Climate Change Vulnerability Assessment for Tennessee Wildlife and Habitats

Prepared by:

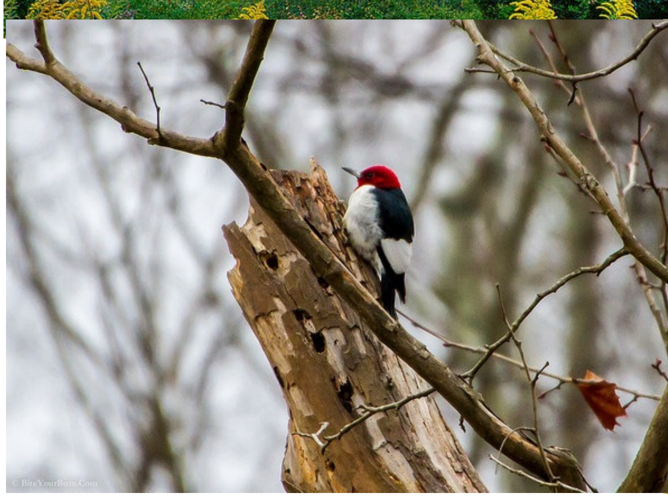
Patty Glick (National Wildlife Federation)

Sally Palmer and Joey Wisby (The Nature Conservancy – Tennessee)

For

The Tennessee Wildlife Resources Agency
Nashville, Tennessee

September 2015



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1 EXECUTIVE SUMMARY

Tennessee is home to a tremendous diversity of ecological systems and native species, representing a rich natural heritage intimately connected to the quality of life for citizens statewide. This diversity, however, will be affected by a changing climate now and in coming decades in a multitude of ways as average temperatures rise and precipitation patterns become more variable and extreme across the state and the Southeast U.S. region. Furthermore, climate change does not occur in isolation but rather acts synergistically with other stressors, exacerbating many of the conservation challenges managers already face.

Developing meaningful strategies to protect the state's valued natural resources requires an understanding of the regional and localized impacts of climate change within this broader context. Climate change vulnerability assessments are an important tool for providing natural resource managers with the type of information needed to make informed decisions in an increasingly complex management context. Accordingly, the Tennessee Wildlife Resources Agency (TWRA) has engaged in a collaborative effort to assess the vulnerability of both species and habitats to help inform its State Wildlife Action Plan (SWAP) and other relevant conservation strategies. The Tennessee assessment focuses on three main areas: species vulnerability, potential vegetation change, and landscape feature resilience.

A significant part of Tennessee's effort has been the application of the NatureServe Climate Change Vulnerability Index (CCVI) to a subset of the state's species of Greatest Conservation Need (GCN). Species were selected for the CCVI assessment based on factors such as the species' role as an indicator of ecosystem health and the potential susceptibility of its habitat to climate change. State fish, plant, and wildlife experts assessed a total of 189 of its more than 1,400 GCN plant and animal species, including 15 mammals, 51 birds, 17 reptiles, 26 amphibians, 19 fish, 27 freshwater mussels, 8 crayfish, and 26 plants.

Hellbender (*Cryptobrandhus alleganiensis*) – Brian Gratwicke, Flickr Creative Commons

Overall, 119 (63%) of the species assessed scored as Presumed Stable or Increase Likely, while 70 (37%) were considered at least Moderately Vulnerable. Mammals, birds, and reptiles (e.g., Indiana bat [*Myotis sodalis*], American bittern [*Botaurus lentiginosus*], and Alligator snapping turtle [*Macrochelys temminckii*]) comprise most of the species ranked as Presumed Stable or Increase Likely, due in part to their mobility and other factors that enhance their adaptive capacity. Fish, mussels, and plants (e.g., brook trout [*Salvelinus fontinalis*], longsolid [*Fusconaia subrotunda*], and Ruth's golden aster [*Pityopsis ruthii*]) comprised the greatest number of species that ranked as Moderately Vulnerable or above due to a variety of reasons, including existence of natural and anthropogenic barriers to dispersal, restricted habitat range, and high levels of physiological sensitivity to changing temperatures and moisture.

Some of the most-significant impacts of climate change on Tennessee's fish and wildlife species will be associated with changes to their habitats. To supplement the CCVI analysis, this report provides a brief summary of the scientific literature highlighting recent and projected changes to terrestrial and aquatic habitats across the state and region. Notable impacts include:

- Changes in the composition of associated plant species in both forest and grassland systems, particularly in the western portion of the state;
- An increase in the frequency and severity of disturbances such as wildfires and outbreaks of already-problematic species such as southern pine beetle (*Dendroctonus frontalis* Zimmermann) and hemlock wooly adelgid (*Adelges tsugae*);
- Shifts in the location and extent of suitable habitat for fish and other aquatic species due to higher water temperatures and altered water quality, with areas of coldwater habitat likely to decline and warmwater habitat projected to expand;
- Changes in the timing and magnitude of streamflows and other hydrological conditions, resulting in changes to the physical structure of habitats in streams and increased drying of ephemeral pools important to amphibians and other wildlife.

Tennessee's assessment also includes a spatial analysis of climate change vulnerability across terrestrial habitats to help inform land management efforts. The study includes comparisons between Terrestrial Habitat Priority areas identified in the 2015 State Wildlife Action Plan and several established indices of potential climate stress and resilience, including the Terrestrial Climate Stress Index (TCSI) developed by the U.S. Forest Service and areas identified as Resilient Sites for Terrestrial Conservation by The Nature Conservancy (TNC). By overlaying various maps indicating areas of current significance for terrestrial GCN species, potential changes in climatic variables and associated vegetation types, and features such as high geological and topographic diversity and habitat connectivity, managers will be able to identify lands that might be especially important for conservation in an era of climate change. While there is a fair amount of complexity in results across the state depending on the various factors considered, terrestrial habitat priority areas in certain regions, such as the Mississippi Alluvial Plain and parts of the Interior Low Plateau, appear especially vulnerable to climate change compared to other areas, such as the Cumberland Plateau and Mountains and portions of the Blue Ridge.

With a greater understanding of the vulnerability of its species and habitats to changing climate conditions, Tennessee has laid an important foundation to address the challenges of climate change as part of its ongoing efforts to conserve its valued fish and wildlife resources for current and future generations.

2 INTRODUCTION

Recent and projected changes in climate conditions across the nation have galvanized state fish and wildlife agencies to develop strategies to prepare for and cope with associated impacts as part of their State Wildlife Action Plans (SWAP) (Joyce et al. 2008, AFWA 2009, National Fish, Wildlife and Plants Climate Adaptation Partnership 2012). There is growing recognition that, without consideration of climate change, it will become increasingly difficult to achieve the goals of protecting priority habitats and preventing wildlife species from declining to the point of endangerment.

The traditional practice of relying on historical conditions for factors such as average temperatures, precipitation, the timing of streamflows, habitat ranges, and species assemblages will no longer be sufficient as a benchmark or goal for conservation decisions (Stein et al. 2014). As diverse species respond to climate change in different ways, important inter-specific connections – such as between pollinators and the plants they fertilize, or breeding birds and the insects on which they feed – will be broken (Root and Schneider 2006). In addition, studies suggest that climate change will contribute to complete biome changes in some areas (Gonzalez et al. 2010, Staudinger et al. 2013). These and other impacts will pose key challenges for state fish and wildlife management. For example:

- The suitable habitat range of target species of fish and wildlife may shift outside of the state's borders or disappear altogether (Kelly and Goulden 2008, Loarie et al. 2009, Chen et al. 2011).
- Changes in species assemblages and phenological events may alter ecological processes that are fundamental to achieving current conservation goals and objectives (Walther 2010, Blois et al. 2013).
- More-intense storms and associated flooding may alter habitats and damage key infrastructure such as fish passage culverts and roads (Karetinov et al. 2008).
- Threatened and endangered species may be at increased risk of population declines due to limited adaptive capacity and climate change effects on key habitats (Pearson et al. 2014, Urban 2015).
- Impacts outside of the state and region could intensify threats to migratory birds and other migratory species (Small-Lorenz et al. 2013).

As Tennessee strives to conserve its highly-diverse ecosystems and associated fish and wildlife species, addressing the significant risks from climate change is essential.

Flooding after a heavy rainstorm – Lindsey Turner, Flickr Creative Commons

Tennessee is characterized by considerable variability in topography, climate regimes, and terrestrial vegetation types, which is one of the reasons it happens to be among the most biologically-diverse inland states in the United States (Stein et al. 2000, Dale et al. 2010). These factors alone will mean that the effects of climate change are likely to be complex. Adding to the challenge is the fact that the ecological impacts associated with climate change do not exist in isolation but combine with and exacerbate other stressors on the state's and region's natural systems. Indeed, much of Tennessee's habitats have already been altered over the last two centuries due to human activities, including urban, industrial, and agricultural development, construction of roads and rail lines, and forestry and water resource practices. These activities have fragmented and destroyed habitats, restricted river flows, polluted the air and waterways, and contributed to exotic species invasions (TWRA 2005).

Addressing these stresses will become increasingly challenging in an era of climate change, particularly as the state's human population continues to grow. Habitat fragmentation, for example, may make it difficult for some species to move to new areas in search of favorable climate conditions. Heavier rainfall events may contribute to greater erosion and polluted runoff from urban and agricultural areas into lakes and streams. Deforestation and grazing in riparian areas may increase exposure of stream systems to higher temperatures and siltation from erosion. As discussed further below, understanding the synergies and linkages among multiple stressors, including climate change, is necessary for the development of a successful fish and wildlife conservation strategy.

Based on projected climate change across the southeastern United States, including Tennessee, this report highlights recent efforts to assess the vulnerability of some of the state's wildlife species and habitats. The information presented is intended to help inform the implementation of the Tennessee SWAP, TWRA's *Strategic Plan 2014-2020* (TWRA 2014), the Southeast Conservation Adaptation Strategy (SECAS) (https://griffingroups.com/groups/profile/1500/secas, accessed June 17, 2015), and other relevant conservation strategies.

2.1 CLIMATE CHANGE VULNERABILITY ASSESSMENTS IN BRIEF

Climate change vulnerability assessments can provide two essential types of information needed for adaptation planning: 1) identification of which species or ecological systems are likely to be most strongly affected by projected changes, which can help in prioritizing species and habitats that will be the focus of relevant management actions; and 2) an understanding of the specific reasons why those species and habitats are vulnerable, which can inform the development of specific management strategies (Glick et al. 2011, Stein et al. 2014).

Vulnerability to climate change, as it is commonly defined, has three principle components:

1. *Exposure*, which is a measure of how much of a change in climate and associated impacts (e.g., changes in hydrology) the target species or system is likely to experience;
2. *Sensitivity*, which is the measure of whether and how a species or system is likely to be affected by or responsive to particular changes in climatic variables and/or related factors; and
3. *Adaptive capacity*, which refers to a species' or system's ability to accommodate or cope with change, including both innate and extrinsic characteristics associated with the conservation target.

Recognizing these individual components is important in that it can help managers more clearly identify the specific factors that contribute to the vulnerability of the species or system being assessed and, in turn, help them to develop relevant adaptation strategies. Because climate change can both exacerbate and be exacerbated by many of the stressors that have long been of concern to fish and wildlife managers, many of these other factors can be brought into the vulnerability assessment process, both directly and indirectly.

It is important to recognize that climate change vulnerability assessments do not dictate which species or habitats to choose as targets for conservation. For example, while a vulnerability assessment can provide a factual underpinning for differentiating between species and systems likely to decline and those likely to thrive, the choice of whether to focus conservation efforts on the most vulnerable, the most viable, or a combination of the two, will of necessity be based on a range of variables. Nor do climate change vulnerability assessments dictate specific management actions to take. Rather, they provide additional information to inform such decisions within the context of broader conservation planning.

There are a variety of tools and methods for conducting climate change vulnerability assessments, including vulnerability indices, quantitative ecological models, spatial analyses of current and predicted distributions, multi-disciplinary models, and expert elicitation processes (Glick et al. 2011, Stein et al. 2014). The choice of which approach or approaches will depend on a range of factors, including the management questions of concern, the types of conservation targets (e.g., species, habitats, ecosystems, etc.), the geographic scope, available data, technical expertise, financial resources, and time constraints. Often, a combination of approaches, as adopted by Tennessee, will be most effective in informing management decisions (Young et al. 2014).

3 Elements of Exposure: Climate Change in Tennessee

Understanding the potential range of species and habitat vulnerabilities to climate change begins with a review of key elements of exposure – specifically temperature and precipitation – and their historic and projected trends. This section highlights recent trends and climate change projections, drawing largely from *Third National Climate Assessment* for the United States (Kunkel et al. 2013) and data from the Tennessee Climatological Service (https://ag.tennessee.edu/climate/Pages/climatedataTN.aspx, accessed June 17, 2015).

