up if they exceeded a

0.5 threshold). The scores were then used to assign the appropriate category of High (≥2.5), Moderate (1.5 - 2.4), or Low (0 - 1.4).

4.2 Current Condition: 3 Rs

Current condition is informed using historical and current information as well as habitat and demographic metrics applied to a 3Rs analysis. Resiliency, redundancy, and representation are the components for understanding the current condition of a species throughout its range.

Cobblestone tiger beetle is historically known from 45 AUs extending from New Brunswick, Canada to Alabama in the United States. Using the latest survey data from each area of the CTB range, we identified 27 AUs that are extant representing 63 percent of the historical range. Two of these AUs (Flat Brook-Delaware River and Raymondskill Creek-Delaware River) have zero beetle observations in the last 7 years, despite multiple surveys. These AUs are still considered extant populations, but they are designated as "unknown" because it is not known if the lack of observations is due to population extirpation or low detectability.

4.2.1 Resiliency

Resiliency describes the ability for a species to withstand environmental or demographic stochastic events. This is generally informed by looking at the health of each population throughout the range. We examined both habitat and demographic metrics to analyze AU resiliency (see section 4.1, Methodology). Using these metrics, we determined overall resiliency for each extant AU (Table 11, Table A-2, Figures 10, 11 and 12).

There are 13 AUs with a High resiliency category, 9 AUs with a Moderate resiliency category, and 3 AUs with a Low resiliency category. Two AUs along the Delaware River are considered Status Unknown due to negative survey data from 2012, 2014, 2016, and 2017. The CTB has been found within both of these AUs within the last 20 years indicating they could be extant populations, however, CTB has not been observed since 2001 (Raymondskill Creek-Delaware River) and 2011 (Flat Brook-Delaware River). Due to the non-standardized survey methodology and the cyclic nature of the CTB life cycle, we do not have enough information to consider these AUs extirpated. Eighteen of the 45 AUs (40 percent) found in the historical range are considered to be historical or extirpated. All 18 of the historical/extirpated AUs are located within the U.S. For the 25 extant AUs with known status, AUs with a designation of Low resiliency comprise 12 percent, Moderate resiliency comprise 36 percent, and High resiliency comprise 52 percent of the population. Although the majority of the extant AUs received a designation of High, the loss of 40 percent of the historical AUs led us to designate the overall CTB resiliency as Moderate.

Table 11. Resiliency metrics and categorization of analytical units throughout the CTB range

State	AU	Habitat Metrics				Demographic Metrics			Overall Resiliency Score
		Substrate / Sedimentation	Suitable Scour/ vegetation density	Managed Flows	Overall Habitat Score	AU Population Category	Metapopulation Category	Overall Demographic Score	
AL	Mill Creek-Cahaba River	High	High	High	High	High	Moderate	Moderate	High
AL	Soapstone Creek-Alabama River	High	Low	Low	Low	High	Low	Moderate	Low
AL	Upper Cahaba River	High	High	High	High	High	Low	Moderate	High
AL	Weoka Creek - Coosa River	High	Low	Low	Low	Extirpated	Extirpated	Extirpated	Extirpated
IN	Pipe Creek-Whitewater River	High	Low	High	Moderate	Low	Low	Low	Moderate
IN	East Fork Whitewater River	High	Low	High	Moderate	Extirpated	Extirpated	Extirpated	Extirpated
OH	Taylor Creek-Great Miami River	High	Low	High	Moderate	Low	Low	Low	Moderate
IN/OH	Whitewater River	High	Low	High	Moderate	Low	Low	Low	Moderate
KY[11]	McCreary County	High	High	High	High	Moderate	Low	Low	Moderate
MA	Lower Deerfield River	High	Low	Low	Low	Extirpated	Extirpated	Extirpated	Extirpated
ME	Lower Carrabassett River	High	High	High	High	Moderate	High	High	High
ME	Middle Carrabassett River	High	High	High	High	High	High	High	High
MS	Clay County	High	Low	Moderate	Moderate	Extirpated	Extirpated	Extirpated	Extirpated
MS	Lowndes County	High	Low	Moderate	Moderate	Extirpated	Extirpated	Extirpated	Extirpated
NH	Middle Pemigewasset River	High	High	High	High	Moderate	Moderate	Moderate	High
NH	Upper Pemigewasset River	High	High	High	High	Low	Moderate	Moderate	Moderate

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[11] Office of Kentucky Nature Preserves 2018

NH/VT	Mill Brook-Connecticut River	High	High	Moderate	Moderate	High	High	High	Moderate
NH/VT	Vernon Dam-Connecticut River	High	High	Moderate	Moderate	High	Low	Moderate	Moderate
NJ/PA	Flat Brook-Delaware River	High	Low	Low	Low	Status Unknown	Status Unknown	Status Unknown	Status Unknown
NJ/PA	Raymondskill Creek-Delaware River	High	Low	Low	Low	Status Unknown	Status Unknown	Status Unknown	Status Unknown
NJ/PA	Lower Delaware River	Low	Low	Low	Low	Extirpated	Extirpated	Extirpated	Extirpated
NJ/PA	Upper Delaware River	High	Low	Low	Low	Extirpated	Extirpated	Extirpated	Extirpated
NY	Caneadea Creek-Genesee River	High	High	High	High	Moderate	High	High	High
NY	Cattaraugus Creek	High	High	High	High	High	High	High	High
NY	Cold Creek-Genesee River	High	High	High	High	Moderate	High	High	High
NY	Headwaters Cattaraugus Creek	High	High	High	High	Low	Moderate	Moderate	High
NY	Outlet Silver Lake-Genesee River	High	High	Moderate	Moderate	High	High	High	High
NY	Saw Mill River - Hudson River	High	Low	Low	Low	Extirpated	Extirpated	Extirpated	Extirpated
NY/PA	Middle Delaware River	High	Low	Low	Low	Extirpated	Extirpated	Extirpated	Extirpated
OH	Kinnikinnick Creek - Scioto River	High	Low	High	Moderate	Extirpated	Extirpated	Extirpated	Extirpated
OH	Ralston Run - Paint Creek	High	Low	High	Moderate	Extirpated	Extirpated	Extirpated	Extirpated
OH	Headwaters Todd Fork	High	Low	High	Moderate	Extirpated	Extirpated	Extirpated	Extirpated
OH/WV	French Creek-Ohio River	High	High	High	High	Moderate	Moderate	Moderate	High

OH/WV	Little Sandy Creek - Ohio River	High	Low	High	Moderate	Extirpated	Extirpated	Extirpated	Extirpated
OH/WV	Little Hocking River - Ohio River	High	Low	High	Moderate	Extirpated	Extirpated	Extirpated	Extirpated
PA	Allegheny River	High	Low	Low	Low	Low	Low	Low	Low
PA	Susquehanna River (0205030210)	High	Low	Low	Low	Extirpated	Extirpated	Extirpated	Extirpated
PA	Susquehanna River (0205030617)	High	Low	Low	Low	Extirpated	Extirpated	Extirpated	Extirpated
PA	Middle Schuykill River	High	Low	Low	Low	Extirpated	Extirpated	Extirpated	Extirpated
VT	Rock River-West River	High	Low	Moderate	Moderate	Moderate	Low	Low	Moderate
VT	White River	High	High	High	High	High	High	High	High
VT	Winooski River	High	Low	Low	Low	Low	Low	Low	Low
WV	Upper Monongahela River	High	Low	Moderate	Moderate	Extirpated	Extirpated	Extirpated	Extirpated
CAN	01AJB00	No Data	High	Moderate	Moderate	High	Low	Moderate	Moderate
CAN	01AO000	No Data	High	High	High	High	High	High	High