3.1 Historical Climate and Recent Trends

Historically, the climate of the southeastern United States has been characterized by both interannual and interdecadal variability, and it is influenced by a range of factors, including latitude, topography, and proximity to the oceans (Ingram et al. 2013). Within the state of Tennessee, a diverse topography, in particular, contributes to considerable variation in average conditions, with the lower-lying plains and the Ridge and Valley ecoregion experiencing generally higher average temperatures than the higher-elevation Cumberland Plateau and Great Smoky Mountains (Tennessee Climatological Service 2014). Across the state, average annual temperature varies from 62° F in the extreme southwest to 45° F in the highest peaks to the east. Average temperatures in Tennessee and throughout the southeast region have risen since the early 1970s, although some of this increase is attributed to land use changes (e.g., increased urbanization). The frequency of minimum temperatures exceeding 75° F also has been increasing across much of the region.

Topography also has an influence on precipitation, with average annual precipitation ranging from 46-55 inches (Tennessee Climatological Service 2014). Over the Cumberland Plateau, average precipitation ranges from 50-55 inches per year. Precipitation is generally highest in the mountainous eastern border with North Carolina, where average precipitation can reach up to 80 inches per year (see Figure 1). Precipitation is lowest in the northern portion of the Ridge and Valley, which is shadowed by the Great Smoky Mountains to the southeast and Cumberland Plateau to the northwest. Most of the precipitation in Tennessee occurs during winter and early spring due to more frequent large-scale storms. Thunderstorms also contribute to significant precipitation in mid-summer, particularly in the mountains. Prolonged dry spells tend to occur in summer and fall. The Southeast U.S. region also experiences a range of extreme weather events, including heavy rainfall and droughts and extreme heat and cold spells. Severe snow and ice storms can occur as well, particularly across the northern tier, although historically the events have tended to be short-lived.

Variability in precipitation from year to year (e.g., an exceptionally wet summer followed by and exceptionally dry summer) has increased compared to the middle of the 20th century (Groisman and Knight 2008, Wang et al. 2010). In addition, the frequency of extreme precipitation events has risen across the southeastern United States, although the trend has been most pronounced in the lower Mississippi River Valley and the northern Gulf Coast (Kunkel et al. 2013). Average snowfall totals across the northern tier of the southeastern region have declined by 1% per year since the late 1930s, although the frequency of snowstorms has increased since the 1960s (Chagnon et al. 2006).

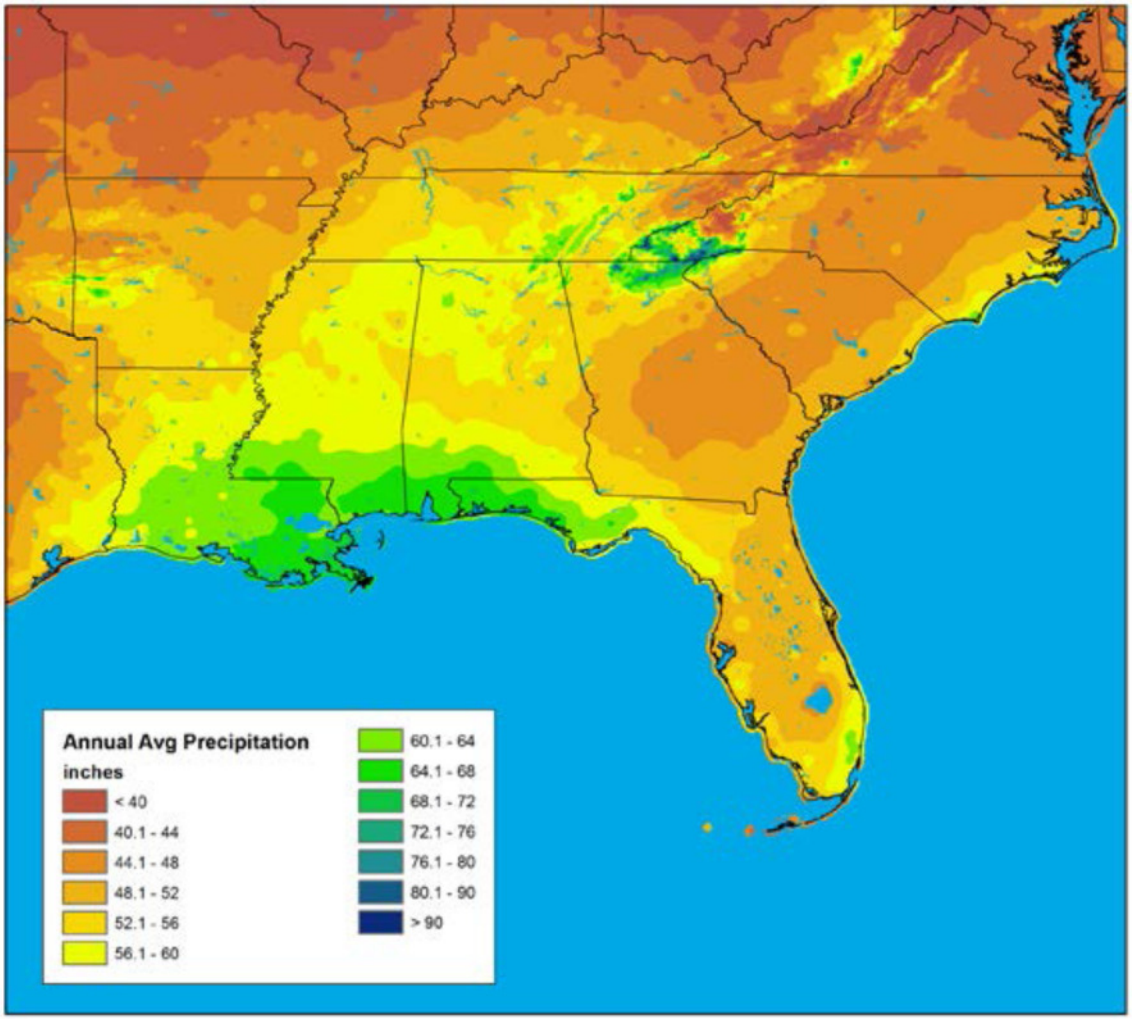


Figure 1. Annual average precipitation for the Southeast region using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Kunkel et al. 2013).

3.2 PROJECTED FUTURE CLIMATE CONDITIONS

Projections of change in climate conditions in Tennessee and across the Southeast in the coming decades vary, depending on the particular climate models and assumptions used, as well as the scenario or scenarios chosen for how much greenhouse gas emissions are expected to change over time. No projection can be considered "right" or "wrong." Determining which projections to consider when planning for climate change depends on many factors, such as: the spatial and temporal scales at which associated management decisions will be made; the availability of regionally-specific data; the level of detail required; the degrees of uncertainty in model results and underlying data; and the level of risk managers are willing to accept in making decisions under uncertainty. For some decisions, more-generalized projections such as changes in average annual temperature and precipitation patterns across a relatively broad region will be sufficient. For other cases, more-detailed, downscaled information may be necessary. Often, observations and expert opinion can augment climate projections.

This section summarizes general projections for climate change across the Southeast, derived from information developed and compiled for the *Third National Climate Assessment* (Kunkel et al. 2013). Primary changes include the following:

- Mean annual temperatures are projected to increase across the Southeast through the 21st century. By 2050, the largest increases (3°F to 5°F) are projected over the interior of the region. The greatest warming is projected to take place in summer months (see Figure 2).
- The average annual number of days with maximum temperatures exceeding 95°F is expected to increase across the region.
- Overall warming in the northern tier of the region is projected to increase the length of the freeze-free season by as much as 30 days in the mid-21st century, and the number of growing degree days (with a base of 50°F) is expected to increase by nearly 25%.
- An increase in interannual precipitation variability is noted across the Southeast through the first half of the 21st century, with the greatest variability projected during the summer season (see Figure 3).
- In general, projections for changes in precipitation are less certain than those for temperature. In the short range (i.e., by 2035), projected changes in annual precipitation across the region are smaller than typical year-to-year variations seen in the historical record. By the end of the 21st century, however, annual precipitation is projected to decrease by as much as 12% across Louisiana and Arkansas, with increases of up to 6% across the eastern part of the region, including Tennessee.
- The annual number of days with extreme precipitation is expected to increase by the mid-21st century, particularly along the southern Appalachians as well as parts of Tennessee and Kentucky.

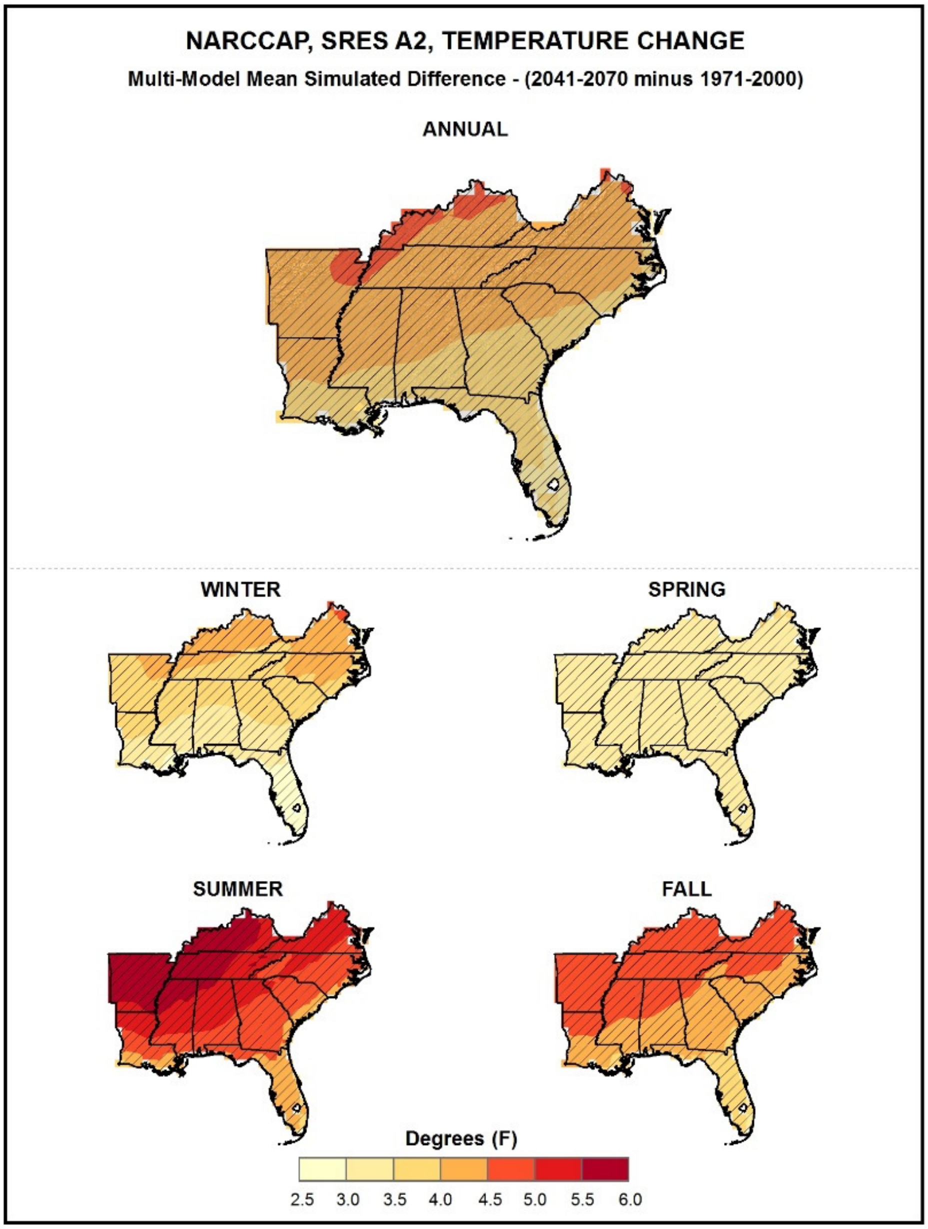


Figure 2. Simulated difference in annual and seasonal mean temperature (°F) for the Southeast region, for 2041-2070 with respect to the reference period of 1971-2000. Hatched areas indicate that the projected changes are significant and consistent among models (Kunkel et al. 2013).

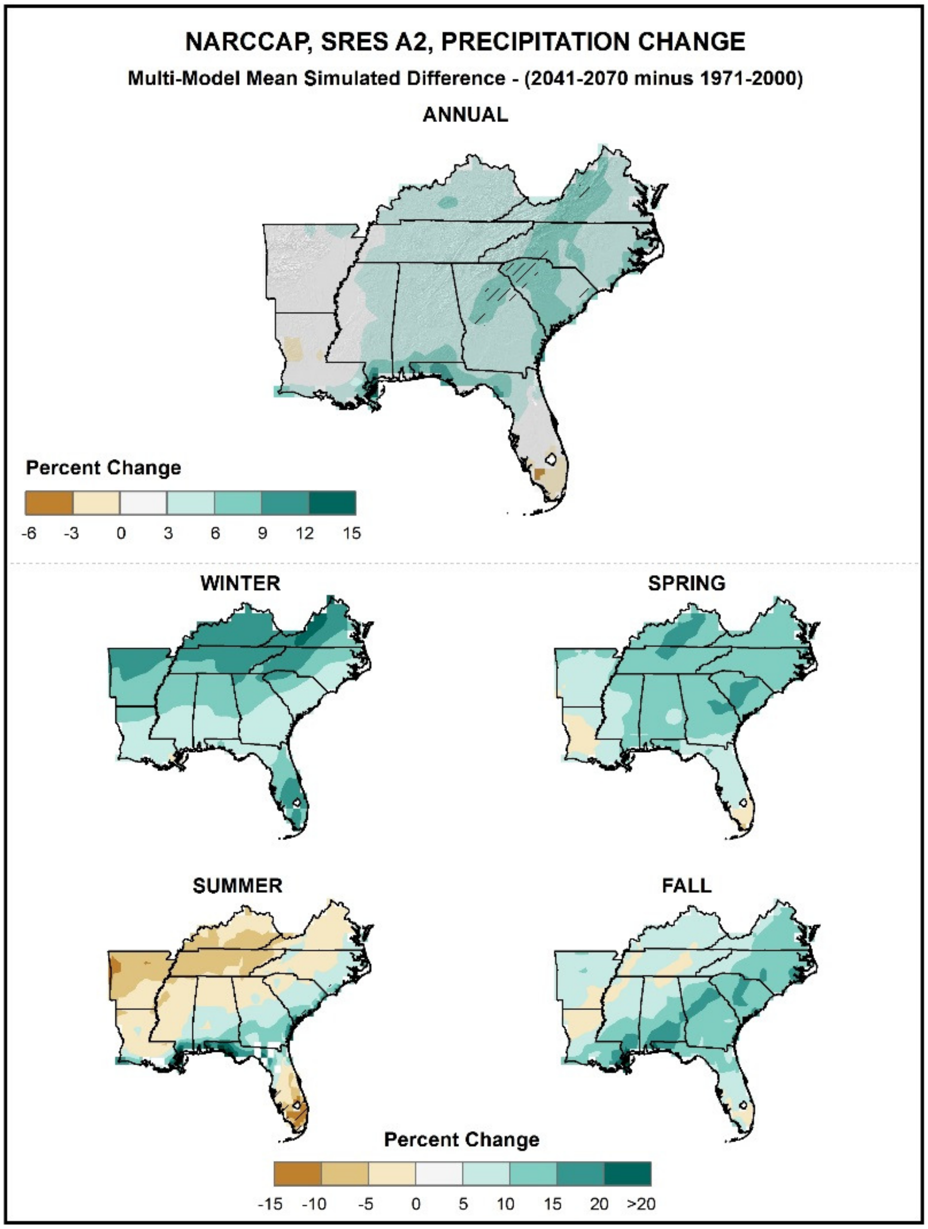


Figure 3. Simulated difference in annual and seasonal mean precipitation (%) for the Southeast region, for 2041-2070 with respect to the reference period of 1971-2000. Hatched areas indicate that the projected changes are significant and consistent among models (Kunkel et al. 2013).

These changes will have associated impacts on ecological features that may be important for many fish and wildlife species, such as stream hydrology, wildfires, and plant and animal phenology. For example:

- Higher temperatures are expected to contribute to an increase in the frequency and intensity of wildfires across the Southeast, including an increase in the total area burned and longer fire seasons. The potential increase in drought frequency also could increase fire risk in some areas.
- Climate change affects hydrologic process and water resources directly (i.e., through changes in precipitation, evapotranspiration, groundwater recharge, timing and volume of streamflows, and

water yield) and indirectly (e.g., through changes in water quality and water use for irrigation and other human uses).

- Although there is considerable uncertainty among models in projections for changes in hydrological conditions in the southeastern United States, annual water yield across the region is projected to decline in the first half of the 21st century (see Figure 4).

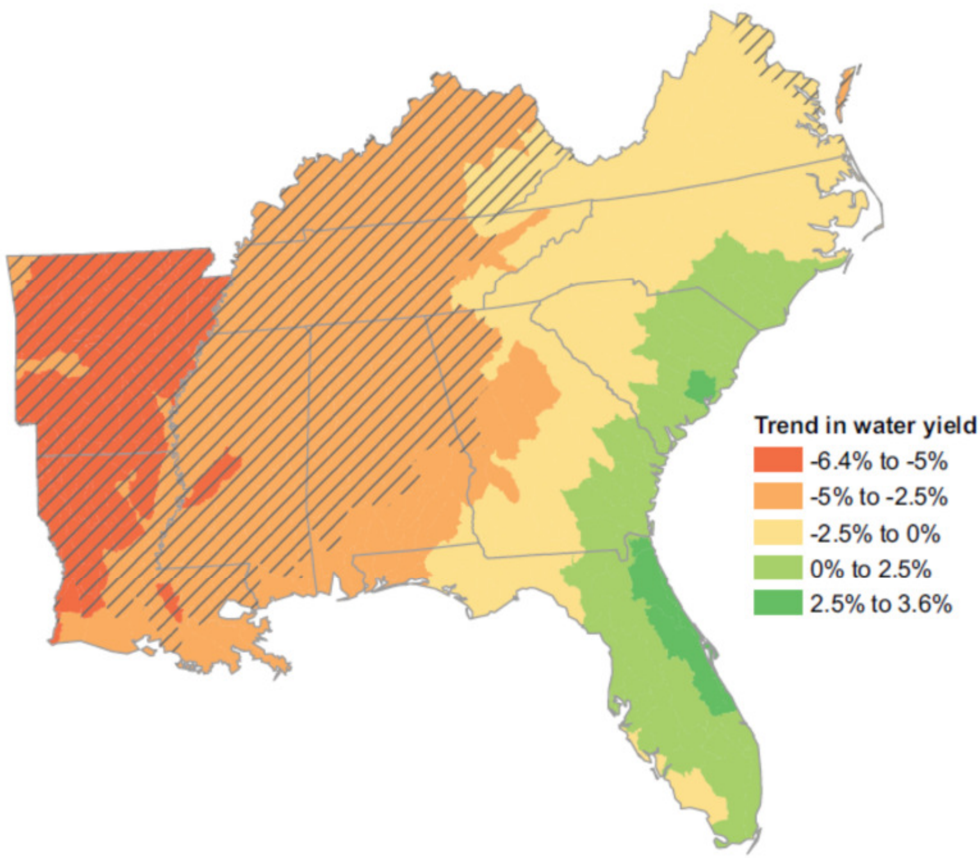


Figure 4. Mean trends predicted for 2010 to 2060 in mean annual water yield, normalized by the 2001 to 2010 mean annual water yield. Hatched area represents locations where the predicted trend in water yield is statistically significant ($p<0.05$) (Ingram et al. 2013).

4 PUTTING THE PIECES TOGETHER: CLIMATE CHANGE VULNERABILITY ASSESSMENT FOR TENNESSEE WILDLIFE AND HABITATS

Tennessee has taken a multi-pronged approach to address climate change as part of the development and implementation of its updated State Wildlife Action Plan (SWAP). In 2009, the Tennessee Wildlife Resources Agency (TWRA) compiled the report *Climate Change and Potential Impacts to Wildlife in Tennessee*, which provides a summary of relevant scientific literature published up to the time on the effects of climate change on a range of habitats and species, including: forests; birds; caves, karst, and bats; nonvolant mammals; and aquatic environments and aquatic life (TWRA 2009). As part of the 2015 comprehensive revision of the SWAP, the agency also put together species and habitat expert teams from several state and federal agencies, academic institutions, and non-governmental organizations to identify and provide additional information needed to assess the vulnerability of relevant conservation targets.

Indiana bat (*Myotis sodalis*) – Andrew King, FWS

A major emphasis of the species and habitat teams was the application of the NatureServe Climate Change Vulnerability Index (CCVI) (Young et al. 2011) to selected species of greatest conservation need (GCN), as highlighted in Section 4.1 and described in detail in the appendices. In addition, TWRA has worked with The Nature Conservancy (TNC), the National Wildlife Federation (NWF), and the U.S. Forest Service (USFS) to develop spatial analyses that improve our understanding of where and what types of terrestrial habitats may be most vulnerable to change over time. This information includes maps of climate stress and vegetation change, measured by the USFS Terrestrial Climate Stress Index (TCSI), and areas of relative landscape vulnerability (and, conversely, resilience), as identified by TNC's Resilient Sites for Terrestrial Conservation methodology (Joyce et al. 2008, USDA Forest Service 2012, USDA Forest Service *in press*, and Anderson et al. 2014). These different sets of spatial information were also examined along with the 2015 SWAP terrestrial priority areas to determine where in the state different habitats and species populations may be vulnerable to change (see Section 4.4).

As illustrated by Figure 5, these three elements – assessment of *species* vulnerability using the CCVI; assessment of terrestrial *habitat* vulnerability comparing the Tennessee Terrestrial Habitat Priority areas and the TCSI; and evaluation of relative vulnerability/resilience based on *geophysical settings* using the Resilient Sites framework – complete a so-called "vulnerability triangle." The focus on these elements together is intended to provide managers with a more-comprehensive picture of climate change vulnerability by incorporating factors relevant to both species and habitats.

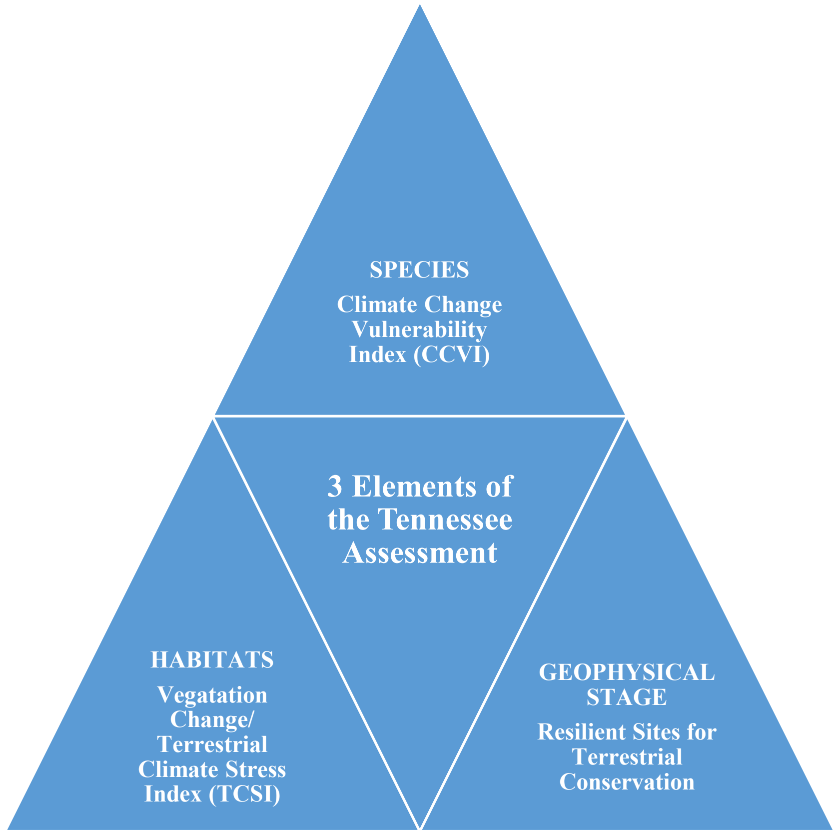


Figure 5. Climate change "vulnerability triangle." The three elements of the Tennessee assessment include a focus on *species* (i.e., the application of the Climate Change Vulnerability Index (CCVI)), terrestrial habitats (i.e., Terrestrial Habitat Priority Areas and projections for climate and vegetation change ranked with the Terrestrial Climate Stress Index (TCSI)), and elements of the state's *geophysical settings* that are likely to be associated with climate resilience in support of biological diversity (i.e., areas identified as Resilient Sites for Terrestrial Conservation). Together, these elements provide managers with information on both species- and habitat-related vulnerabilities.

This report highlights the results of the CCVI assessment, briefly summarizes additional information about the vulnerability of associated terrestrial and aquatic habitats based on a review of the literature (as a supplement to the TWRA 2009 report and other sources), and provides an overview of the spatial vulnerability analyses conducted by the team to date.