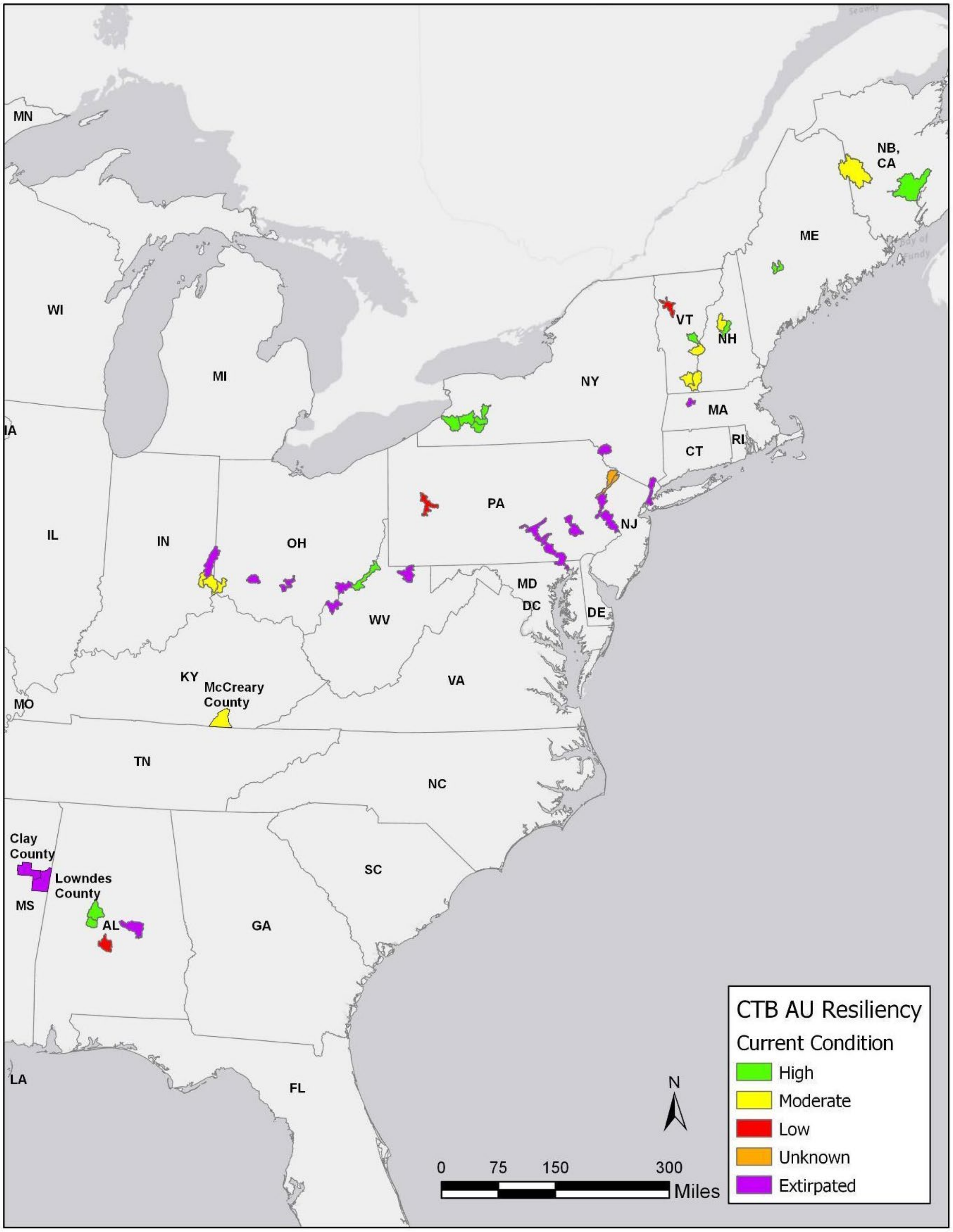

Figure 10. CTB Current Condition Resiliency Categories–Rangewide

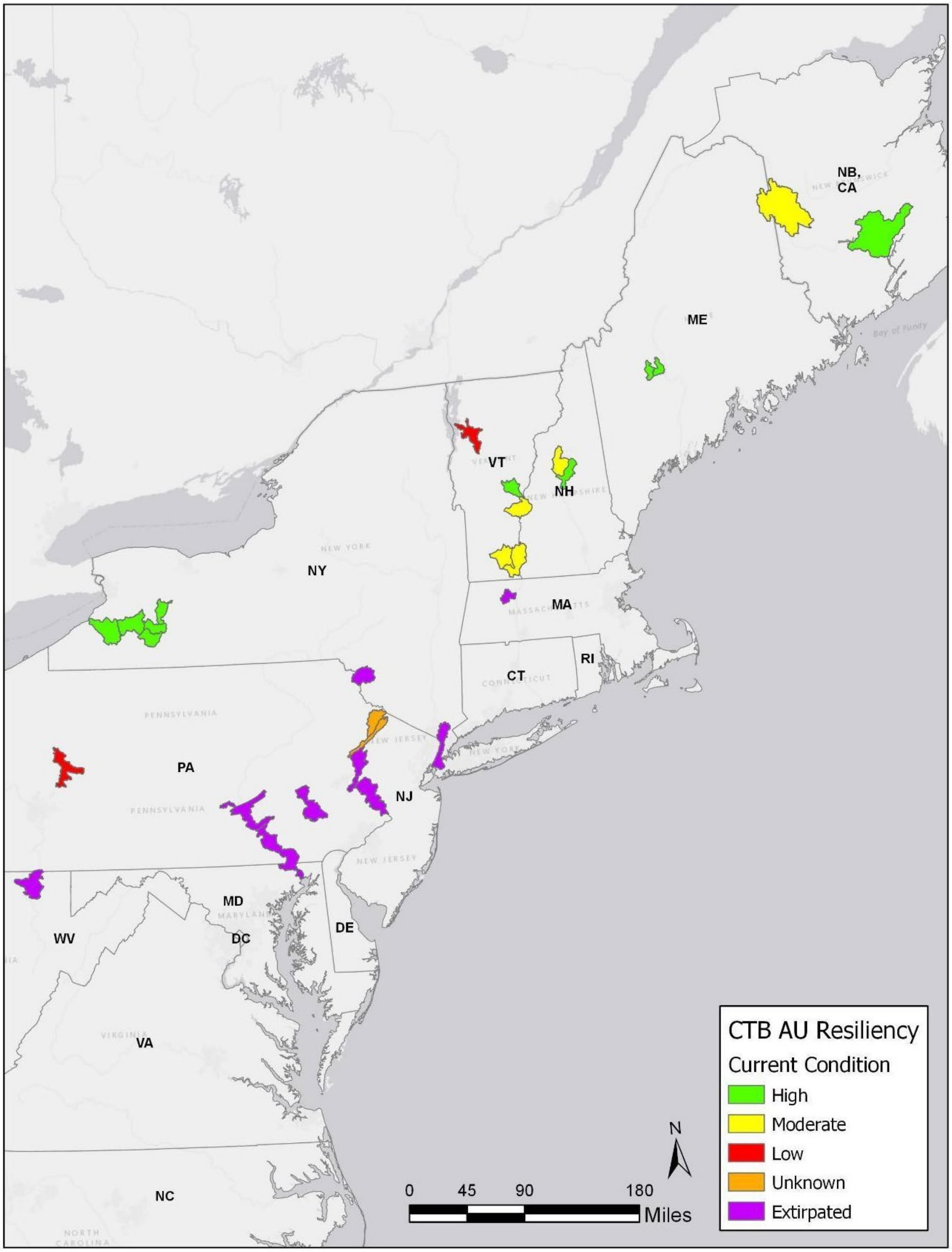

Figure 11. CTB Current Condition Resiliency Categories–Northern United States and New Brunswick, Canada

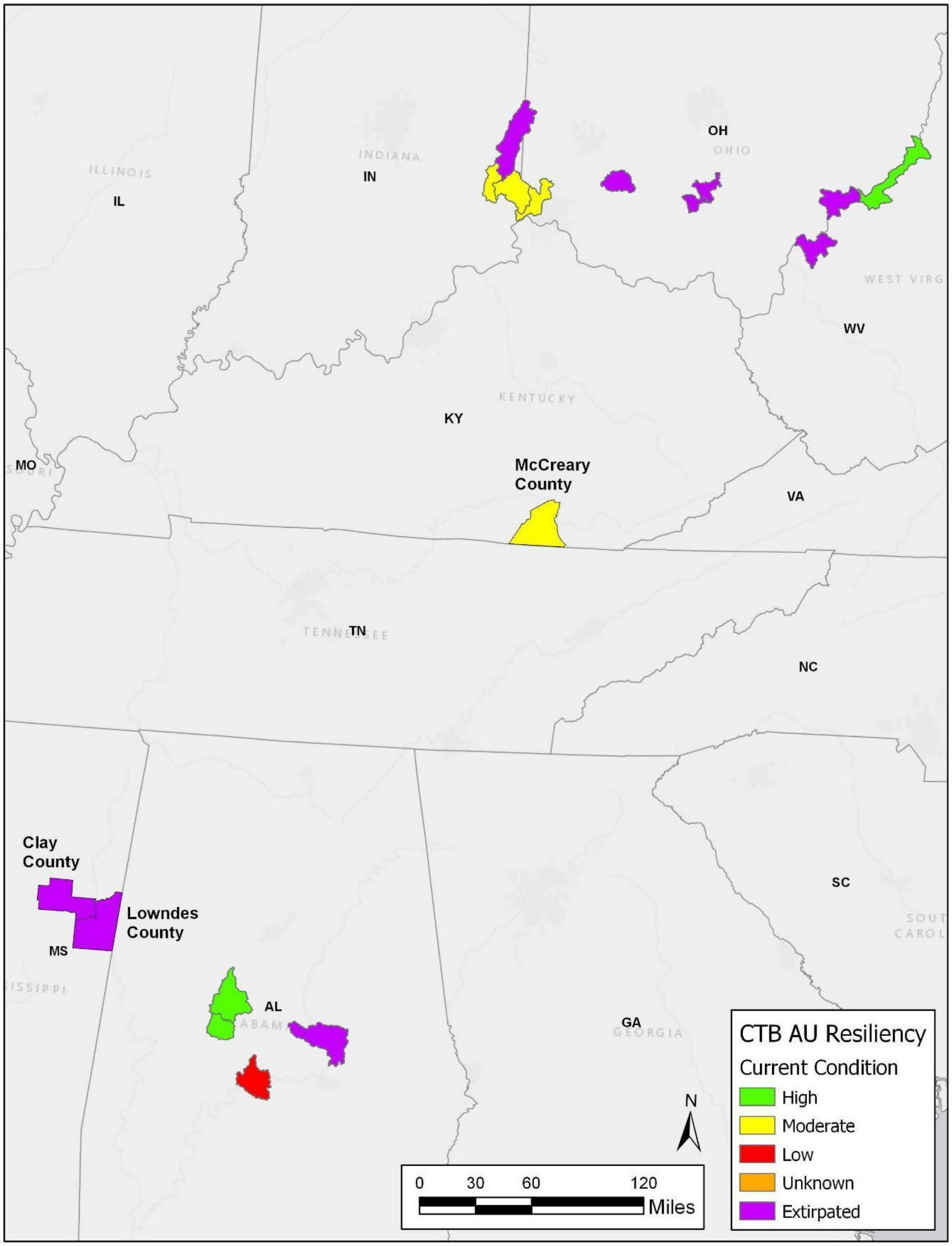

Figure 12. CTB Current Condition Resiliency Categories–Midwest and Southeast United States

4.2.2 Redundancy

Redundancy describes a species' ability to withstand catastrophic events. This is usually informed by the number of resilient populations and their distribution throughout the range. To ensure the viability of the CTB requires multiple resilient populations spread throughout its range. Evidence suggests that CTB populations were once more broadly distributed throughout the species' historical range. Whereas the overall range of the CTB has not changed significantly, it has lost populations throughout its range. Both populations and metapopulations were examined within each AU to identify CTB redundancy.

Within the historical distribution, 40 percent of the AUs have been lost. With this loss, distribution of the extant AUs has become more disjunct throughout the range. Metapopulations are important to the population structure of the CTB, and it is likely that many populations were lost with the loss of historical AUs. Despite the reduction in AUs, we found 16 extant metapopulations throughout the range, most of which are located in the northern part of the range (Table 12). Four of these metapopulations span two AUs and there are two metapopulations that are found within a single AU. In New York, the Caneadea Creek-Genesee River and Cold Creek-Genesee River AUs represent a single metapopulation containing 23 populations. The Headwaters Cattaraugus Creek and Cattaraugus Creek AUs also represent a single metapopulation consisting of five populations. Although only one population resides within the Headwaters Cattaraugus Creek AU, the one population is within 5 miles of a population within the Cattaraugus Creek AU, creating a metapopulation that spans two AUs. The Lower Carrabassett River and Middle Carrabassett River AUs in Maine make up a single metapopulation with 11 populations. Lastly, the metapopulation in New Hampshire spans the Middle Pemigewasset River and Upper Pemigewasset River AUs and contains three populations. Within the Grand Lake AU, two metapopulations were identified and are labeled "01AO000 (Grand Lake "north")" and "01AO000 (Grand Lake "south")" for differentiation.

Table 12. Analytical units with extant populations throughout the CTB range including metapopulation designation and number of populations within those metapopulations

States	AU (or AUs if one metapopulation spans 2 AUs)	Metapopulation (# populations)	Geographic Range (miles)
AL	Mill Creek-Cahaba River	Yes (3)	3.2
AL	Soapstone Creek – Alabama River	No	0[13]
AL	Upper Cahaba River	Yes (2)	1
IN	Pipe Creek-Whitewater River	No	0[13]
OH	Taylor Creek-Great Miami River	No	0[13]
IN/OH	Whitewater River	No	0[13]
KY	McCreary County	Yes (NA)	1.1
ME	Lower Carrabassett River/Middle Carrabassett River	Yes (11)	7.2
NH	Middle Pemigewasset River/Upper Pemigewasset River	Yes (3)	6.7
NH/VT	Mill Brook-Connecticut River	Yes (5)	15.8
NH/VT	Vernon Dam-Connecticut River	No	0[13]
NJ/PA[12]	Flat Brook-Delaware River	Unknown	Unknown
NJ/PA	Raymondskill Creek-Delaware River	Unknown	Unknown
NY	Caneadea Creek-Genesee River/Cold Creek-Genesee River	Yes (23)	10.7
NY	Cattaraugus Creek/Headwaters Cattaraugus Creek	Yes (5)	7.3
NY	Outlet Silver Lake-Genesee River	Yes (9)	5.5
OH/WV	French Creek-Ohio River	Yes (4)	6.4
PA	Allegheny River	No	0[13]
VT	Rock River-West River	Yes (2)	0.3
VT	White River	Yes (10)	5.8
VT	Winooski River	Yes (2)	0.8
CAN	01AO000 (Grand Lake "north")	Yes (4)	1.8
CAN	01AO000 (Grand Lake "south")	Yes (5)	NA
CAN	01AJB00 (Saint John River)	Yes (3)	6.4

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[12] Gray shading denotes unknown status due to insufficient survey data.

[13] Indicates isolated population.

Overall, 6 out of the 27 extant AUs do not support a metapopulation. Although 40 percent of the historical AUs have been lost, the presence of metapopulations within the extant AUs could be an indicator of habitat availability, which is an important factor for this species as it is genetically adapted to colonize habitat patches (Knisley 2018). The number of populations within a metapopulation could be an indicator of habitat conditions and overall population health. The average number of populations per metapopulation is approximately four populations.

4.2.3 Representation

Identifying and evaluating representative units that contribute to a species' adaptive potential are important components of assessing overall species' viability (Smith *et al.* 2018, entire). This is because populations that are distributed throughout multiple representative units may buffer a species' response to environmental changes over time. Representation describes the ability of a species to adapt to changing environmental conditions over time and is characterized by the breadth of genetic and environmental diversity within and among populations. Representation for the CTB can be described in terms of variability among latitudes, and physiographic provinces.

We assessed the CTB range under different physiographic provinces to understand whether the species has a wide capacity to adapt to varying geological conditions. Each physiographic province has a characteristic geomorphology, and often specific subsurface rock type or structural elements. Although overall the physiographic regions may differ with respect to ecosystem types, geomorphology and climate, it is clear that the basic habitat requirements do not vary.

The historical CTB range spans from Canada to Alabama, encompassing seven physiographic provinces: with populations representing the New England, Saint Lawrence Valley, Piedmont, Valley and Ridge, Appalachian Plateaus, Central Lowland, and Coastal Plain (Figure 13). Distribution has since become patchy in the central portions of the range with the extirpation of 17 AUs. The CTB has lost all of its representation in the Piedmont physiographic provinces and many of the AUs representing the Central Lowland province accounting for a combined loss of 8 AUs (Table 13). The New England province maintains 79 percent of the historical AUs and accounts for some of the largest metapopulations throughout the range. Although there have been some extirpations in the other represented provinces, more than half of the AUs are still present in the New England, Saint Lawrence Valley, Appalachian Plateaus, and Coastal Plain provinces. The status of AUs within the Valley and Ridge physiographic province are unknown.