4.1 VULNERABILITY OF TENNESSEE SPECIES

4.1.1 Climate Change Vulnerability Index Assessment for Selected Species of Greatest Conservation Need

4.1.1.1 Brief Overview of the Climate Change Vulnerability Index (CCVI)

The CCVI is a worksheet-based tool designed to facilitate coarse-scale assessments of the potential vulnerability of plant and animal species to climate change within a defined geographic area (Young et al. 2011, Young et al. 2012, Young et al. 2014). The CCVI is especially useful for assessing a large number of species, and it has been widely used by state and federal agencies, non-governmental organizations, and other fish and wildlife practitioners to assist in the development of relevant climate change adaptation strategies (e.g., Byers and Norris 2011, Dubois et al. 2011, Furedi et al. 2011, Schlesinger et al. 2011, Steel et al., 2011, Walk et al. 2011, Bruno et al. 2012, Szabo 2012, Hoving et al. 2013, Ring et al. 2013, Pocewicz et al 2014).

The CCVI (Release 2.1, which is the version used in this analysis) uses a scoring system that integrates projected direct exposure to climate change with three sensitivity factors: 1) indirect exposure to climate change; 2) species-specific sensitivity factors; and 3) documented responses to climate change. The relevance and degree of influence of indirect exposure and sensitivity factors on vulnerability for the species assessed are based on the particular landscape context and generalized natural history characteristics of the species. While more-detailed information about the CCVI is provided in the tables in Appendices A and B and relevant literature cited, key information is summarized in Figure 6 and in the following sections to assist readers in understanding and interpreting the results highlighted herein.

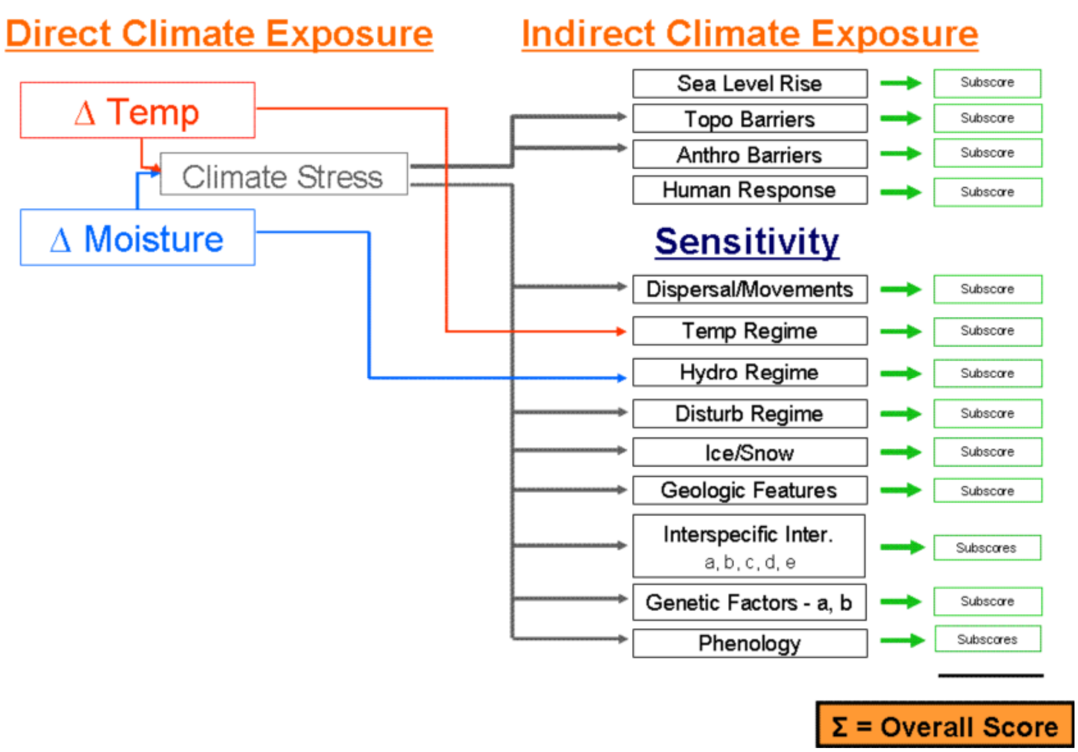


Figure 6. General schematic of the inputs and outputs of the CCVI (Young et al. 2011).

Sensitivity of a species to climate change is assessed by scoring species against the various indirect exposure and species-specific sensitivity factors, as noted in Tables 13 and 14, respectively, in Appendix A. For each factor, the species is given a numeric score based on a sliding scale from greatly increasing vulnerability (which receives a score of 3), to no effect on vulnerability (which receives a score of 0), to decreasing vulnerability (which receives a score of -2). The indirect exposure and sensitivity results are then combined with direct exposure factors (highlighted in Table 12 of Appendix A and specified for the Tennessee assessment in Appendix B). The numeric sum of these factors is converted into an overall score by comparing it to relevant threshold values. Final vulnerability categories are described below (and in Table 16 of Appendix A):

- **Extremely Vulnerable (EV)**: Species' abundance and/or range extent within geographical area assessed is extremely likely to substantially decrease or disappear by 2050.
- **Highly Vulnerable (HV)**: Species' abundance and/or range extent within the geographical area assessed is likely to decrease significantly by 2050.
- **Moderately Vulnerable (MV)**: Species' abundance and/or range extent within the geographical area assessed is likely to decrease by 2050.
- **Not Vulnerable/Presumed Stable (PS)**: Available evidence does not suggest that the species' abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.
- **Not Vulnerable/Increase Likely (IL)**: Available evidence suggests that the species' abundance and/or range extent within the geographical area assessed is likely to increase by 2050.

4.1.1.2 Vulnerability and Conservation Rank

The CCVI is intended to be used in conjunction with NatureServe conservation status ranks (e.g., Global Rank and State Rank, as defined in Table 1). Because population size, range size, and demographic factors may influence both conservation status and vulnerability to climate change, the CCVI does not explicitly include those factors in its variables for sensitivity. The Global Rank and State Rank thus are not necessarily an indication of climate change vulnerability, as one might have assumed.

Indeed, climate change may pose a new challenge for species that otherwise may be considered stable or common at the global and/or state level (e.g., a species may rank as Extremely Vulnerable but have a conservation ranking of S5). Conversely, it may be that climate change is not significant compared to other stressors that contribute to the species' conservation rank. For example, some species may be considered rare or imperiled due to factors such as overharvest, habitat loss, or disease but may not be especially sensitive to changing climate conditions. That said, special attention might be warranted for species that are ranked as both vulnerable to climate change and otherwise imperiled (e.g., have lower S- and/or G-rank scores), as they are likely to have lower adaptive capacity and might be more vulnerable to extreme weather events or other disturbances (Young et al. 2011). Looking at both the vulnerability scores and conservation rank can provide a more-thorough understanding of species' conservation status under changing climate conditions (Hoving et al. 2013).

Table 1. Global and state conservation ranking system for species (TWRA 2005)	
Global (G) Rank	
G1	Critically imperiled globally; 5 or fewer occurrences worldwide
G2	Imperiled globally; 6 to 20 occurrences worldwide
G3	Very rare or restricted throughout range; 21-100 occurrences worldwide
G4	Apparently secure globally though locally rare sometimes; 100-1000 occurrences worldwide
G5	Demonstrably secure globally; over 1000 occurrences worldwide
G?	Uncertain global rank
GH	Historic global occurrence; possibly extinct
GNR	Not ranked currently at global level
G#Q	Questionable taxonomy
G#G#	Mixed rank due to uncertainty
G#T#	Rank of a subspecies or variety
State (S) Rank	
S1	Critically imperiled in state; 5 or fewer occurrences statewide
S2	Imperiled within state; 6-20 occurrences statewide
S3	Rare and uncommon in state; 20-100 occurrences statewide
S4	Apparently secure globally, though locally rare sometimes; 100-1000 occurrences statewide
S5	Demonstrably widespread and secure in the state
S?	Uncertain state rank
SH	Historical occurrence in state
SNR	Not ranked currently at state level
SP	Potentially occurs in state
SR	Reported to occur in state
SX	Believed extirpated from state
S#S#	Mixed rank due to uncertainty

4.1.1.3 Approach Used by the Tennessee Team

After conducting an exploratory assessment using CCVI for 119 GCN species in western Tennessee to evaluate the potential value in using the tool (Colvin et al. 2013), the TWRA team selected 189 of its GCN species (approximately 12% of the total number) for a full assessment. The choice of which species to assess was based on a range of criteria established by the team. While specific criteria for selecting species varied among the taxonomic groups, the general criteria were comprised of one or more of the following conditions:

- The species is limited to a certain region of the state;
- The species selected may represent other, similar species that could be excluded from the assessment;
- The species is an indicator of ecosystem health;
- The species has a measurable habitat distribution in the state;
- The species has a narrow distribution within its range;
- The species' primary habitat may be sensitive to climate change effects;
- The species was previously common in the state, and taxonomic splits have made finer distinctions;
- The species is at the edge of its range in Tennessee;
- The species has restricted breeding habitat;

- The species is representative of a particular habitat type (e.g., riparian forest, marsh).

4.1.2 CCVI Assessment Results for Selected Tennessee Species

4.1.2.1 Overall Comparison among Species and Taxonomic Groups

One way to interpret the results of CCVI assessments is to compare relative vulnerability among the various species and taxonomic groups assessed. Table 2 indicates the final vulnerability scores for each of the species included in the Tennessee study, sorted by the CCVI score, taxonomic group, and species' common name. Figure 7 illustrates how those scores compare across the associated taxonomic groups.

Overall, 119 (63%) of the 189 species assessed scored as Presumed Stable or Increase Likely, and 70 (37%) were considered at least Moderately Vulnerable. Mammals, birds, and reptiles comprise most of the species ranked as Presumed Stable or Increase Likely due, in part, to their mobility and other factors that enhance their adaptive capacity. Plants, fish, and mussels comprised the greatest number of species that ranked as Moderately Vulnerable or above for a variety of reasons, including the presence of natural and anthropogenic barriers to dispersal, restricted habitat range, and high levels of sensitivity to changes in temperature and moisture.

It is important to note that the comparison across taxonomic groups should be interpreted only generally, as the species assessed within each taxonomic group were chosen for varying reasons and represent a subset of all Tennessee species within those groups. Comparisons within the specific taxonomic groups and the specific results for the various factors contributing to vulnerability among individual species, as described below and in Appendix C, are likely to be especially useful in identifying potential management responses.

Table 2. CCVI scores for selected Tennessee GCN species

Taxonomic Group	Scientific Name	Common Name	CCVI Score
Fish	*Salvelinus fontinalis*	Brook trout	Extremely Vulnerable
Fish	*Acipenser vulvescens*	Lake sturgeon	Extremely Vulnerable
Fish	*Etheostoma boschungi*	Slackwater darter	Extremely Vulnerable
Plant	*Asplenium scolopendrium* var. *americanum (*syn. *Phyllitis scolopendrium* var. *americana)*	American hart's-tongue	Extremely Vulnerable
Plant	*Astragalus bibullatus*	Pyne's ground-plum	Extremely Vulnerable
Plant	*Hedyotis purpurea* var. *montana (*syn. *Houstonia montana)*	Roan Mountain bluet/Venus' pride	Extremely Vulnerable
Plant	*Gymnoderma lineare*	Rock gnome lichen	Extremely Vulnerable
Plant	*Pityopsis ruthii*	Ruth's golden aster	Extremely Vulnerable
Plant	*Paysonia perforate*	Spring Creek bladderpod	Extremely Vulnerable
Plant	*Xyris tennesseensis*	Tennessee yellow-eyed grass	Extremely Vulnerable
Plant	*Helianthus verticillatus*	Whorled sunflower	Extremely Vulnerable
Mammal	*Glaucomys sabrinus coloratus*	Carolina northern flying squirrel	Highly Vulnerable
Amphibian	*Cryptobranchus alleganiensis*	Hellbender	Highly Vulnerable
Fish	*Attractosteus spatula*	Alligator gar	Highly Vulnerable
Fish	*Etheostoma sagitta*	Arrow darter	Highly Vulnerable