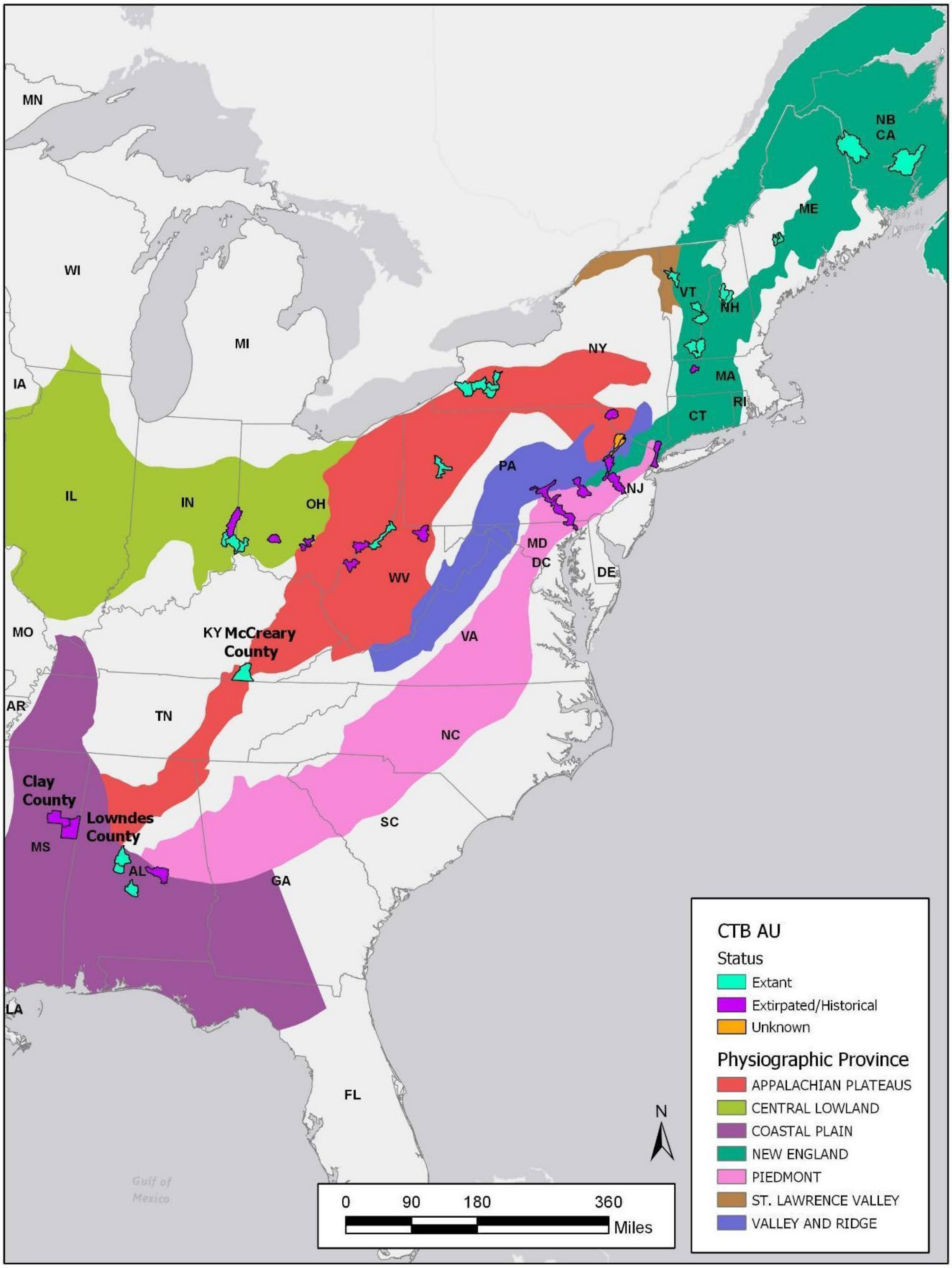

Figure 13. Physiographic provinces of the conterminous United States and Canada

As evaluated through hydrological systems, latitudinal variability, and physiographic provinces, the current distribution of the CTB reflects some loss in historical representation. The current CTB range remains in five of the seven historical physiographic provinces to varying extent, from the far northern United States and Canada to the far southern United States (Table 11). Based on this, it is likely that the species maintains some adaptive potential and variability amongst its populations against catastrophic events.

Table 13. Number of historical and current AUs within each physiographic province throughout the CTB range.

Physiographic Provinces	Number of AUs Historically	Number of Extant AUs	Status Unknown	Percent AUs Remaining
Appalachian Plateaus	12	8		66%
Central Lowland	7	3		43%
Coastal Plain	6	3		50%
New England	14[14]	11[14]		79%
Piedmont	4	0		0%
St. Lawrence Valley	1[14]	1[14]		100%
Valley and Ridge	2		2	0%

4.2.4 Uncertainty

There is uncertainty regarding the biological status of the CTB due to the lack of survey and life history data. We used the best available data for our habitat resiliency factors, but in many cases these data were at a coarse scale. With a lack of site specific information, uncertainty was involved with some of the habitat metrics. In these cases, we used a combination of the best available scientific literature, GIS mapping, and expert observations to identify the most appropriate category designation. The use of sedimentation as a metric incorporated additional uncertainty. We used 303(d) impairment information to inform this metric; however, we are uncertain of the ecological significance at that scale. To help demonstrate this uncertainty, we weighted sedimentation impairment less than the other metrics.

In addition to uncertainty in our habitat metrics, we found sources of uncertainty within our demographic metrics as well. Using the best available data, we classified the AU populations

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[14] One AU is found within both the New England and St. Lawrence Valley physiographic provinces.

based on counts. However, some sites have not undergone recent surveys or surveys have not been conducted systematically to allow for an accurate estimation of population size. It is likely that most count data substantially underestimate population size, and this was taken into account for future scenarios (see Chapter 5). Some sites that were surveyed did not result in count data, but have presence/absence information. These data were factored into the persistence of the site, but in areas where surveys were lacking, there is uncertainty about the actual persistence of the site. Furthermore, there is uncertainty pertaining to the metapopulations. Through expert consultation, we determined populations within 5 miles could be considered a metapopulation. However, the amount of movement between populations is uncertain and these metrics could be under or over-estimating the distance that CTBs could move between populations.

There has been noted uncertainty regarding the status of the southern-most, disjunct populations within Alabama. Anatomical differences have been noted, and some hypothesize the possibility of a subspecies. At this time, genetic analysis has not been conducted to support this hypothesis. While we acknowledge the identified uncertainty, we used the best available data and coordination with experts to develop the most ecologically significant metrics and conclusions with supporting data to inform resiliency, redundancy, and representation.

Chapter 5 Species' Future Viability

5.1 Methods

We now consider the future viability of the CTB, applying the 3Rs approach (Smith *et al.* 2018 entire). We apply the future scenarios to forecasts for 30 and 60 years, as medium- and long-term projections, roughly corresponding to the years 2050 and 2080. Each period integrates changes over multiple generations (15 and 30 for a 2-year life cycle, see section 2.2). These time periods were selected because they are consistent with those used in other published future climate change projections. For example, the U.S. Forest Service forecasts of land use change was provided for every 10 years from 2010 to 2060 (Wear 2011, p.1, 10-16). Climate change projections in the Fourth National Climate Assessment (Vose *et al.* 2017, p. 196; Easterling *et al.* 2017, p. 217) provide estimates for 2036-2065 and 2070-2099; thus projections for 2050 and 2080 are within these two periods. Licenses for dams are issued for 30 to 50 years, (as discussed in section 3.1.1.4), and the relicensing process offers the opportunity for efforts to minimize adverse impacts or improve CTB habitat.

We use the following influencing factors, which we consider as most important for constructing these scenarios: substrate/sedimentation, suitable scour and vegetation density, climate trajectory and effects, and conservation actions. Other factors such as shoreline housing development, urbanization, and the operation of dams are discussed as influencing factors for specific CTB habitats.

5.2 Future Scenarios

We outline three plausible scenarios (Table 14) to forecast future conditions for 2050 and 2080. *Scenario A* is a continuation scenario in which the influencing factors are projected to change in a similar manner as in the present day. Climate change is projected under RCP8.5, the most likely path (see section 3.5). *Scenario B* is a scenario in which the influencing factors change on a trajectory that is different than the continuation scenario, largely due to conservation actions that may partially counteract some projected adverse effects and a lesser climate change projection (RCP4.5) than the other two scenarios. *Scenario C* is a scenario in which some of the influencing factors would change to a greater extent than under *Scenario A*, largely due to a lack of conservation actions. We recognize that not all influencing factors have negative impacts and that CTB habitat and populations are affected by multiple factors, some of which may affect habitats in a positive manner, others in a negative manner.

In some cases, the projected changes are the same for all three scenarios. For example, four AUs (Soapstone Creek, Whitewater River, Raymondskill Creek-Delaware River and Flat Brook-Delaware River) were identified as having the greatest increase in urban land use between 1997 and 2020 (see section 3.2.1). These four AUs also have the largest projected increases in urban land use in 2060 compared with 1997 (about 15 percent; Wear 2011, p. 1 and excel spreadsheet). The increase in urbanization in all other AUs with extant populations or Unknown Status is between 0.5 and 6.1%. We conclude that urbanization should be included in Table 14 as an influencing factor (in these four AUs only), but that there is no rationale for preparing different projections for each of the three scenarios.

Table 14. Summary of Influencing Factors for Future Scenarios

Influencing Factor	**Scenario A**	**Scenario B**	**Scenario C**
Bank stabilization	continue current practices	avoid hardened bank stabilization	implement hardened bank stabilization
Climate RCP	RCP 8.5	RCP 4.5	RCP 8.5
Climate effects: summer drought	↑↑[a] intensity and duration	↑ intensity and duration	↑↑ intensity and duration
Climate effects: ice scour	↓↓ in north	↓ in north	↓↓ in north
Conservation: sampling	continue ad hoc	↑ frequency and ↑ quality	continue ad hoc
Dam construction	no new dams	no new dams	additional dams built
Dam operations	continue current practices	flow regimes beneficial to the CTB	flow regimes harmful to the CTB
Land protection	continue current practices	↑ land purchases and conservation easements	↓ land purchases and conservation easements
Translocation; captive propagation	Not currently occurring	To be used as part of a conservation strategy along with habitat restoration and protection	None
Pollution effects	continue current practices	apply best management practices identified in SWAPs; ↑ efforts to control agricultural and urban runoff; ↑ protection of riparian zones	↓ efforts to control agricultural and urban runoff; ↓ protection of riparian zones
Protection from recreation impacts	continue ad hoc	↑ efforts including enforcement and signage	↓ efforts including enforcement and signage
Urbanization	Substantial ↑ in 4 AUs: Soapstone Creek, Whitewater R., Raymondskill Creek–Delaware R., and Flat Brook–Delaware R.	Substantial ↑in 4 AUs: Soapstone Creek, Whitewater R., Raymondskill Creek–Delaware R., and Flat Brook–Delaware R.	Substantial ↑ in 4 AUs: Soapstone Creek, Whitewater R., Raymondskill Creek–Delaware R., and Flat Brook–Delaware R.

[a]: ↑: increase, ↑↑ greater increase, ↓ decrease, ↓↓ greater decrease

Under *Scenario A*, the recent changes and trends affecting CTB habitat and populations extend with the same trajectory through the two forecast periods. For example, climate change would continue along the RCP 8.5, which we conclude in section 3.5 would be the most likely scenario for changes through the middle of the 21st century. In the northern part of the range, CTB habitat would be affected such that the decrease in scour due to ice flow and an increase in intensity and duration of precipitation events could alter or eliminate cobble bars (see section 3.5). Throughout the range, and especially in Alabama, Ohio, and Indiana, increased intensity and duration of summer drought could reduce soil moisture, adversely affecting the ability of larvae to construct burrows (for example). The trends in urbanization for each of the AUs continue along the same path as discussed in section 3.2. For the Grand Lake sites there are no predictions regarding the extent of future shoreline development (New Brunswick Forest Planning and Stewardship 2018).

Under *Scenario A*, no additional conservation measures would be initiated and CTB sites would continue to be surveyed on an ad hoc basis. There would be no changes in the management of the dams by revising current flow management efforts to be more protective of CTB habitats and populations. Protection from recreational activities would continue on the current ad hoc basis.

With *Scenario B*, these changes and trends occur on a lower trajectory than Scenario A. Climate change (see section 3.5) would be forecast to proceed along the RCP4.5 scenario, taking into account the refined projections of global temperature change proposed by Brown and Caldeira (2017, p. 47). As discussed in section 3.5, whereas proceeding along RCP8.5 is more likely, RCP4.5 is still plausible and is used in the Fourth National Climate Assessment (Hayhoe *et al.* 2017, pp. 135-149). Thus, under Scenario B, in the future forecasts for 2050 and 2080, temperature increases would be less and drought would be less severe and shorter than is projected under Scenario A. Similarly, the projected changes in ice scour and resultant effects on CTB habitat would occur at a slower rate.

Under *Scenario B*, conservation actions (section 3.8) would be implemented that would help to maintain or improve CTB habitats and populations. These actions would include those listed as “common threads” in the SWAPs (section 3.8.1) and include the minimization of point and non-point pollution through use of Best Management Practices; maintenance and restoration of riparian areas and system connectivity; increased surveys, monitoring, and research to fill population and life history gaps; and avoidance of hardened bank stabilization measures. Additional activities (see section 3.8.2) would include use of conservation easements and/or land acquisition to protect existing populations. Translocation of nearby populations to restored habitats would be conducted as part of a conservation strategy, if warranted. The three New York City water supply reservoirs (see section 3.1.1.4) that may have adversely affected the Raymondskill Creek-Delaware River and Flat Brook-Delaware River AUs (and possibly several extirpated/historical sites) would be managed to benefit aquatic species including the CTB. Dam relicensing decisions would result in implementation of flows that are beneficial to CTB and these benefits would be in place for 40 to 50 years (see section 3.1.1.4).

With *Scenario C*, changes are projected to occur that would be detrimental to CTB habitats and populations compared with *Scenarios A* and *B*. The climate change scenario would be RCP8.5 with projected changes identical to *Scenario A*. Dam management for power needs, flood control, or water supply would not address CTB conservation needs. As was the case for *Scenario A*, there would be no additional conservation measures initiated and CTB sites would continue to be surveyed on an ad hoc basis. There would be a decline in actions (such as enforcement or signage) aimed to protect habitats from the effects of recreational activities.

Other actions or lack of actions under *Scenario C* that could be detrimental to CTB habitats, include bank stabilization with hardened materials in response to increased bank erosion, and a failure to control point and non-point source pollution. In short, the recommended actions that could be implemented as conservation measures (see section 3.8 and those highlighted under *Scenario B*) would not be implemented. Thus, the stressors associated with nearby land use would continue without regulatory or voluntary measures.

5.3 Future Condition

We provide comparisons between the different scenario outcomes in both table (Table 15) and map formats (Figures 14 and 15) to better visualize the possible outcomes of each future scenario.

Table 15. Future Resiliency Condition Categories of CTB AUs for Current Condition and Scenarios A, B, and C (Individual AU conditions in Table A-3, with numeric scores in Tables A-4, A-5, and A-6).

Resiliency Category	Current Condition AUs	Scenario A AUs		Scenario B AUs		Scenario C AUs	
		2050	2080	2050	2080	2050	2080
High	13 (29%)	10 (22%)	7 (16%)	14 (31%)	15 (33%)	4 (9%)	1 (2%)
Moderate	9 (20%)	12 (27%)	14 (31%)	8 (18%)	14 (31%)	17 (38%)	18 (40%)
Low	3 (7%)	2 (4%)	2 (4%)	5 (11%)	5 (11%)	1 (2%)	2 (5%)
Hist/Ext	18 (40%)	21 (47%)	22 (49%)	18 (40%)	11 (25%)	23 (51%)	24 (53%)
Unknown	2 (4%)						

5.3.1 Scenario A

Resiliency

Under Scenario A, the number of AUs in the High and Low resiliency categories are projected to decrease in 2050 and 2080, while the number of AUs in the Moderate and Historical/Extirpated resiliency categories increase by 2080. (Table 15; Figures 14 and 15). The projected changes in the Moderate category are due to 6 High resilient AUs dropping to Moderate by 2080 with one Moderate projected to become Historical/Extirpated (Table A-3).

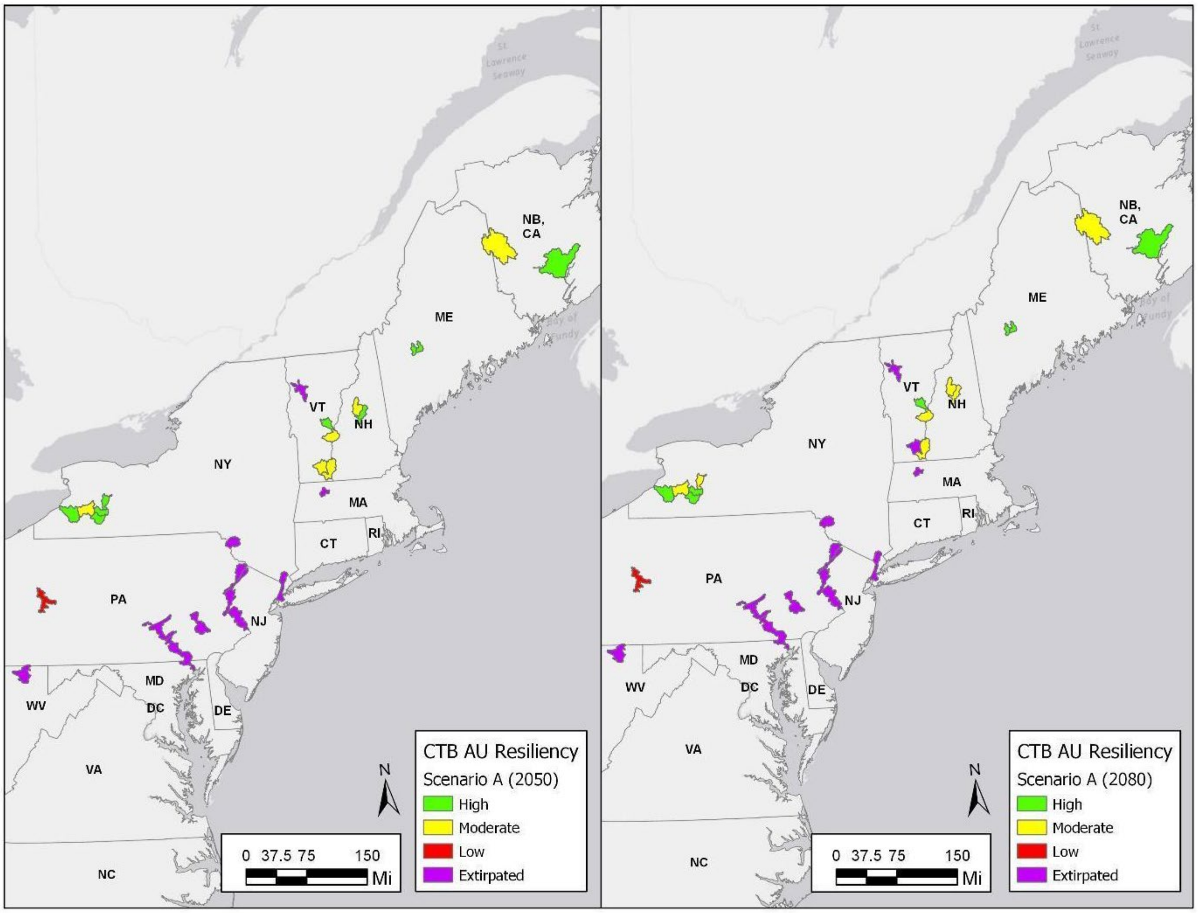

Figure 14. Scenario A - Northern U.S. and New Brunswick, Canada

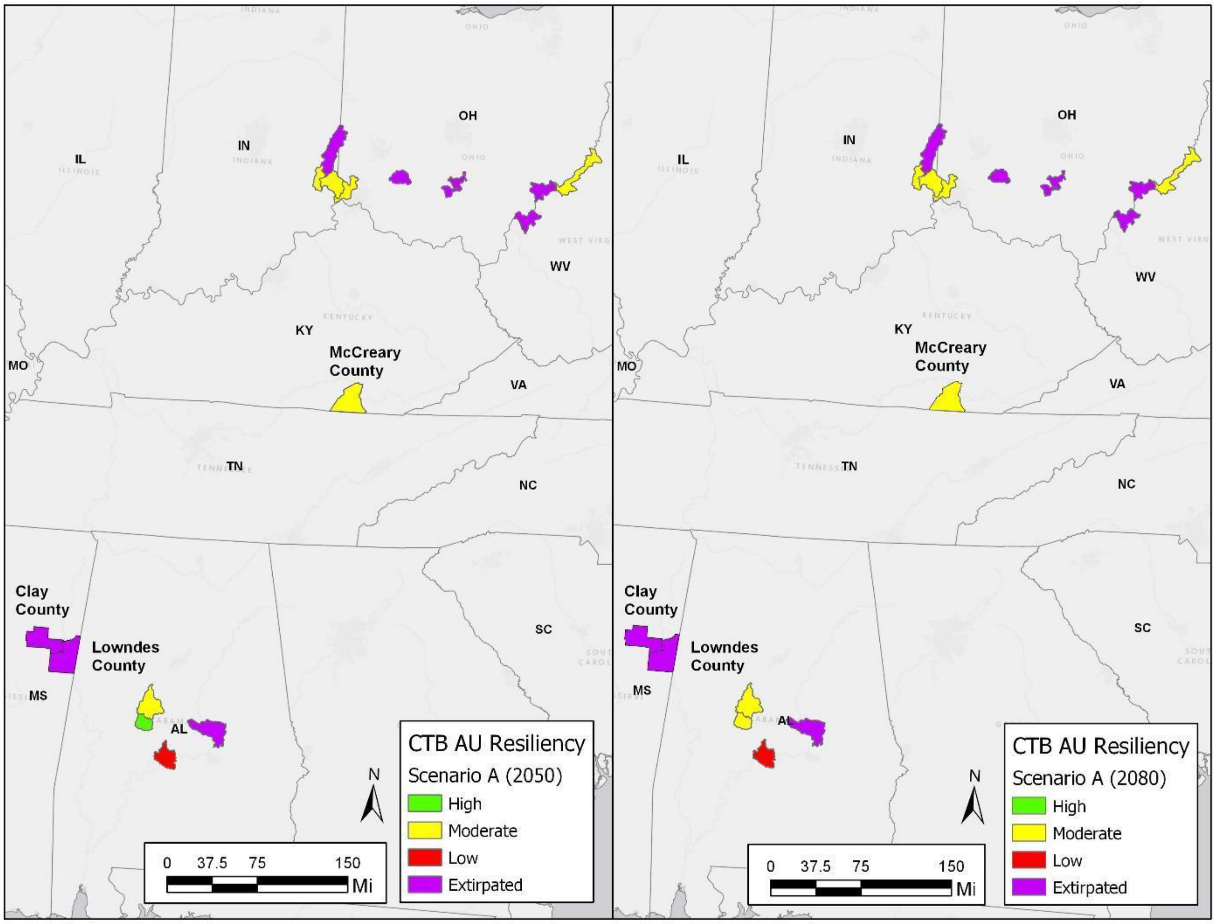

Figure 15. Scenario A – Midwest and Southeast U.S.

Redundancy

Under Scenario A, we predict that six AUs in High resiliency condition will decline to a Moderate condition by either 2050 or 2080 potentially affecting 29 percent of metapopulations in the Northern and Southern portions of the range. We predict that two AUs, Flat Brook-Delaware River and Raymondskill Creek-Delaware River, will be extirpated by 2050 and two additional AUs, Winooski River and Rock River-West River, will become extirpated by 2080 reducing the range by 7 percent by 2050 and 14 percent by 2080. The loss of these populations is likely to make the CTB slightly more vulnerable to stochastic disturbance events, especially in Vermont and Pennsylvania, where all of the projected extirpations occur. Winooski River and Rock River - West River AUs both contain metapopulations consisting of two populations each and both with a geographic range of < 1 mile. Extirpation of these AUs leads to a 10 percent reduction in metapopulations throughout the range.

Representation

We predict that the CTB will continue to demonstrate representation at the end of our time horizon (2080). Although four AUs are predicted to become extirpated by 2080, the species' distribution is not expected to significantly contract (7 percent by 2050, 14 percent by 2080). However, the CTB will show a slight decline in physiographic province representation by 2080.

With the extirpation of Winooski River, Flat Brook Creek - Delaware River, and Raymondskill Creek - Delaware River, there is a projected loss of representation in the St. Lawrence Valley and Valley and Ridge physiographic provinces by 2050. By 2080, there will be a reduction in representation within the New England province with the loss of Rock River - West River AU.

5.3.2 Scenario B

Resiliency

For Scenario B, the effect of conservation actions and a lower climate pathway (RCP 4.5 vs. 8.5) will maintain higher resiliency categories in many of the analytical units (Table 15). For the 13 AUs with current resilient conditions in the High category, we predict an increase in the number of AUs in the High category through 2080. For the nine AUs in the Current Condition Moderate category, there is a decline in 2050 and an increase in 2080. This can be attributed to AUs moving to the High category as they become more resilient due to improving habitat conditions (potentially as a result of conservation actions) or movement to the Low Category if conservation actions were not implemented or not completed in time to increase the AU resiliency. By 2080, we predict that High, Moderate and Low resilient categories will increase, primarily as a result of population introduction/augmentations in historical/extirpated sites. For example, we predict the Mill Brook–Connecticut River population is projected to improve to High in 2050 and remain High in 2080, if habitat is restored as a result of favorable flow regimes from beneficial FERC relicensing negotiations (section 3.1.1.4). The Upper Pemigewasset River AU is projected to improve to High in 2080. The Upper Pemigewasset River AU, which currently has only one population, is projected to expand under favorable natural processes as additional habitat may be created and colonized by CTB. We also theorize that the two AUs with Unknown status under current conditions, Flat Brook–Delaware River and Raymondskill Creek–Delaware River, are projected to have Low resiliency in 2050 and 2080. These AUs persist as a result of conservation measures implemented through Scenario B, and the lower adverse climate impacts under RCP4.5. We also predict that conservation measures under Scenario B are projected to result in the restoration of seven extirpated AUs by 2080 (Figures 16 and 17), either through translocation of genetically suitable individuals from nearby populations or possibly through captive propagation (see section 3.8).