Table 2. CCVI scores for selected Tennessee GCN species			
Taxonomic Group	**Scientific Name**	**Common Name**	**CCVI Score**
Fish	*Noturus crypticus*	Chucky madtom	Highly Vulnerable
Fish	*Polyodon spathula*	Paddlefish	Highly Vulnerable
Mussel	*Fusconaia subrotunda*	Longsolid	Highly Vulnerable
Mussel	*Villosa vanuxemensis*	Mountain creekshell	Highly Vulnerable
Mussel	*Villosa taeniata*	Painted creekshell	Highly Vulnerable
Mussel	*Toxolasma lividus*	Purple lilliput	Highly Vulnerable
Mussel	*Obovaria subrotunda*	Round hickorynut	Highly Vulnerable
Mussel	*Pleurobema oviforme*	Tennessee clubshell	Highly Vulnerable
Plant	*Solidago spithamaea*	Blue Ridge goldenrod	Highly Vulnerable
Plant	*Boechera perstellata (syn. Arabis perstellata)*	Braun's rockcress	Highly Vulnerable
Plant	*Physaria globosa (syn. Lesquerella globosa)*	Short's bladderpod	Highly Vulnerable
Plant	*Geum radiatum*	Spreading avens/Appalachian avens	Highly Vulnerable
Plant	*Spiraea virginiana*	Virginia spiraea/Virginia meadowsweet	Highly Vulnerable
Plant	*Platanthera integrilabia*	White fringeless orchid/monkey-face orchid	Highly Vulnerable
Mammal	*Microtus chrotorrhinus carolinensis*	Southern rock vole	Moderately Vulnerable
Bird	*Scolopax minor*	American woodcock	Moderately Vulnerable
Bird	*Aimophila aestivalis*	Bachman's sparrow	Moderately Vulnerable
Reptile	*Glyptemys muhlenbergii*	Bog turtle	Moderately Vulnerable
Amphibian	*Hyla gratiosa*	Barking treefrog	Moderately Vulnerable
Amphibian	*Gyrinophilius gulolineatus*	Berry Cave salamander	Moderately Vulnerable
Amphibian	*Lithobates areolatus*	Crawfish frog	Moderately Vulnerable
Amphibian	*Hemidactylium scutatum*	Four-toed salamander	Moderately Vulnerable
Amphibian	*Hyla versicolor*	Gray treefrog	Moderately Vulnerable
Amphibian	*Aneides aeneus*	Green salamander	Moderately Vulnerable
Amphibian	*Psedacris brachyphona*	Mountain chorus frog	Moderately Vulnerable
Amphibian	*Desmognathus aeneus*	Seepage salamander	Moderately Vulnerable
Amphibian	*Acris gryllus*	Southern cricket frog	Moderately Vulnerable
Amphibian	*Gyrinophilius palleucus*	Tennessee cave salamander	Moderately Vulnerable
Amphibian	*Plethodon welleri*	Weller's salamander	Moderately Vulnerable
Fish	*Cycleptis elongatus*	Blue sucker	Moderately Vulnerable
Fish	*Carpiodes velifer*	Highfin carpsucker	Moderately Vulnerable
Fish	*Chrosomus saylori*	Laurel dace	Moderately Vulnerable
Fish	*Etheostoma bellum*	Orangefin darter	Moderately Vulnerable
Fish	*Noturus fasciatus*	Saddled madtom	Moderately Vulnerable
Fish	*Clinostomus funduloides*	Smoky dace	Moderately Vulnerable
Fish	*Percina aurantiaca*	Tangerine darter	Moderately Vulnerable
Mussel	*Strophitis connasaugaensis*	Alabama creekmussel	Moderately Vulnerable
Mussel	*Villosa nebulosa*	Alabama rainbow	Moderately Vulnerable
Mussel	*Medionidus conradicus*	Cumberland moccasinshell	Moderately Vulnerable
Mussel	*Alasmidonta marginata*	Elktoe	Moderately Vulnerable
Mussel	*Pleurobema hanleyianum*	Georgia pigtoe	Moderately Vulnerable
Mussel	*Obovaria olivaria*	Hickorynut	Moderately Vulnerable
Mussel	*Villosa lienosa*	Little spectaclecase	Moderately Vulnerable
Mussel	*Pleurobema cordatum*	Ohio pigtoe	Moderately Vulnerable

Table 2. CCVI scores for selected Tennessee GCN species			
Taxonomic Group	**Scientific Name**	**Common Name**	**CCVI Score**
Mussel	*Actinonaias pectorosa*	Pheasantshell	Moderately Vulnerable
Mussel	*Pleurobema rubrum*	Pyramid pigtoe	Moderately Vulnerable
Mussel	*Quadrula cylindrica*	Rabbitsfoot	Moderately Vulnerable
Mussel	*Pleuronaia dolabelloides*	Slabside pearlymussel	Moderately Vulnerable
Mussel	*Alasmidonta viridis*	Slippershell mussel	Moderately Vulnerable
Mussel	*Cumberlandia monodonta*	Spectaclecase	Moderately Vulnerable
Mussel	*Lasmigona holstonia*	Tennessee heelsplitter	Moderately Vulnerable
Mussel	*Pleuronaia barnesiana*	Tennessee pigtoe	Moderately Vulnerable
Plant	*Conradina verticillata*	Cumberland rosemary	Moderately Vulnerable
Plant	*Dalea foliosa*	Leafy prairie-clover	Moderately Vulnerable
Plant	*Echinacea tennesseensis*	Tennessee purple coneflower	Moderately Vulnerable
Mammal	*Neotoma magister*	Allegheny woodrat	Presumed Stable
Mammal	*Sorex palustris*	American water shrew	Presumed Stable
Mammal	*Myotis leibii*	Eastern small-footed bat	Presumed Stable
Mammal	*Myotis grisescens*	Gray bat	Presumed Stable
Mammal	*Parascalops breweri*	Hairy-tailed mole	Presumed Stable
Mammal	*Myotis sodalis*	Indiana bat	Presumed Stable
Mammal	*Mustela nivalis*	Least weasel	Presumed Stable
Mammal	*Myotis septentrionalis*	Northern myotis	Presumed Stable
Mammal	*Corynorhinus rafinesquii*	Rafinesque's big-eared bat	Presumed Stable
Mammal	*Tamiasciurus hudsonicus*	Red squirrel	Presumed Stable
Mammal	*Sorex fumeus*	Smoky shrew	Presumed Stable
Mammal	*Condylura cristata*	Star-nosed mole	Presumed Stable
Mammal	*Napaeozapus insignis*	Woodland jumping mouse	Presumed Stable
Bird	*Botaurus lentiginosus*	American bittern	Presumed Stable
Bird	*Pluvialis dominica*	American golden plover	Presumed Stable
Bird	*Anhinga anhinga*	Anhinga	Presumed Stable
Bird	*Riparia riparia*	Bank swallow	Presumed Stable
Bird	*Vireo bellii*	Bell's vireo	Presumed Stable
Bird	*Thryomanes bewickii*	Bewick's wren	Presumed Stable
Bird	*Vermiforma pinus*	Blue-winged warbler	Presumed Stable
Bird	*Sitta pusilla*	Brown-headed nuthatch	Presumed Stable
Bird	*Tryngites subruficollis*	Buff-breasted sandpiper	Presumed Stable
Bird	*Setophaga cerulea*	Cerulean warbler	Presumed Stable
Bird	*Caprimulgus carolinensis*	Chuck-will's-widow	Presumed Stable
Bird	*Ammodramus savannarum*	Grasshopper sparrow	Presumed Stable
Bird	*Wilsonia citrina*	Hooded warbler	Presumed Stable
Bird	*Oporornis formosus*	Kentucky warbler	Presumed Stable
Bird	*Rallus elegans*	King rail	Presumed Stable
Bird	*Chondestes grammacus*	Lark sparrow	Presumed Stable
Bird	*Ixobrychus exilis*	Least bittern	Presumed Stable
Bird	*Egretta caerulea*	Little blue heron	Presumed Stable
Bird	*Lanius ludovicianus*	Loggerhead shrike	Presumed Stable
Bird	*Limosa fedoa*	Marbled godwit	Presumed Stable
Bird	*Parula americana*	Northern parula	Presumed Stable
Bird	*Dendroica discolor*	Prairie warbler	Presumed Stable
Bird	*Protonotaria citrea*	Prothonotary warbler	Presumed Stable
Bird	*Calidris canutus*	Red knot	Presumed Stable
Bird	*Melanerpes erythrocephalus*	Red-headed woodpecker	Presumed Stable
Bird	*Tyrannus forficatus*	Scissor-tailed flycatcher	Presumed Stable

Table 2. CCVI scores for selected Tennessee GCN species			
Taxonomic Group	**Scientific Name**	**Common Name**	**CCVI Score**
Bird	*Accipiter striatus*	Sharp-shinned hawk	Presumed Stable
Bird	*Calidris himantopus*	Stilt sandpiper	Presumed Stable
Bird	*Limnothlypis swainsonii*	Swainson's warbler	Presumed Stable
Bird	*Elanoides forficatus*	Swallow-tailed kite	Presumed Stable
Bird	*Bartramia longicauda*	Upland sandpiper	Presumed Stable
Bird	*Pooecetes gramineus*	Vesper sparrow	Presumed Stable
Bird	*Calidris mauri*	Western sandpiper	Presumed Stable
Bird	*Numenius phaeopus*	Whimbrel	Presumed Stable
Bird	*Caprimulgus vociferus*	Whip-poor-will	Presumed Stable
Bird	*Vireo griseus*	White-eyed vireo	Presumed Stable
Bird	*Charadrius wilsonia*	Wilson's plover	Presumed Stable
Bird	*Hylocichla mustelina*	Wood thrush	Presumed Stable
Bird	*Helmitheros vermivorum*	Worm-eating warbler	Presumed Stable
Bird	*Coccyzus americanus*	Yellow-billed cuckoo	Presumed Stable
Reptile	*Plestiodon anthracinus*	Coal skink	Presumed Stable
Reptile	*Terrapene carolina*	Eastern box turtle	Presumed Stable
Reptile	*Herterodon platirhinos*	Eastern hognose snake	Presumed Stable
Reptile	*Ophisaurus attenuatus longicaudus*	Eastern slender glass lizard	Presumed Stable
Reptile	*Clonophis kirtlandii*	Kirtland's snake	Presumed Stable
Reptile	*Nerodia cyclopion*	Mississippi green watersnake	Presumed Stable
Reptile	*Pituophis melanoleucus melanoleucus*	Northern pine snake	Presumed Stable
Reptile	*Virginia striatula*	Rough earthsnake	Presumed Stable
Reptile	*Apalone mutica*	Smooth softshell turtle	Presumed Stable
Reptile	*Crotalus horridus*	Timber rattlesnake	Presumed Stable
Reptile	*Sistrurus miliarius streckeri*	Western pygmy rattlesnake	Presumed Stable
Reptile	*Western Ribbonsnake*	Western ribbonsnake	Presumed Stable
Reptile	*Nerodia erythrogaser flavigaster*	Yellowbelly watersnake	Presumed Stable
Amphibian	*Desmognathus welteri*	Black Mountain dusky salamander	Presumed Stable
Amphibian	*Desmagnatus abditus*	Cumberland dusky salamander	Presumed Stable
Amphibian	*Desmognathus imitator*	Imitator salamander	Presumed Stable
Amphibian	*Plethodon jordani*	Jordan's red-cheeked salamander	Presumed Stable
Amphibian	*Pseudtriton montanus*	Mud salamander	Presumed Stable
Amphibian	*Plethodon montanus*	Northern gray-cheeked salamander	Presumed Stable
Amphibian	*Desmognathus organi*	Northern pygmy salamander	Presumed Stable
Amphibian	*Plethodon shermani*	Red-legged salamander	Presumed Stable
Amphibian	*Desmognathus wrighti*	Southern pygmy salamander	Presumed Stable
Amphibian	*Plethodon richmondi*	Southern ravine salamander	Presumed Stable
Amphibian	*Ambystoma barbouri*	Streamside salamander	Presumed Stable
Amphibian	*Plethodon aureolus*	Tellico salamander	Presumed Stable
Amphibian	*Plethodon wehrlei*	Wehrle's salamander	Presumed Stable
Amphibian	*Plethodon yonahlossee*	Yonahlossee salamander	Presumed Stable
Fish	*Cyprinella caerulea*	Blue shiner	Presumed Stable
Fish	*Etheostoma cervus*	Chickasaw darter	Presumed Stable
Fish	*Etheostoma pyrrhogaster*	Firebelly darter	Presumed Stable