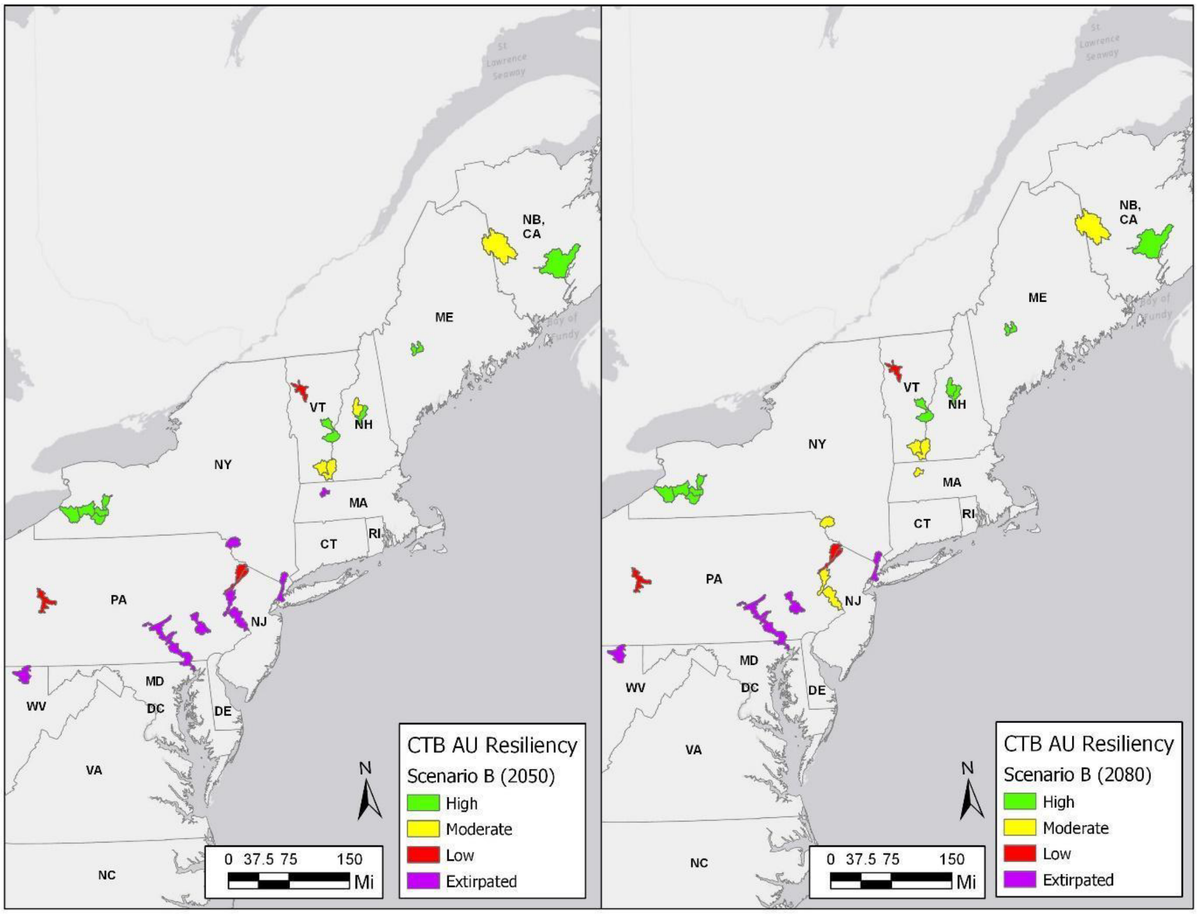

Figure 16. Scenario B - Northern U.S. and New Brunswick, Canada

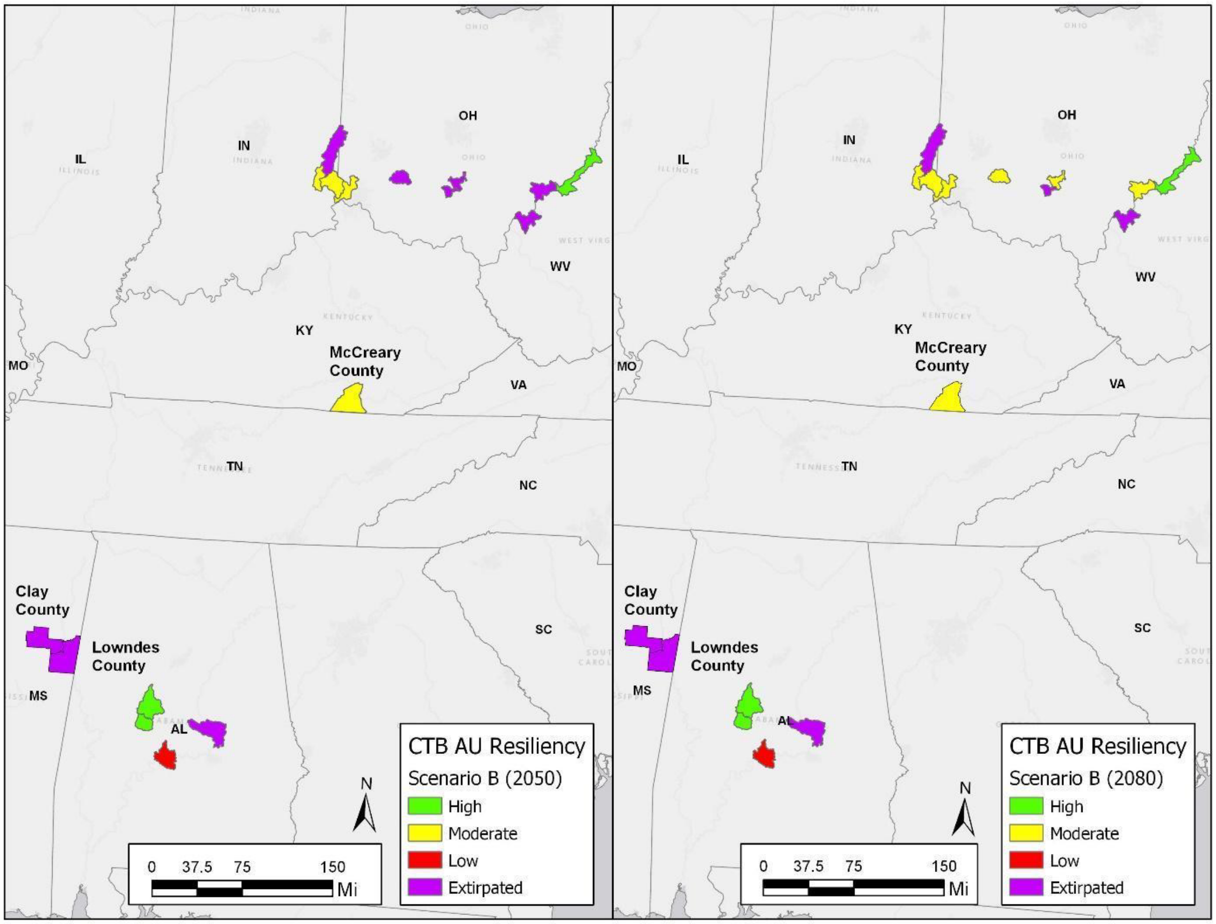

Figure 17. Scenario B Midwest and Southeastern U.S.

Redundancy

Under Scenario B, we predict that the CTB will improve its redundancy over our time period. AUs that currently have High resiliency will continue to have High resiliency in 2080. We also predict that seven currently extirpated AUs will be restored by 2080, due to conservation efforts, resulting in a 26 percent increase in the number of AUs. The restored AUs are located in the Northern, Central, and Western portions of the range.

Representation

Given our measure of representation for the CTB, which is described in terms of variability among hydrologic systems, latitudes, and physiographic provinces, we predict that the CTB will continue to demonstrate representation at the end of our time horizon (2080). Under Scenario B, the CTB continues to exhibit hydrologic system variability within the majority of its range. The CTB will continue to have latitudinal variability and physiographic province representation across its range with no predicted extirpations of AUs. Under Scenario B, seven currently extirpated AUs will be restored by 2080 due to conservation efforts. These restorations will increase representation in four physiographic provinces: New England (increasing by two AUs), Piedmont (one AU), Appalachian Plateau (one AU), and Central Lowland (two AUs) resulting in all seven historical provinces being represented by 2080.

5.3.3 Scenario C

Resiliency

We predict that under Scenario C, the effects of climate change under RCP8.5, a lack of conservation actions, and activities such as dam reconstruction or changes to dam flow regimes will result in further adverse impacts to many CTB AUs (Table 15). Of the 13 AUs with current conditions in the High resilient category, there is a decline to 4 AUs by 2050 and only 1 (Grand Lake, New Brunswick) remains High through 2080. We predict an increase over the number of Moderate AUs under the Current Condition for both 2050 and 2080, primarily as a result of High resilient AUs declining in resiliency.

Extirpation risk increases in this scenario. Two of the three AUs in the Low resiliency category under current conditions, are projected to become extirpated by 2050 (Winooski River and Allegheny River) and the third, Soapstone Creek - Alabama River, is projected to be extirpated by 2080. Both of the AUs currently in the Unknown category become extirpated by 2050. The total number of extirpated AUs increased under Scenario C from the current count of 18 to 23 by 2050 and 24 by 2080.(Figures 18 and 19).