Table 2. CCVI scores for selected Tennessee GCN species			
Taxonomic Group	**Scientific Name**	**Common Name**	**CCVI Score**
Fish	*Typhlichthys subterraneus*	Southern cavefish	Presumed Stable
Fish	*Noturus flavipinnis*	Yellowfin madtom	Presumed Stable
Mussel	*Ligumia recta*	Black sandshell	Presumed Stable
Mussel	*Strophitus undulatus*	Creeper	Presumed Stable
Mussel	*Pleurobema sintoxia*	Round pigtoe	Presumed Stable
Mussel	*Villosa vibex*	Southern rainbow	Presumed Stable
Mussel	*Lasmigona complanata*	White heelsplitter	Presumed Stable
musse	*Orconectes pagei*	Big Sandy crayfish	Presumed Stable
Crayfish	*Cambarus bouchardi*	Big southfork crayfish	Presumed Stable
Crayfish	*Orconectes burri*	Blood River crayfish	Presumed Stable
Crayfish	*Barbicambarus cornutus*	Bottlebrush crayfish	Presumed Stable
Crustaction	*Orconectes wrighti*	Hardin County crayfish	Presumed Stable
Crayfish	*Fallicambarus hortoni*	Hatchie burrowing crayfish	Presumed Stable
Crayfish	*Orconectes alabamensis*	Stateline crayfish	Presumed Stable
Crayfish	*Orconectes incomptus*	Tennessee cave crayfish	Presumed Stable
Plant	*Hottonia inflata*	American featherfoil	Presumed Stable
Plant	*Minuartia cumberlandensis (*syn. *Arenaria cumberlandensis)*	Cumberland sandwort/Cumberland stitchwort	Presumed Stable
Plant	*Scutellaria montana*	Large-flowered skullcap	Presumed Stable
Plant	*Clematis morefieldii*	Morefield's leatherflower	Presumed Stable
Plant	*Buckleya distichophylla*	Pirate bush	Presumed Stable
Plant	*Apios priceana*	Price's potato bean	Presumed Stable
Plant	*Isotria medeoloides*	Small whorled pagonia/little five leaves	Presumed Stable
Bird	*Tyto alba*	Barn owl	Increase Likely
Bird	*Spiza americana*	Dickcissel	Increase Likely
Bird	*Ardea alba*	Great egret	Increase Likely
Bird	*Limosa haemastica*	Hudsonian godwit	Increase Likely
Bird	*Seiurus motacilla*	Louisiana waterthrush	Increase Likely
Bird	*Ictinia mississippiensis*	Mississippi kite	Increase Likely
Bird	*Icterus spurius*	Orchard oriole	Increase Likely
Bird	*Passerina ciris*	Painted bunting	Increase Likely
Bird	*Passerculus sandwichensis*	Savannah sparrow	Increase Likely
Reptile	*Macrochelys temminckii*	Alligator snapping turtle	Increase Likely
Reptile	*Masticophis flagellum*	Coachwhip	Increase Likely
Reptile	*Anolis carolinensis*	Green anole	Increase Likely
Plant	*Helianthus eggertii*	Eggert's sunflower	Increase Likely
Plant	*Panax quinquefolius*	Ginseng	Increase Likely

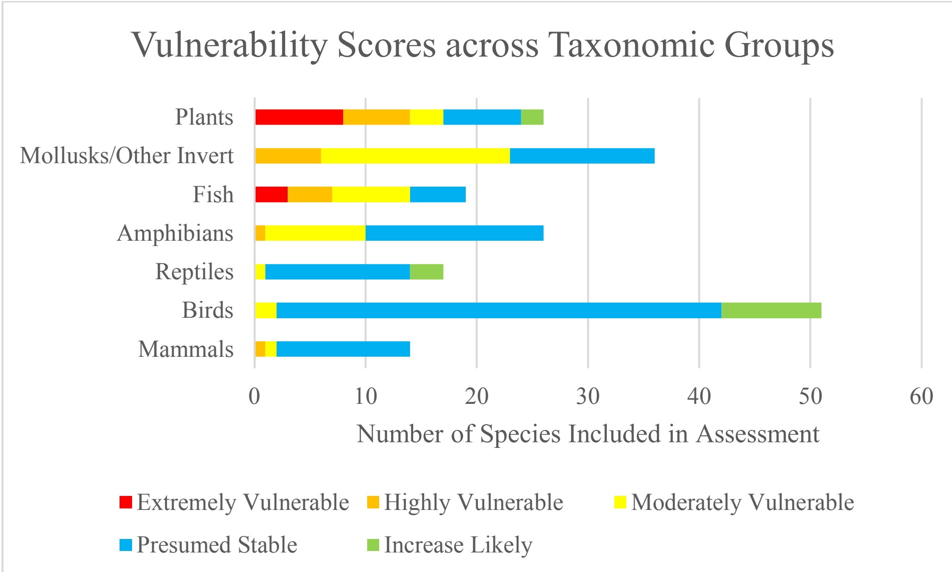


Figure 7. Comparison of CCVI vulnerability scores across taxonomic groups.

4.1.2.2 Vulnerability by Taxonomic Group

4.1.2.2.1 Mammals

The team included 15 GCN mammals in the state-wide CCVI assessment. As highlighted in Table 3 (sorted by CCVI score and species' common name), 12 species were scored as Presumed Stable, which is primarily attributed to the relatively high mobility and few barriers to dispersal among those species (see Figure 8 and Table 18 in Appendix C). The Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*) scored as Highly Vulnerable due to the existence of natural barriers to dispersal and the species' relatively narrow physiological thermal niche within its Tennessee range. Two species, the southern rock vole (*Microtus chrotorrhinus carolinensis*) and the American water shrew (*Sorex palustris*), scored as Moderately Vulnerable. Both mammals prefer cool, higher-elevation forest habitats and are likely to be highly sensitive to increasing temperatures. They also face significant natural barriers (e.g., their habitats limited to high elevation areas, or "sky islands") that limit their ability to move to other areas in search of more climatically-suitable habitat conditions (Laerm et al. 2007, Linzey and NatureServe 2008, USGS 2015).

Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*) – FWS

The five bat species assessed, including Rafineque's big-eared bat

(*Corynorhinus rafinesquii*), gray bat (*Myotis grisescens*), eastern small-footed bat (*Myotis leibii*), northern myotis (*Myotis septentrionalis*), and Indiana bat (*Myotis sodalis*), are assumed to have relatively lower sensitivity to climate change given their natural dispersal ability. The least weasel (*Mustela nivalis*), which prefers early successional habitats, could benefit from an increase of these habitats after wildfires or other disturbances. Confidence in results was very high for all species assessed.

Table 3. Conservation status and CCVI score for selected Tennessee GCN mammals

Scientific Name	Common Name	Relative Range	Global Rank	State Rank	CCVI Score
Glaucomys sabrinus coloratus	Carolina northern flying squirrel	East/west edge of range	G5T2	S1S2	Highly Vulnerable
Sorex palustris	American water shrew	Southern edge of range	G5	S2	Moderately Vulnerable
Microtus chrotorrhinus carolinensis	Southern rock vole	Southern edge of range	G4T3	S2	Moderately Vulnerable
Neotoma magister	Allegheny woodrat	Southern edge of range	G3G4	S3	Presumed Stable
Myotis leibii	Eastern small-footed bat	Southern edge of range	G1G3	S2S3	Presumed Stable
Myotis grisescens	Gray bat	Center of range	G3	S2	Presumed Stable
Parascalops breweri	Hairy-tailed mole	Southern edge of range	G5	S3	Presumed Stable
Myotis sodalis	Indiana bat	Southern edge of range	G2	S1	Presumed Stable
Mustela nivalis	Least weasel	Southern edge of range	G5	S2	Presumed Stable
Myotis septentrionalis	Northern myotis	Southern edge of range	G2G3	S4	Presumed Stable
Corynorhinus rafinesquii	Rafinesque's big-eared bat	Center of range	G3G4	S3	Presumed Stable
Tamiasciurus hudsonicus	Red squirrel	Southern edge of range	G5	S4S5	Presumed Stable
Sorex fumeus	Smoky shrew	Southern edge of range	G5	S4	Presumed Stable
Condylura cristata	Star-nosed mole	Southern edge of range	G5	S2	Presumed Stable
Napaeozapus insignis	Woodland jumping mouse	Southern edge of range	G5	S4	Presumed Stable

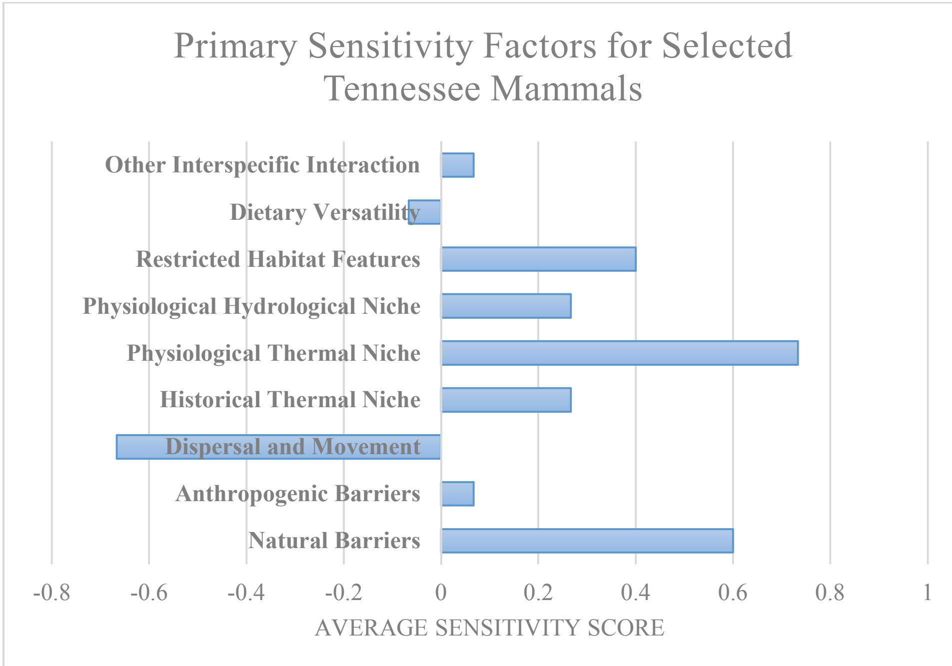


Figure 8. Primary CCVI sensitivity factors for selected Tennessee mammals. The x-axis indicates the average CCVI score for relevant indirect exposure and sensitivity factors among all mammals assessed (see Tables 13 and 14 in Appendix A for detailed descriptions). Negative numbers indicate factors that decrease vulnerability, positive scores reflect increased vulnerability. Factors with a 0 average score are not included in the chart, although it is important to recognize that these are average scores – in some cases, individual factors that contribute to vulnerability might be offset by factors that decrease vulnerability. Accordingly, this chart should be seen as supplemental to Table 18 in Appendix C.

4.1.2.2.2 Birds

The majority (49) of the 51 GCN birds included in the CCVI study for Tennessee were assessed as Presumed Stable or Increase Likely (see Table 4). The primary reason for this is that the relatively high dispersal ability of birds are likely to provide them with greater capacity to adapt to changes in climate conditions at a broader landscape scale than less-mobile species (see Figure 9, below, and Table 19 in Appendix C). It is important to recognize, however, that the CCVI tool is generally used to assess species within a fixed geographic range. For highly-migratory species, such as many birds, habitat needs may well span beyond the local, state, or regional boundaries considered in the CCVI assessment. Accordingly, some birds may well be vulnerable to climate change and associate impacts in other parts of their broader habitat range (Small-Lorenz et al. 2013).

American woodcock (*Scolopax minor*) – FWS

Only two species, American woodcock (*Scolopax minor*) and Bachman's sparrow (*Aimophila aestivalis*), ranked as Moderately Vulnerable. Both of these ground-nesting birds' rely on early-successional habitat for breeding, nesting, and foraging (Meyer 2006, Innes 2010). For instance, Bachman's sparrow is a habitat specialist endemic to longleaf pine forests, and requires open pine stands with little to no midstory, and a dense, herbaceous understory dominated by grasses (Colvin et al. 2013). An increase in the frequency and extent of wildfires in Tennessee due to warmer, drier conditions could alter habitat conditions for foraging and nesting. On the other hand, the potential for climate change to contribute to an expansion of open shrub and grassland habitat in parts of the state, it could be favorable for the birds (Kelley and Williamson 2008). For those species ranked as Increase Likely, a number of factors may be at play. In particular, the barn owl (*Tyto alba*), scissor-tailed flycatcher (*Tyrannus forficatus*), and Louisiana waterthrush (*Seiurus motacilla*) may benefit from relatively high dispersal ability, heat tolerance, and dietary versatility. The barn owl, for instance, is known for its large home range and wide natal dispersion (Colvin et al. 2013). Confidence in index results was very high for all species except American woodcock, for which it was considered low.

Table 4. Conservation status and CCVI score for selected Tennessee GCN birds

Scientific Name	Common Name	Relative Range	Global Rank	State Rank	CCVI Score
Scolopax minor	American woodcock	Entire range	G5	S4B	Moderately Vulnerable
Aimophila aestivalis	Bachman's sparrow	Entire range	G3	S2	Moderately Vulnerable
Botaurus lentiginosus	American bittern	Northern edge of range	G4	S1	Presumed Stable
Pluvialis dominica	American golden plover	Entire range	G5	S1	Presumed Stable
Anhinga anhinga	Anhinga	Southern edge of range	G5	S1B	Presumed Stable
Riparia riparia	Bank swallow	Entire range	G5	S3	Presumed Stable
Vireo bellii	Bell's vireo	East/west edge of range	G5	SHB	Presumed Stable
Thryomanes bewickii	Bewick's wren	East/west edge of range	G5	S1	Presumed Stable
Vermiforma pinus	Blue-winged warbler	Entire range	G5	S4	Presumed Stable
Sitta pusilla	Brown-headed nuthatch	Entire range	G5	S2B	Presumed Stable
Tryngites subruficollis	Buff-breasted sandpiper	Entire range	G4	S3N	Presumed Stable
Setophaga cerulea	Cerulean warbler	Entire range	G4	S3B	Presumed Stable
Caprimulgus carolinensis	Chuck-will's-widow	Entire range	G5	S3S4	Presumed Stable
Ammodramus savannarum	Grasshopper sparrow	Entire range	G5	S4	Presumed Stable
Wilsonia citrina	Hooded warbler	Entire range	G5	S4	Presumed Stable
Oporornis formosus	Kentucky warbler	Entire range	G5	S4	Presumed Stable

Table 4. Conservation status and CCVI score for selected Tennessee GCN birds					
Scientific Name	**Common Name**	**Relative Range**	**Global Rank**	**State Rank**	**CCVI Score**
Rallus elegans	King rail	Entire range	G4	S2	Presumed Stable
Chondestes grammacus	Lark sparrow	Entire range	G5	S1B	Presumed Stable
Ixobrychus exilis	Least bittern	Entire range	G5	S2B	Presumed Stable
Egretta caerulea	Little blue heron	Entire range	G5	S2B S3N	Presumed Stable
Lanius ludovicianus	Loggerhead shrike	Entire range	G4	S3	Presumed Stable
Limosa fedoa	Marbled godwit	Entire range	G5	N2BN3N	Presumed Stable
Parula americana	Northern parula	Entire range	G5	S5	Presumed Stable
Dendroica discolor	Prairie warbler	Entire range	G5	S3 S4	Presumed Stable
Protonotaria citrea	Prothonotary warbler	Entire range	G5	S4	Presumed Stable
Calidris canutus	Red knot	Entire range	G4	S2N	Presumed Stable
Melanerpes erythrocephalus	Red-headed woodpecker	Entire range	G5	S4	Presumed Stable
Tyrannus forficatus	Scissor-tailed flycatcher	Entire range	G5	S1B	Presumed Stable
Accipiter striatus	Sharp-shinned hawk	Entire range	G5	S3B	Presumed Stable
Calidris himantopus	Stilt sandpiper	Entire range	G5	S3N	Presumed Stable
Limnothlypis swainsonii	Swainson's warbler	East/west edge of range	G4	S3	Presumed Stable
Elanoides forficatus	Swallow-tailed kite	Entire range	G5	N2BN3N	Presumed Stable
Bartramia longicauda	Upland sandpiper	Entire range	G5	SNA	Presumed Stable
Pooecetes gramineus	Vesper sparrow	Entire range	G5	S1BS4N	Presumed Stable
Calidris mauri	Western sandpiper	Entire range	G5	S4N	Presumed Stable
Numenius phaeopus	Whimbrel	Entire range	G5	N2BN3N	Presumed Stable
Caprimulgus vociferus	Whip-poor-will	Entire range	G5	S3S4	Presumed Stable
Vireo griseus	White-eyed vireo	Entire range	G5	S4	Presumed Stable
Charadrius wilsonia	Wilson's plover	Entire range	G5	N2B,N3I nc	Presumed Stable
Hylocichla mustelina	Wood thrush	Entire range	G5	S4	Presumed Stable
Helmitheros vermivorum	Worm-eating warbler	Entire range	G5	S4	Presumed Stable

Table 4. Conservation status and CCVI score for selected Tennessee GCN birds					
Scientific Name	**Common Name**	**Relative Range**	**Global Rank**	**State Rank**	**CCVI Score**
Coccyzus americanus	Yellow-billed cuckoo	Entire range	G5	S4S5	Presumed Stable
Tyto alba	Barn owl	Entire range	G5	S3	Increase Likely
Spiza americana	Dickcissel	Entire range	G5	S4	Increase Likely
Ardea alba	Great egret	Entire range	G5	S2BS3N	Increase Likely
Limosa haemastica	Hudsonian godwit	Entire range	G4	N2BN3N	Increase Likely
Seiurus motacilla	Louisiana waterthrush	Entire range	G5	S4	Increase Likely
Ictinia mississippiensis	Mississippi kite	East/west edge of range	G5	S2 S3	Increase Likely
Icterus spurius	Orchard oriole	Entire range	G5	S4	Increase Likely
Passerina ciris	Painted bunting	East/west edge of range	G5	S2	Increase Likely
Passerculus sandwichensis	Savannah sparrow	Entire range	G5	S1B S4N	Increase Likely

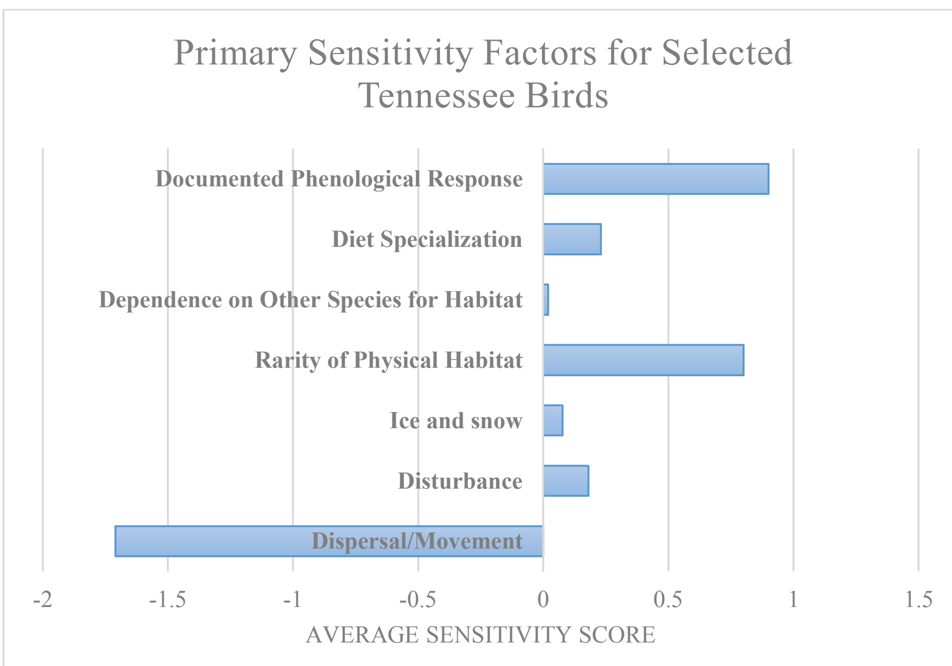


Figure 9. Primary CCVI sensitivity factors for selected Tennessee birds. The x-axis indicates the average CCVI score for relevant indirect exposure and sensitivity factors among all birds assessed (see Tables 13 and 14 in Appendix A for detailed descriptions). Negative numbers indicate factors that decrease vulnerability, positive scores reflect increased vulnerability. Factors with a 0 average score are not included in the chart, although it is important to recognize that these are average scores – in some cases, individual factors that contribute to vulnerability might be offset by factors that decrease vulnerability. Accordingly, this chart should be seen as supplemental to Table 19 in Appendix C.

4.1.2.2.3 Reptiles

A total of 17 GCN reptile species were included in the state-wide CCVI assessment (see Table 5). Of those, 13 species were assessed as Presumed Stable. Three species, including coachwhip (*Masticophis flagellum*), green anole (*Anolis carolinensis*), and alligator snapping turtle (*Macrochelys temminckii*) were assessed as Increase Likely. The alligator snapping turtle is not considered vulnerable to climate change and could, in fact, benefit given its ability to burrow in deep aquatic holes within rivers and creeks or in deep, open water, all of which can serve as refugia from unfavorable environmental conditions (Howey and Dinkelacker 2009). Green anole and coachwhip both seem to prefer warmer temperatures and have relatively-generalized habitat needs. The bog turtle (*Glyptemys muhlenbergii*) was the only species identified as Moderately Vulnerable to climate change, primarily due to its relatively-narrow habitat requirements (i.e., reliance on bogs and seeps) as well as its dependence on other species to generate habitat. The species has also been found to have relatively-low genetic diversity among its populations, which may limit its adaptive capacity over time (Rosenbaum et al. 2007).

Bog turtle (*Glyptemys muhlenbergii*) – FWS

Figure 10, below, and Table 20 in Appendix C highlight the primary factors contributing to vulnerability for the reptile group, based on average sensitivity scores. Limited dispersal capabilities and the existence of anthropogenic barriers were the primary factors increasing vulnerability. On the other hand, several species appear to favor temperatures at the higher end of their physiological niche, and historical exposure to variability in precipitation and moisture regimes may indicate a certain amount of adaptive capacity. Confidence in results was very high for all species assessed.

Table 5. Conservation status and CCVI score for selected Tennessee GCN reptiles

Scientific Name	Common Name	Relative Range	Global Rank	State Rank	CCVI Score
Glyptemys muhlenbergii	Bog turtle	Southern edge of range	G3	S1	Moderately Vulnerable
Plestiodon anthracinus	Coal skink	East/west edge of range	G5	S1	Presumed Stable
Terrapene carolina	Eastern box turtle	East/west edge of range	G5	S4	Presumed Stable
Heterodon platirhinos	Eastern hognosed snake	East/west edge of range	G5	S4	Presumed Stable
Ophisaurus attenuatus longicaudus	Eastern slender glass lizard	East/west edge of range	G5T5	S3	Presumed Stable
Clonophis kirtlandii	Kirtland's snake	Southern edge of range	G2	S1	Presumed Stable

Nerodia cyclopion	Mississippi green watersnake	East/west edge of range	G5	S2	Presumed Stable
Pituophis melanoleucus melanoleucus	Northern pinesnake	East/west edge of range	G4T4	S3	Presumed Stable
Virginia striatula	Rough earth snake	East/west edge of range	G5	S2S3	Presumed Stable
Apalone mutica	Smooth softshell turtle	East/west edge of range	G5	S4	Presumed Stable
Crotalus horridus	Timber rattlesnake	Center of range	G4	S4	Presumed Stable
Sistrurus miliarius streckeri	Western pygmy rattlesnake	East/west edge of range	G5T5	S2S3	Presumed Stable
Thamnophis proximus	Western ribbonsnake	East/west edge of range	G5	S4	Presumed Stable
Nerodia erythrogaster flavigaster	Yellowbelly watersnake	East/west edge of range	G5T5	HYB	Presumed Stable
Macrochelys temminckii	Alligator snapping turtle	East/west edge of range	G3G4	S2S3	Increase Likely
Masticophis flagellum	Coachwhip	Northern edge of range	G5	S2	Increase Likely
Anolis carolinensis	Green anole	Northern edge of range	G5	S3	Increase Likely

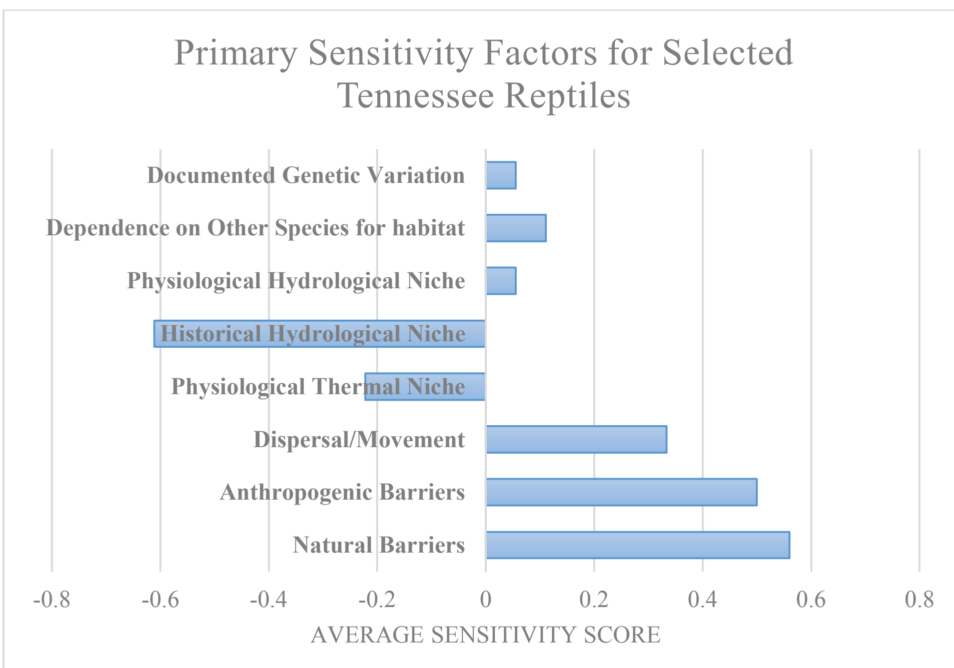


Figure 10. Primary CCVI sensitivity factors for selected Tennessee reptiles. The x-axis indicates the average CCVI score for relevant indirect exposure and sensitivity factors among all reptiles assessed (see Tables 13 and 14 in Appendix A for detailed descriptions). Negative numbers indicate factors that decrease vulnerability, positive scores reflect increased vulnerability. Factors with a 0 average score are not included in the chart, although it is important to recognize that these are average scores – in some cases, individual factors that contribute to vulnerability might be offset by factors that decrease vulnerability. Accordingly, this chart should be seen as supplemental Table 20 in Appendix C.