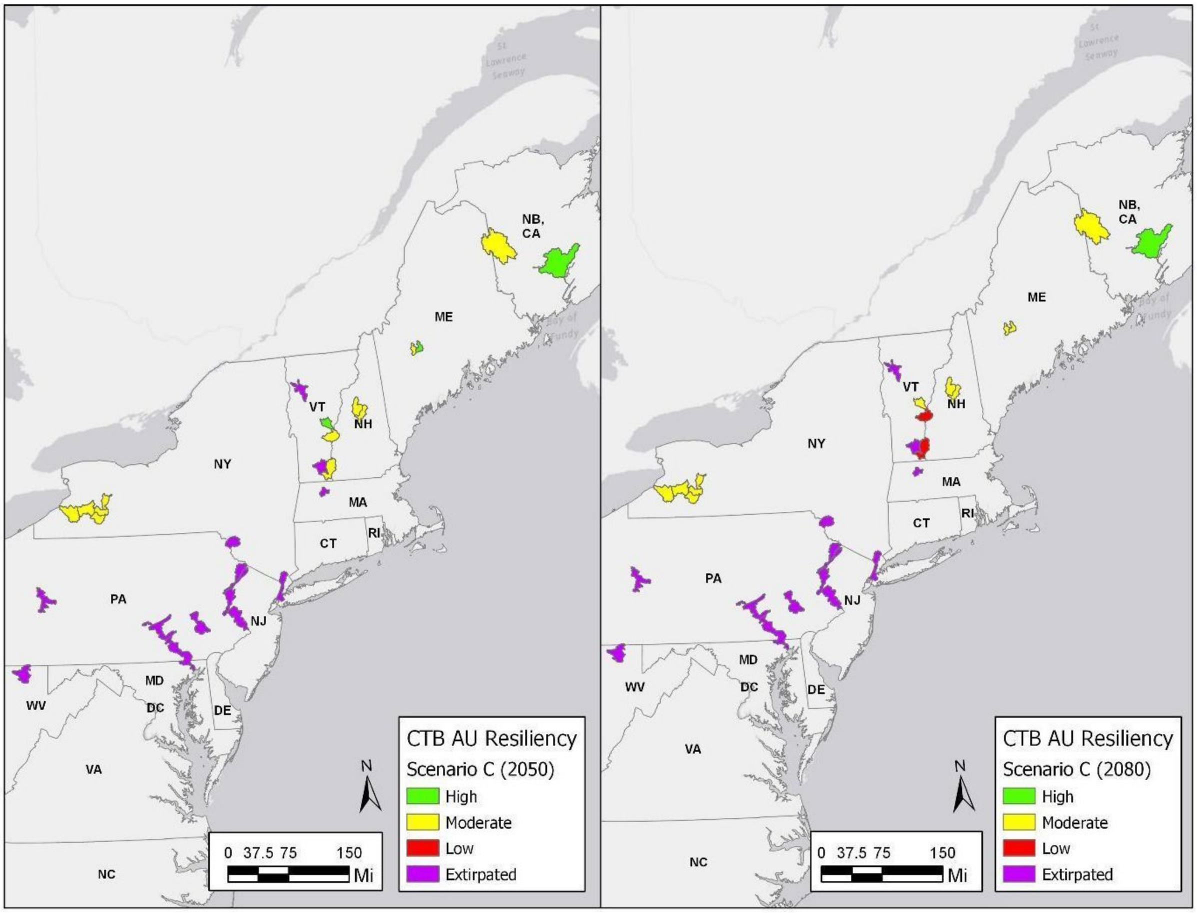

Figure 18. Scenario C: Northern United States and New Brunswick, Canada

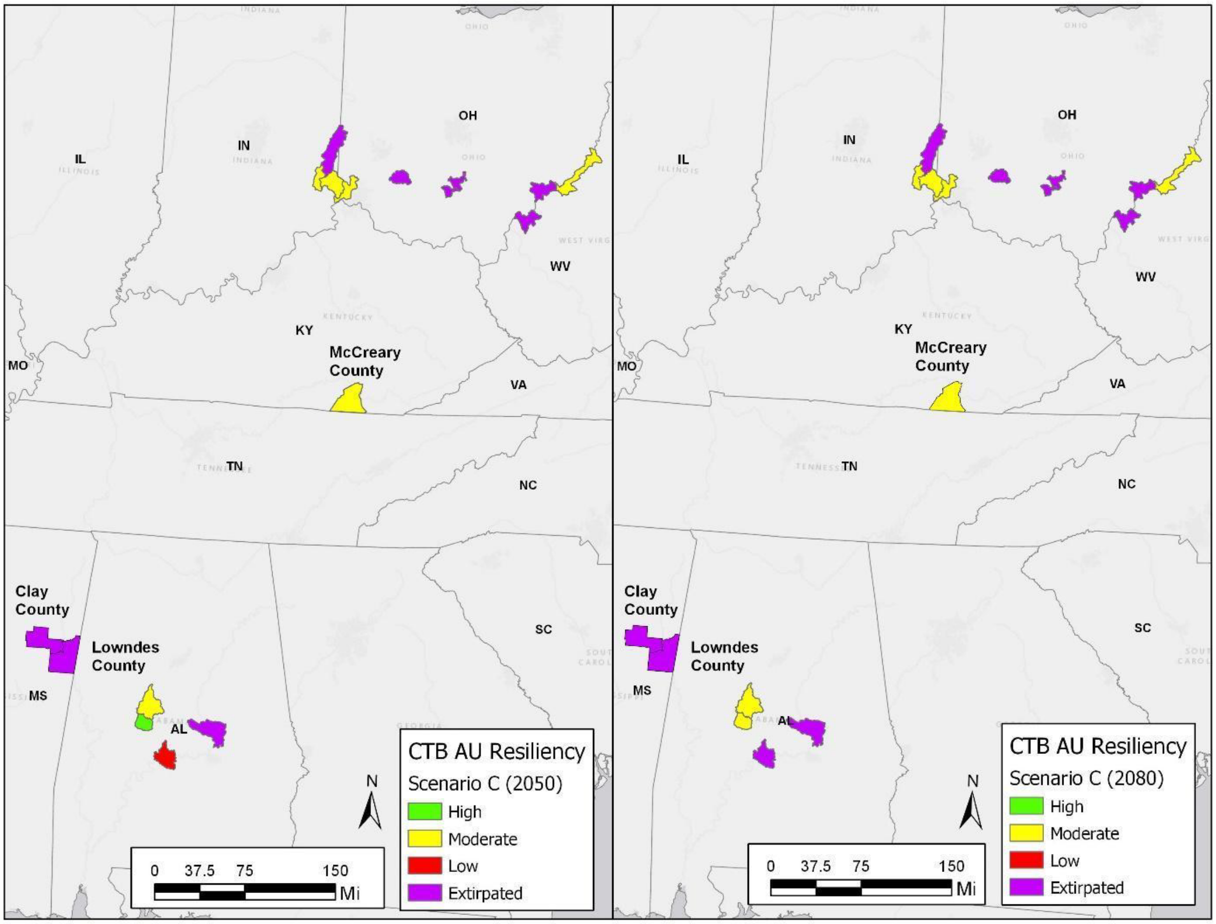

Figure 19. Scenario C. Midwest and Southeast U.S

Redundancy

Under Scenario C, we predict that 9 to 11 AUs in a current High resiliency condition will decline to a Moderate condition by either 2050 or 2080 reducing resiliency of 48 percent of the range. We predict that five AUs will be extirpated by 2050 and one additional AU, Soapstone Creek-Alabama River, will become extirpated by 2080 causing a 19 percent range reduction by 2050 and 22 percent reduction by 2080. These extirpations occur in the Northern, Central, and Southern portion of the range. Of the extirpated sites, two of the AUs are metapopulations, consisting of 2 populations each and a geographic range of <1 mile. The loss of these AUs causes a 10 percent decline in metapopulations throughout the range. This decline in condition, as well as the loss of several AUs, is likely to make the CTB more vulnerable to stochastic disturbance events, especially in Vermont and Pennsylvania.

Representation

Given our measure of representation for the CTB, which is described in terms of variability among hydrologic systems, latitudes, and physiographic provinces, we predict that the CTB will demonstrate a lower level of representation at the end of our time horizon (2080). Under Scenario C, the CTB continues to exhibit hydrologic system variability with AUs. The CTB will continue to have latitudinal variability; although with the predicted extirpation of six AUs by

2080, the species' distribution is expected to contract (22 percent reduction in range). The CTB will show a decline in physiographic province representation by 2050 with the loss of one AU in the Appalachian Plateau and one AU in the New England province. By 2080, representation will decline further with the loss of one AU in the Coastal Plain province. All representation within the St. Lawrence Valley and Valley and Ridge provinces will be lost by 2080.

5.3.4 Uncertainty

This SSA is based on best available information. As summarized below in section 6.0, there are uncertainties, assumptions, and data gaps throughout the analysis of current condition, all of which apply to the analysis of future condition.

We constructed the three scenarios based on best available information, recognizing that many assumptions are included. In brief, there are uncertainties in climate pathways RCP8.5 and RCP4.5 and how changes in climate indicators affect AUs (see section 3.5). For Scenario B, there is no way to estimate how many conservation actions will be applied and how effective they will be in maintaining or improving resiliency for particular AUs. Similarly, for Scenario C, the impacts of a lack of conservation actions or the implementation of adverse actions are unknown. Thus, the trajectories and projections of resiliency status under each scenario may be overestimated (status rated too high) or underestimated (status rated too low).

5.3.5 Summary

We used the best available information to describe the future viability of the CTB in terms of resiliency, representation, and redundancy. To capture the uncertainty associated with the degree and extent of potential future conditions and their impacts on the CTB, each of the 3Rs were assessed using three plausible future scenarios. The CTB faces risks from the operation and construction of dams, the effects of climate change, and loss or destruction of habitat (resulting from development, bank stabilization activities, recreational impacts, and invasive vegetation). These risks play a large role in the future viability of the CTB. If AUs lose resiliency, they are more vulnerable to extirpation, with resulting losses in representation and redundancy.

Overall, we have found that Scenario A shows a continuation of CTB viability trends in resiliency, representation, and redundancy. AUs continue to slowly decline in condition and become more disjunct throughout their distribution and more metapopulations are lost. Scenario B shows an increase in CTB viability trends with the recovery and restoration of several AUs. This recovery extends the currently occupied AUs into a more contiguous distribution and encourages the development of metapopulations. Scenario C shows a significant decrease in CTB viability with the quick decline of High condition AUs and a larger number of extirpations, relative to the other scenarios. The effects of this decline are similar to Scenario A, however, the impacts are seen more quickly and are more drastic within the projected time period.

Chapter 6 Uncertainty

There is a lack of information on the basic CTB life history, such as the life cycle (2 or 3 years) and the taxonomic description of larvae (section 2.4.1). The egg laying and larval habitat has not been identified. Therefore, many of the projected adverse impacts to the CTB life stages under Scenarios A and C (for example, reduced productivity and changes in suitable larval habitat as a result of droughts and desiccation) are based on the known response to these impacts by other tiger beetle species. There has been noted uncertainty of the species status of the southern-most, disjunct populations within Alabama. Although physiological differences have been noted, genetic analysis has not been conducted to determine if these populations represent a separate subspecies.

There is a lack of information on individual population estimates, and there is currently no model developed to estimate population numbers. To determine the resiliency of a metapopulation or individual population, we had to make assumptions about the persistence of the populations based on very limited survey data. For the Kentucky AU, we were only given information confirming an extant metapopulation with a geographic range of 1.1 miles but no information regarding the number of populations within the range (Office of Kentucky Nature Preserves 2018). For two AUs along the Delaware River, the lack of recent survey data led us to consider their current condition as Unknown.

Much of the resource needs we identified are based on data for other tiger beetle species. There are many data gaps in describing the hydrological factors that maintain cobble bar habitat suitable for CTB reproduction, including sediment grain size and sparse vegetation. The extent that CTB larvae are vulnerable to stressors such as inundation and desiccation is largely unknown. Additional stressors such as development leading to greater urbanization are uncertain because the land use projections we used are based on a county rather than AU scale. The channel adjustments within each river system undergoing the effects of urbanization will vary across space and time.

Because CTB habitat is only partially aquatic (i.e., on cobble bars rather than in the water column or bottom sediments), the relevance of water quality impairments due to contaminants is uncertain. The 303(d) lists are based on available monitoring data. Monitoring programs vary across states and watersheds in sampling design, the number of samples within streams, and the list of analyses. Thus, there is uncertainty as to how well-characterized the river reaches are in terms of listed impairments including sediments and nutrients, the water quality stressors we assume have the greatest direct impacts to CTB habitat.

Eleven AUs incorporating six metapopulations and three isolated populations and two AUs with unknown status occur on rivers affected by dam operations (Table 3). There are no data that describe the CTB status or extent of occupied habitat for these populations prior to the construction and management of the dams affecting their river reaches. Thus, there is uncertainty as to whether CTB populations were impacted by the dam construction and operation. It is also unknown whether current managed flows are affecting CTB populations by limiting available habitat or incurring prolonged inundation that may affect productivity.

For determining current condition, there is uncertainty regarding some of the habitat metrics. In these cases, we used a combination of the best available scientific literature, GIS mapping, and expert observations to identify the most appropriate category designation. There is also uncertainty with respect to demographic metrics. Using the best available data, we classified the AU populations based on counts; however, some sites lacked recent surveys, or surveys have not been conducted systematically to allow for an accurate estimation of population size. It is likely that most count data are underestimates of the population, and this was taken into account for future scenarios. Some sites that were surveyed did not result in count data, but did have presence/absence information. These data were factored into the persistence of the site, but in areas where surveys were lacking, there is uncertainty about the actual persistence of the site. Furthermore, there is uncertainty pertaining to the metapopulations. Through expert consultation, we determined populations within 5 miles could be considered a metapopulation; however, the amount of movement between populations is uncertain and these metrics could be under or over estimating the distance the CTB actually moves between populations.

For the future scenarios, there are uncertainties in climate pathways RCP8.5 and RCP4.5 and how changes in climate indicators affect AUs (see section 3.5). For Scenario B, there is no way to estimate how many conservation actions will be applied and how effective they will be in maintaining or improving resiliency for particular AUs or in restoring populations to previously occupied locations. Similarly, for Scenario C, the impacts of a lack of conservation actions or the implementation of adverse actions is unknown. Thus, the trajectories and projections of resiliency status under each scenario may be overestimated (status rated too high) or underestimated (status rated too low).

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Appendix A: Supplemental Information

A-1 Supplemental text: Methodology for current condition.

Habitat Metric Score:
In this analysis, sediment has a weight of 0.5. Because we lack information on site-specific sediment loading, the metric was determined by looking at impaired versus non-impaired streams. The broad range of the scale makes the metric informative, but less informative than the other metrics that were used, thus the lower weighting. Vegetation density has a weight of 1 to reflect its relative importance to CTB habitat structure. Managed flows received a weight of 2 because of how drastically flow management can impact CTB habitat. The score for the individual metric was determined, added to the other habitat metric scores, and then all divided by 3.5. The outcome was then assigned to the appropriate category (rounding non-whole numbers up if they exceeded a 0.5 threshold).

HUC Population Methodology:
If individuals were found at a site within the last 20 years but negative data showed they have not been found during the most recent survey period, we assigned the site a count of "0." For example, positive survey results exist at one site for 2001; however, the most recent survey in 2016 yielded no CTBs. Therefore, we gave the site a count of "0." Such sites are indicative of populations that could potentially be extirpated, but were not excluded from the analysis due to lack of information regarding current habitat and population conditions. We used the best available data to determine AU counts, but in many cases these data were not collected every year or consistently. Many of the counts were incidental sightings rather than standardized efforts, which likely vastly underestimates the population counts. To give additional insight to population health, we also looked at site persistence and used a combination of known population counts and site persistence to determine population categories.

We calculated site persistence using the earliest survey date through the most recent survey date in which beetles were documented. The earliest year of all populations within an AU and the latest year of all populations within a HUC determine the persistence of the AU. The number of years spanning this time informs presence for the CTB with an assumption that at least one population persisted throughout that period. Because most count data were not collected using a standardized survey protocol, we weighted persistence data 1.5 times compared to count when assigning AU population status.

Metapopulation Determination:
Although dispersal distances are not very well known, some tiger beetles have been known to travel several miles with wind assistance and have been documented to move between cobble bars at a distance in excess of 0.3 miles (500 meters) (Environment Canada 2013 p. 11; Hudgins *et al.* 2011 p. 310). In most cases, metapopulations are contained within a single AU, but there are four metapopulations that span two AUs. When evaluating these metapopulations, we consider the populations only contained within each individual AU. For example, a

metapopulation containing five populations spanning two AUs with two populations in one AU and three populations in another AU will have the populations evaluated separately for their respective AUs. We then consider geographic range, which uses the entire metapopulation regardless of how many AUs are within the metapopulation. Many populations have nearby cobble bars that have not necessarily been documented as occupied by the CTB, but could provide transitory dispersal habitat, since the CTB are thought to be genetically adapted to colonize habitat patches (Knisley 2018).

Demographic Score:
The historical or extirpated AUs received a designation of "extirpated" that corresponds with a score of 0. Because of the uncertainty associated with the AU population category, the metric received a weight of 1 whereas the metapopulation received a weight of 2. The metapopulation category carries less uncertainty relative to the HUC 0 population category, but could potentially be an indicator of additional uncolonized habitat that is important to the species. The scores for each metric were determined, added, and then divided by 3 to give an overall score (rounding non-whole numbers up if they exceeded a .5 threshold).

A-2 Supplemental Tables

Table A-1. Land use (1997 data, from Wear 2011, excel file) in relation to extirpated populations.

AU	County, State	Area (1000s of acres)	% Agricultural	% Forested	% Urban	% Other
Lower Deerfield R.	Franklin, MA	449.34	10.3	75.4	6.9	7.4
Saw Mill R.–Hudson R.	New York, NY	18.18	0.0	0.0	66.0	34.0
Upper Delaware R.	Northampton, PA	239.30	35.1	30.1	27.7	7.1
Middle Delaware R.	Sullivan, NY	620.67	12.9	75.9	5.9	5.3
Lower Delaware R.	Bucks, PA	388.86	34.1	19.3	39.5	7.2
Susquehanna R. (0205030617)	Lancaster, PA	607.42	53.8	13.6	23.4	9.2
Susquehanna R. (0205030210)	Dauphin, PA	336.19	28.6	41.1	18.8	11.5
Middle Schuylkill R.	Berks, PA	549.89	39.5	34.9	18.8	6.8
Upper Monongahaela R.	Monongalia, WV	231.2	15.8	65.5	10.6	8.2
Little Sandy Creek - Ohio R.	Meigs, OH	260.74	9.5	16.4	67.7	6.4
Little Hocking R. – Ohio R.	Wood, WV	235.14	28.5	55.3	10.9	5.3
Kinnikinnick Creek - Scioto R	Ross, OH	440.64	46.9	38.1	6.0	8.9
Ralston Run - Paint Creek	Clinton, OH	262.98	76.5	10.8	5.2	7.4
Headwaters Todd Fork	Clinton, OH	262.98	76.5	10.8	5.2	7.4
East Fork Whitewater R.	Wayne, IN	258.30	69.7	10.5	9.0	10.7
Weoka Creek–Coosa R.	Elmore, AL	397.8	21.2	58.8	7.7	12.3
Tombigbee R.	Clay, MS	261.5	38.8	45.1	3.8	12.3

Tombigbee R.	Lowndes, MS	321.5	35.3	43.0	2.9	18.8
	Minimum		0.0	0.0	2.9	5.3
	Maximum		76.5	75.9	67.7	34.0
	Median		34.6	36.5	9.8	7.8

Table A-2. Current resiliency metrics, weights, and scores.

State	HUC10 Name	Habitat Metrics				Demographic Metrics			Overall Resiliency Score
		Substrate / Sedimentation (0.5)	Suitable Scour/ vegetation density (1)	Managed Flows (2)	Overall Habitat Score (1.5)	HUC Population Category (1)	Metapopulation Category (2)	Overall Demographic Score (1)	
AL	Mill Creek-Cahaba R.	3.0	3.0	3.0	3.0	3.0	2.0	2.3	2.7
AL	Soapstone Creek-Alabama R.	3.0	1.0	1.0	1.3	3.0	1.0	1.7	1.4
AL	Upper Cahaba R.	3.0	3.0	3.0	3.0	3.0	1.0	1.7	2.5
AL	Weoka Creek - Coosa River	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
IN	Pipe Creek-Whitewater R.	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
IN	East Fork Whitewater River	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
IN,OH	Taylor Creek-Great Miami R.	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
IN,OH	Whitewater R.	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
KY	KY HUC	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
MA	Lower Deerfield River	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
ME	Lower Carrabassett River	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
ME	Middle Carrabassett River	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
MS	Clay County	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
MS	Lowndes County	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
NH	Middle Pemigewasset River	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.6
NH	Upper Pemigewasset River	3.0	3.0	3.0	3.0	1.0	2.0	1.7	2.4
NH,VT	Mill Brook-Connecticut River	3.0	3.0	2.0	2.4	3.0	3.0	3.0	2.7
NH,VT	Vernon Dam-Connecticut River	3.0	3.0	2.0	2.4	3.0	1.0	1.7	2.1

NJ, PA	Lower Delaware River	1.0	1.0	1.0	1.0	Extirpated	Extirpated	Extirpated	Extirpated
NJ, PA	Upper Delaware River	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NJ,PA	Flat Brook-Delaware River	3.0	1.0	1.0	1.3	Status Unknown	Status Unknown	Status Unknown	Low
NJ,PA	Raymondskill Creek-Delaware River	3.0	1.0	1.0	1.3	Status Unknown	Status Unknown	Status Unknown	Low
NY	Caneadea Creek-Genesee River	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
NY	Cattaraugus Creek	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
NY	Cold Creek-Genesee River	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
NY	Headwaters Cattaraugus Creek	3.0	3.0	3.0	3.0	1.0	2.0	1.7	2.5
NY	Outlet Silver Lake-Genesee River	3.0	3.0	2.0	2.4	3.0	3.0	3.0	2.7
NY	Saw Mill River - Hudson River	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NY, PA	Middle Delaware River	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
OH	Kinnikinnick Creek - Scioto River	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
OH	Ralston Run - Paint Creek	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
OH	Headwaters Todd Fork	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
OH,WV	French Creek-Ohio River	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.6
PA	Allegheny River	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
PA	Susquehanna River (0205030210)	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
PA	Susquehanna River (0205030617)	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
PA	Middle Schuykill River	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
VT	Rock River-West River	3.0	1.0	2.0	1.9	2.0	1.0	1.3	1.6
VT	White River	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

VT	Winooski River	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
WV	Upper Monongahela River	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
WV, OH	Little Sandy Creek - Ohio River	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
WV, OH	Little Hocking River - Ohio River	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
CAN	01AJB00	No Data	3.0	2.0	2.4	3.0	1.0	1.7	2.1
CAN	01AO000	No Data	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Table A-3. Future Condition (Resiliency) of CTB AUs under Scenarios A-C.

State	Analytical Unit	Current Condition Resiliency Category	Scenario A		Scenario B		Scenario C	
			2050	2080	2050	2080	2050	2080
AL	Mill Creek-Cahaba River	High	High	Moderate	High	High	High	Moderate
AL	Soapstone Creek-Alabama River	Low	Low	Low	Low	Low	Low	Extirpated
AL	Upper Cahaba River	High	Moderate	Moderate	High	High	Moderate	Moderate
AL	Weoka Creek - Coosa River	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated
IN	Pipe Creek-Whitewater River	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
IN	East Fork Whitewater River	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated
OH	Taylor Creek-Great Miami River	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
IN/OH	Whitewater River	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
KY	McCreary County	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
MA	Lower Deerfield River	Extirpated	Extirpated	Extirpated	Extirpated	Moderate	Extirpated	Extirpated
ME	Lower Carrabassett River	High	High	High	High	High	High	Moderate
ME	Middle Carrabassett River	High	High	High	High	High	Moderate	Moderate
MS	Clay County	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated
MS	Lowndes County	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated
NH	Middle Pemigewasset River	High	High	Moderate	High	High	Moderate	Moderate

NH	Upper Pemigewasset River	Moderate	Moderate	Moderate	Moderate	High	Moderate	Moderate
NH/VT	Mill Brook-Connecticut River	Moderate	Moderate	Moderate	High	High	Moderate	Low
NH/VT	Vernon Dam-Connecticut River	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low
NJ/PA	Lower Delaware River	Extirpated	Extirpated	Extirpated	Extirpated	Moderate	Extirpated	Extirpated
NJ/PA	Upper Delaware River	Extirpated	Extirpated	Extirpated	Extirpated	Moderate	Extirpated	Extirpated
NJ/PA	Flat Brook-Delaware River	Unknown	Extirpated	Extirpated	Low	Low	Extirpated	Extirpated
NJ/PA	Raymondskill Creek-Delaware River	Unknown	Extirpated	Extirpated	Low	Low	Extirpated	Extirpated
NY	Caneadea Creek-Genesee River	High	High	High	High	High	Moderate	Moderate
NY	Cattaraugus Creek	High	High	High	High	High	Moderate	Moderate
NY	Cold Creek-Genesee River	High	High	High	High	High	Moderate	Moderate
NY	Headwaters Cattaraugus Creek	High	Moderate	Moderate	High	High	Moderate	Moderate
NY	Outlet Silver Lake-Genesee River	High	High	Moderate	High	High	Moderate	Moderate
NY	Saw Mill River - Hudson River	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated
NY/PA	Middle Delaware River	Extirpated	Extirpated	Extirpated	Extirpated	Moderate	Extirpated	Extirpated
OH	Kinnikinnick Creek - Scioto River	Extirpated	Extirpated	Extirpated	Extirpated	Moderate	Extirpated	Extirpated
OH	Ralston Run - Paint Creek	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated

OH	Headwaters Todd Fork	Extirpated	Extirpated	Extirpated	Extirpated	Moderate	Extirpated	Extirpated
OH/WV	French Creek-Ohio River	High	Moderate	Moderate	High	High	Moderate	Moderate
OH/WV	Little Sandy Creek - Ohio River	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated
OH/WV	Little Hocking River - Ohio River	Extirpated	Extirpated	Extirpated	Extirpated	Moderate	Extirpated	Extirpated
PA	Allegheny River	Low	Low	Low	Low	Low	Extirpated	Extirpated
PA	Susquehanna River (0205030210)	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated
PA	Susquehanna River (0205030617)	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated
PA	Middle Schuykill River	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated
VT	Rock River-West River	Moderate	Moderate	Extirpated	Moderate	Moderate	Extirpated	Extirpated
VT	White River	High	High	High	High	High	High	Moderate
VT	Winooski River	Low	Extirpated	Extirpated	Low	Low	Extirpated	Extirpated
WV	Upper Monongahela River	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated
CAN	01AJB00	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
CAN	01AO000	High	High	High	High	High	High	High

Table A-4. Scenario A metrics, weights, and resiliency scores.

State	HUC10 Name	Year	Habitat Metrics				Demographic Metrics			Overall Resiliency Score
			Substrate/ Sedimenta -tion (0.5)	Suitable Scour/ vegetatio n density (1)	Manage d Flows (2)	Overall Habitat Score (1.5)	HUC Population Category (1)	Metapopu- lation Category (2)	Overall Demograp hic Score (1)	
AL	Mill Creek-Cahaba River	2050	3.0	3.0	3.0	3.0	3.0	2.0	2.3	2.7
		2080	3.0	2.0	3.0	2.7	2.0	2.0	2.0	2.4
AL	Soapstone Creek-Alabama River	2050	3.0	1.0	1.0	1.3	2.0	1.0	1.3	1.3
		2080	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
AL	Upper Cahaba River	2050	3.0	3.0	3.0	3.0	3.0	1.0	1.7	2.5
		2080	3.0	2.0	2.0	2.1	3.0	1.0	1.7	2.0
IN	Pipe Creek-Whitewater River	2050	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
		2080	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
IN,OH	Taylor Creek-Great Miami River	2050	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
		2080	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
IN,OH	Whitewater River	2050	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
		2080	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
KY	KY HUC	2050	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
		2080	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
ME	Lower Carrabassett River	2050	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
		2080	3.0	2.0	3.0	2.7	2.0	3.0	2.7	2.7
ME	Middle Carrabassett River	2050	3.0	3.0	3.0	3.0	3.0	2.0	2.3	2.7
		2080	3.0	2.0	3.0	2.7	2.0	2.0	2.0	2.4
NH	Middle Pemigewasset River	2050	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.6
		2080	3.0	2.0	3.0	2.7	2.0	2.0	2.0	2.4
NH	Upper Pemigewasset River	2050	3.0	3.0	3.0	3.0	1.0	2.0	1.7	2.4
		2080	3.0	2.0	3.0	2.7	1.0	2.0	1.7	2.3
NH,VT	Mill Brook-Connecticut River	2050	3.0	3.0	2.0	2.4	2.0	2.0	2.0	2.3
		2080	3.0	2.0	2.0	2.1	2.0	2.0	2.0	2.1
NH,VT	Vernon Dam-Connecticut River	2050	3.0	3.0	2.0	2.4	3.0	1.0	1.7	2.1
		2080	3.0	2.0	2.0	2.1	2.0	1.0	1.3	1.8
NJ,PA	Flat Brook-Delaware River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NJ,PA	Raymondskill Creek-Delaware River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NY	Caneadea Creek-	2050	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
		2080	3.0	2.0	3.0	2.7	2.0	3.0	2.7	2.7

	Genesee River									
NY	Cattaraugus Creek	2050	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		2080	3.0	2.0	3.0	2.7	3.0	3.0	3.0	2.8
NY	Cold Creek-Genesee River	2050	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
		2080	3.0	2.0	3.0	2.7	2.0	3.0	2.7	2.7
NY	Headwaters Cattaraugus Creek	2050	3.0	3.0	3.0	3.0	1.0	2.0	1.7	2.5
		2080	3.0	2.0	3.0	2.7	1.0	2.0	1.7	2.3
NY	Outlet Silver Lake-Genesee River	2050	3.0	3.0	2.0	2.4	3.0	3.0	3.0	2.7
		2080	3.0	2.0	2.0	2.1	3.0	3.0	3.0	2.5
OH,WV	French Creek-Ohio River	2050	3.0	2.0	3.0	2.7	2.0	2.0	2.0	2.4
		2080	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
PA	Allegheny River	2050	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
		2080	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
VT	Rock River-West River	2050	3.0	1.0	2.0	1.9	1.0	1.0	1.0	1.5
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
VT	White River	2050	3.0	2.0	3.0	2.7	3.0	3.0	3.0	2.8
		2080	3.0	2.0	3.0	2.7	3.0	3.0	3.0	2.8
VT	Winooski River	2050	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
MA	Lower Deerfield River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NY	Saw Mill River - Hudson River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NY, PA	Middle Delaware River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NJ, PA	Lower Delaware River	2050	1.0	1.0	1.0	1.0	Extirpated	Extirpated	Extirpated	Extirpated
		2080	1.0	1.0	1.0	1.0	Extirpated	Extirpated	Extirpated	Extirpated
NJ, PA	Upper Delaware River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
PA	Susquehanna River (0205030210)	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
PA	Susquehanna River (0205030617)	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
PA	Middle Schuykill River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
WV	Upper Monongahela River	2050	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated

WV, OH	Little Sandy Creek - Ohio River	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
WV, OH	Little Hocking River - Ohio River	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
OH	Kinnikinnick Creek - Scioto River	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
OH	Ralston Run - Paint Creek	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
OH	Headwaters Todd Fork	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
IN	East Fork Whitewater River	2050	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
AL	Weoka Creek - Coosa River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
MS	Clay County	2050	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
MS	Lowndes County	2050	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
CAN	01AJB00	2050	3.0	3.0	2.0	2.4	3.0	1.0	1.7	2.1
		2080	3.0	2.0	2.0	2.1	2.0	1.0	1.3	1.8
CAN	01AO000	2050	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		2080	3.0	2.0	3.0	2.7	3.0	3.0	3.0	2.8

Table A-5. Scenario B metrics, weights, and resiliency scores.

		Year	Habitat Metrics				Demographic Metrics			
State	HUC10 Name		Substrate/ Sedimentation (0.5)	Suitable Scour/ vegetation density (1)	Managed Flows (2)	Overall Habitat Score (1.5)	HUC Population Category (1)	Metapopulation Category (2)	Overall Demographic Score (1)	Overall Resiliency Score
AL	Mill Creek-Cahaba River	2050	3.0	3.0	3.0	3.0	3.0	2.0	2.3	2.7
		2080	3.0	3.0	3.0	3.0	3.0	2.0	2.3	2.7
AL	Soapstone Creek-Alabama River	2050	3.0	1.0	1.0	1.3	3.0	1.0	1.7	1.4
		2080	3.0	1.0	1.0	1.3	3.0	1.0	1.7	1.4
AL	Upper Cahaba River	2050	3.0	3.0	3.0	3.0	3.0	2.0	2.3	2.7
		2080	3.0	3.0	3.0	3.0	3.0	2.0	2.3	2.7
CAN	St. John River	2050	3.0	3.0	2.0	2.4	3.0	1.0	1.7	2.1
		2080	3.0	3.0	2.0	2.4	3.0	1.0	1.7	2.1
CAN	Grand Lake	2050	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		2080	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
IN	Pipe Creek-Whitewater River	2050	3.0	1.0	3.0	2.4	2.0	2.0	2.0	2.3
		2080	3.0	1.0	3.0	2.4	2.0	2.0	2.0	2.3
IN,OH	Taylor Creek-Great Miami River	2050	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
		2080	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
IN,OH	Whitewater River	2050	3.0	1.0	3.0	2.4	2.0	2.0	2.0	2.3
		2080	3.0	1.0	3.0	2.4	2.0	2.0	2.0	2.3
KY	KY HUC	2050	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
		2080	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
ME	Lower Carrabassett River	2050	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
		2080	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
ME	Middle Carrabassett River	2050	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		2080	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
NH	Middle Pemigewasset River	2050	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.6
		2080	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
NH	Upper Pemigewasset River	2050	3.0	3.0	3.0	3.0	1.0	2.0	1.7	2.4
		2080	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9

NH,VT	Mill Brook-Connecticut River	2050	3.0	3.0	2.0	2.4	3.0	3.0	3.0	2.7
		2080	3.0	3.0	2.0	2.4	3.0	3.0	3.0	2.7
NH,VT	Vernon Dam-Connecticut River	2050	3.0	3.0	2.0	2.4	3.0	1.0	1.7	2.1
		2080	3.0	3.0	2.0	2.4	3.0	2.0	2.3	2.4
NJ,PA	Flat Brook-Delaware River	2050	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
		2080	3.0	2.0	1.0	1.6	2.0	1.0	1.3	1.5
NJ,PA	Raymondskill Creek-Delaware River	2050	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
		2080	3.0	2.0	1.0	1.6	2.0	1.0	1.3	1.5
NY	Caneadea Creek-Genesee River	2050	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		2080	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
NY	Cattaraugus Creek	2050	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		2080	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
NY	Cold Creek-Genesee River	2050	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		2080	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
NY	Headwaters Cattaraugus Creek	2050	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
		2080	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
NY	Outlet Silver Lake-Genesee River	2050	3.0	3.0	2.0	2.4	3.0	3.0	3.0	2.7
		2080	3.0	3.0	2.0	2.4	3.0	3.0	3.0	2.7
OH,WV	French Creek-Ohio River	2050	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.6
		2080	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.6
PA	Allegheny River	2050	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
		2080	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
VT	Rock River-West River	2050	3.0	1.0	2.0	1.9	1.0	2.0	1.7	1.8
		2080	3.0	2.0	2.0	2.1	2.0	2.0	2.0	2.1
VT	White River	2050	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		2080	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
VT	Winooski River	2050	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
		2080	3.0	2.0	1.0	1.6	2.0	1.0	1.3	1.5
MA	Lower Deerfield River	2050	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
		2080	3.0	2.0	2.0	2.1	2.0	1.0	1.3	1.8

NY	Saw Mill River - Hudson River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NY, PA	Middle Delaware River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	2.0	2.0	2.1	1.0	1.0	1.0	1.7
NJ, PA	Lower Delaware River	2050	1.0	1.0	1.0	1.0	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	2.0	2.0	2.1	1.0	1.0	1.0	1.7
NJ, PA	Upper Delaware River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	2.0	2.0	2.1	1.0	1.0	1.0	1.7
PA	Susquehanna River (0205030210)	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
PA	Susquehanna River (0205030617)	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
PA	Middle Schuykill River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
WV	Upper Monongahela River	2050	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
WV, OH	Little Sandy Creek - Ohio River	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
WV, OH	Little Hocking River - Ohio River	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
OH	Kinnikinnick Creek - Scioto River	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
OH	Ralston Run - Paint Creek	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
OH	Headwaters Todd Fork	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
IN	East Fork Whitewater River	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated

AL	Weoka Creek - Coosa River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
MS	Clay County	2050	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
MS	Lowndes County	2050	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated

Table A-6. Scenario C metrics, weights, and resiliency scores.

State	HUC10 Name	Year	Habitat Metrics				Demographic Metrics			Overall Resiliency Score
			Substrate/ Sedimentation (0.5)	Suitable Scour/ vegetation density (1)	Managed Flows (2)	Overall Habitat Score (1.5)	HUC Population Category (1)	Metapopulation Category (2)	Overall Demographic Score (1)	
AL	Mill Creek-Cahaba River	2050	3.0	2.0	3.0	2.7	3.0	2.0	2.3	2.6
		2080	3.0	2.0	3.0	2.7	2.0	2.0	2.0	2.4
AL	Soapstone Creek-Alabama River	2050	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
AL	Upper Cahaba River	2050	3.0	2.0	3.0	2.7	3.0	1.0	1.7	2.3
		2080	3.0	2.0	3.0	2.7	2.0	1.0	1.3	2.2
CAN	01AJB00	2050	3.0	2.0	2.0	2.1	3.0	1.0	1.7	2.0
		2080	3.0	2.0	2.0	2.1	2.0	1.0	1.3	1.8
CAN	01AO000	2050	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		2080	3.0	2.0	3.0	2.7	2.0	3.0	2.7	2.7
IN	Pipe Creek-Whitewater River	2050	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
		2080	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
IN,OH	Taylor Creek-Great Miami River	2050	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
		2080	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
IN,OH	Whitewater River	2050	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
		2080	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
KY	KY HUC	2050	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
		2080	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
ME	Lower Carrabassett River	2050	3.0	2.0	3.0	2.7	2.0	3.0	2.7	2.7
		2080	3.0	1.0	3.0	2.4	2.0	2.0	2.0	2.3
ME	Middle Carrabassett River	2050	3.0	2.0	3.0	2.7	2.0	2.0	2.0	2.4
		2080	3.0	1.0	3.0	2.4	2.0	2.0	2.0	2.3
NH	Middle Pemigewasset River	2050	3.0	2.0	3.0	2.7	2.0	2.0	2.0	2.4
		2080	3.0	1.0	3.0	2.4	2.0	2.0	2.0	2.3
NH	Upper Pemigewasset River	2050	3.0	2.0	3.0	2.7	1.0	2.0	1.7	2.3

		2080	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
NH,VT	Mill Brook-Connecticut River	2050	3.0	2.0	1.0	1.6	2.0	2.0	2.0	1.7
		2080	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
NH,VT	Vernon Dam-Connecticut River	2050	3.0	2.0	1.0	1.6	3.0	1.0	1.7	1.6
		2080	3.0	1.0	1.0	1.3	1.0	1.0	1.0	1.2
NJ,PA	Flat Brook-Delaware River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NJ,PA	Raymondskill Creek-Delaware River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NY	Caneadea Creek-Genesee River	2050	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
		2080	3.0	2.0	3.0	2.7	1.0	2.0	1.7	2.3
NY	Cattaraugus Creek	2050	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		2080	3.0	2.0	3.0	2.7	2.0	2.0	2.0	2.4
NY	Cold Creek-Genesee River	2050	3.0	3.0	3.0	3.0	2.0	3.0	2.7	2.9
		2080	3.0	2.0	3.0	2.7	1.0	2.0	1.7	2.3
NY	Headwaters Cattaraugus Creek	2050	3.0	3.0	3.0	3.0	1.0	2.0	1.7	2.5
		2080	3.0	2.0	3.0	2.7	1.0	1.0	1.0	2.0
NY	Outlet Silver Lake-Genesee River	2050	3.0	3.0	2.0	2.4	3.0	3.0	3.0	2.7
		2080	3.0	2.0	2.0	2.1	2.0	2.0	2.0	2.1
OH,WV	French Creek-Ohio River	2050	3.0	2.0	3.0	2.7	2.0	2.0	2.0	2.4
		2080	3.0	1.0	3.0	2.4	1.0	1.0	1.0	1.9
PA	Allegheny River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
VT	Rock River-West River	2050	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
VT	White River	2050	3.0	2.0	3.0	2.7	3.0	3.0	3.0	2.8
		2080	3.0	1.0	3.0	2.4	2.0	2.0	2.0	2.3
VT	Winooski River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated

		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
MA	Lower Deerfield River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NY	Saw Mill River - Hudson River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NY, PA	Middle Delaware River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NJ, PA	Lower Delaware River	2050	1.0	1.0	1.0	1.0	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
NJ, PA	Upper Delaware River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
PA	Susquehanna River (0205030210)	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
PA	Susquehanna River (0205030617)	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
PA	Middle Schuykill River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
WV	Upper Monongahela River	2050	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
WV, OH	Little Sandy Creek - Ohio River	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
WV, OH	Little Hocking River - Ohio River	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
OH	Kinnikinnick Creek - Scioto River	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
OH	Ralston Run - Paint Creek	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated

		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
OH	Headwaters Todd Fork	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
IN	East Fork Whitewater River	2050	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	3.0	2.4	Extirpated	Extirpated	Extirpated	Extirpated
AL	Weoka Creek - Coosa River	2050	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	1.0	1.3	Extirpated	Extirpated	Extirpated	Extirpated
MS	Clay County	2050	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
MS	Lowndes County	2050	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated
		2080	3.0	1.0	2.0	1.9	Extirpated	Extirpated	Extirpated	Extirpated