4.1.2.2.4 Amphibians

26 of Tennessee's GCN amphibians were included in the state-wide CCVI assessment (see Table 6). Of the total amphibians, 14 species were found to be in the Presumed Stable category. Eleven species, including Berry Cave salamander (*Gyrinophilus gulolineatus*), barking tree frog (*Hyla gratiosa*), crawfish frog (*Lithobates areolatus*), four-toed salamander (*Hemidactylium scutatum*), gray treefrog (*Hyla versicolor*), green salamander (*Aneides aeneus*), mountain chorus frog (*Psedacris brachyphona*), seepage salamander (*Desmognathus aeneus*), southern cricket frog (*Acris gryllus*), Tennessee cave salamander (*Gyrinophilus palleucus*), and Weller's salamander (*Plethodon welleri*), were Moderately Vulnerable. One species, hellbender (*Cryptobranchus alleganiensis*), was found to be Highly Vulnerable.

Barking treefrog (*Hyla gratiosa*) – USGS

Table 6. Conservation status and CCVI score for selected Tennessee GCN amphibians

Scientific Name	Common Name	Relative Range	Global Rank	State Rank	CCVI Score
Cryptobranchus alleganiensis	Hellbender	Center of range	G3G4	S3	Highly Vulnerable
Hyla gratiosa	Barking treefrog	Center of range	G5	S3	Moderately Vulnerable
Gyrinophilus gulolineatus	Berry Cave salamander	Entire range	G1Q	S2	Moderately Vulnerable
Lithobates areolatus	Crawfish frog	Center of range	G5	S3	Moderately Vulnerable
Hemidactylium scutatum	Four-toed salamander	East/west edge of range	G5	S3	Moderately Vulnerable
Hyla versicolor	Gray treefrog	East/west edge of range	G5	S5	Moderately Vulnerable
Aneides aeneus	Green salamander	Center of range	G3G4	S3S4	Moderately Vulnerable
Psedacris brachyphona	Mountain chorus frog	Center of range	G5	s4	Moderately Vulnerable
Desmognathus aeneus	Seepage salamander	Center of range	G3G4	S1	Moderately Vulnerable
Acris gryllus	Southern cricket frog	Northern edge of range	G5	S4	Moderately Vulnerable
Gyrinophilus palleucus	Tennessee cave salamander	Center of range	G2G3	S2	Moderately Vulnerable
Plethodon welleri	Weller's salamander	Center of range	G3	S2	Moderately Vulnerable
Desmognathus welteri	Black Mountain dusky salamander	Southern edge of range	G4	S3	Presumed Stable

Table 6. Conservation status and CCVI score for selected Tennessee GCN amphibians					
Scientific Name	**Common Name**	**Relative Range**	**Global Rank**	**State Rank**	**CCVI Score**
Desmagnatus abditus	Cumberland dusky salamander	Entire range	G2G3	S2S3	Presumed Stable
Desmognathus imitator	Imitator salamander	Center of range	G3G4	S3	Presumed Stable
Plethodon jordani	Jordan's red-cheeked salamander	Center of range	G4	S2S3	Presumed Stable
Pseudtriton montanus	Mud salamander	Center of range	G5	S5	Presumed Stable
Plethodon montanus	Northern gray-cheeked salamander	Center of range	G4	S3	Presumed Stable
Desmognathus organi	Northern pygmy salamander	Center of range	G3	SNR	Presumed Stable
Plethodon shermani	Red-legged salamander	Center of range	G3	S2	Presumed Stable
Desmognathus wrighti	Southern pygmy salamander	Center of range	G3	S3S3	Presumed Stable
Plethodon richmondi	Southern ravine salamander	Center of range	G5	S3	Presumed Stable
Ambystoma barbouri	Streamside salamander	Southern edge of range	G4	S2	Presumed Stable
Plethodon aureolus	Tellico salamander	Center of range	G2G3	S2	Presumed Stable
Plethodon wehrlei	Wehrle's salamander	Southern edge of range	G4	S1	Presumed Stable
Plethodon yonahlossee	Yonahlossee salamander	Center of range	G4	S2	Presumed Stable

Figure 11 shows average sensitivity scores for all of the amphibians included in the Tennessee CCVI analysis (see Table 21 in Appendix C for more detail). For amphibians as a group, the two factors most associated with increased vulnerability to climate change were species' physiological dependence on a relatively narrow precipitation/hydrological regime and limited dispersal ability due to both natural and anthropogenic factors, a result supported by recent literature (e.g., Blaustein et al. 2010, Milanovich et al. 2010, Barrett et al. 2014).

One of the most significant factors in the vulnerability of some species is their reliance on ephemeral pools for reproduction. Both the timing and duration of a wetland's hydroperiod (i.e., the period during which a wetland is saturated) are highly correlated with the breeding behavior and reproductive success of many amphibians (Carey and Alexander 2003, Walls et al. 2013). If projected changes in precipitation and increased evaporation associated with higher temperatures contribute to a decline in the quality and/or availability of those pools, the reproductive success of some species (e.g., mountain chorus frog, barking treefrog, gray treefrog, southern cricket frog, and four-toed salamander), could decline. The hellbender is considered Highly Vulnerable due to sensitivity to elevated stream temperatures and reduced flows.

The one factor that reduced vulnerability for many of the species assessed was their exposure to past variations in precipitation, which may indicate that, despite their specific physiological hydrological needs, they might exhibit some adaptive capacity to deal with greater variability in precipitation.

However, the region is projected to experience greater extremes in temperatures and precipitation, which could exceed some species' adaptive capacity. Moreover, summer months are likely to see the greatest increases in average temperatures (Figure 2, above) and declines in average precipitation (Figure 3), which would lead to earlier drying of ephemeral pools, possibly before maturation into terrestrial forms. For all species assessed, confidence in the information was considered very high.

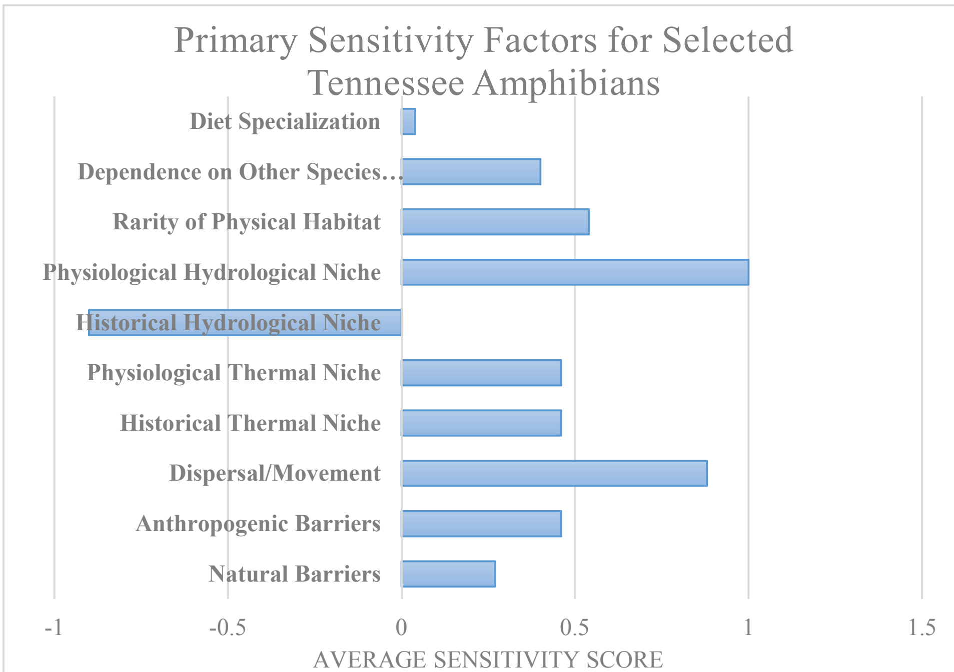


Figure 11. Primary sensitivity factors for selected Tennessee amphibians. The x-axis indicates the average CCVI score for relevant indirect exposure and sensitivity factors among all amphibians assessed (see Tables 13 and 14 in Appendix A for detailed descriptions). Negative numbers indicate factors that decrease vulnerability, positive scores reflect increased vulnerability. Factors with a 0 average score are not included in the chart, although it is important to recognize that these are average scores – in some cases, individual factors that contribute to vulnerability might be offset by factors that decrease vulnerability. Accordingly, this chart should be seen as supplemental to Table 21 in Appendix C.

4.1.2.2.5 Fish

Among all of the taxonomic groups included in the CCVI assessment for Tennessee, fish species were found to be the most vulnerable to climate change (see Table 7). Of the 19 species included in the state-wide assessment, three were found to be Extremely Vulnerable: brook trout (*Salvelinus fontinalis*), lake sturgeon (*Acipenser fulvescens*), and slackwater darter (*Etheostoma boschungi*). The primary reasons for their vulnerability varies (see Figure 12, below, and Table 22 in Appendix C). For brook trout, a major factor is the species' narrow thermal niche and reliance on specific hydrologic conditions (e.g., timing and extent of streamflows) that could be altered with climate change (Clark et al. 2001). Tennessee is also at the southern edge of the species' range, which likely means it is already close to its upper thermal tolerance level in the region. Anthropogenic barriers to dispersal and sensitivity to changes in the timing of hydrologic and temperature conditions required for successful spawning are major factors determining the vulnerability of both lake sturgeon and slackwater darter. Species that rely on headwater habitat, such as slackwater darter, are also vulnerable given limited ability to migrate farther upstream to find cooler temperatures (TWRA 2009).

Lake sturgeon (*Acipenser fulvescens*) – FWS

Four species were found to be Highly Vulnerable to climate change: alligator gar (*Attractosteus spatula*), arrow darter (*Etheostoma sagitta*), chucky madtom (*Notorus crypticus*), and paddlefish (*Polyodon spathula*). Common factors contributing to the vulnerability of these species include presence of natural and anthropogenic barriers and sensitivity due to limited physiological hydrological niche. The presence of dikes, for example, restrict access of the fish to floodplains for spawning. In addition, increasing coal and gas production activities are expected to lead to more roads and culverts, which also may reduce habitat connectivity.

Confidence for the CCVI results was considered low for blue sucker (*Cycleptis elongates*) and highfin carpsucker (*Carpiodes velifer*), moderate for laurel dace (*Chrosomus saylori*) and paddlefish, and high or very high for all other species assessed.

Table 7. Conservation status and CCVI score for selected Tennessee GCN fish

Scientific Name	Common Name	Relative Range	Global Rank	State Rank	CCVI Score
Salvelinus fontinalis	Brook trout	Southern edge of range	G5	S3	Extremely Vulnerable
Acipenser fulvescens	Lake sturgeon	Southern edge of range	G3G4	S1	Extremely Vulnerable

Table 7. Conservation status and CCVI score for selected Tennessee GCN fish					
Scientific Name	**Common Name**	**Relative Range**	**Global Rank**	**State Rank**	**CCVI Score**
Etheostoma boschungi	Slackwater darter	Northern edge of range	G1	S1	Extremely Vulnerable
Attractosteus spatula	Alligator gar	East/west edge of range	G3	S1	Highly Vulnerable
Etheostoma sagitta	Arrow darter	Southern edge of range	G3G4	S2	Highly Vulnerable
Noturus crypticus	Chucky madtom	Entire range	G2	S2	Highly Vulnerable
Polyodon spathula	Paddlefish	Center of range	G4	S3	Highly Vulnerable
Cycleptis elongatus	Blue sucker	East/west edge of range	G3	S2	Moderately Vulnerable
Carpiodes velifer	Highfin carpsucker	Center of range	G4G5	S2S3	Moderately Vulnerable
Chrosomus saylori	Laurel dace	Entire range	G1G2	S1	Moderately Vulnerable
Etheostoma bellum	Orangefin darter	Southern edge of range	G4G5	S3	Moderately Vulnerable
Noturus fasciatus	Saddled madtom	Entire range	G2	S2	Moderately Vulnerable
Clinostomus funduloides	Smoky dace	Northern edge of range	G5	S1	Moderately Vulnerable
Percina aurantiaca	Tangerine darter	Center of range	G4	S3	Moderately Vulnerable
Cyprinella caerulea	Blue shiner	Northern edge of range	G2	S1	Presumed Stable
Etheostoma cervus	Chickasaw darter	Entire range	G2	S2	Presumed Stable
Etheostoma pyrrhogaster	Firebelly darter	Southern edge of range	G2	S2	Presumed Stable
Typhlichthys subterraneus	Southern cavefish	Center of range	G4	S3	Presumed Stable
Noturus flavipinnis	Yellowfin madtom	Center of range	G1	S1	Presumed Stable

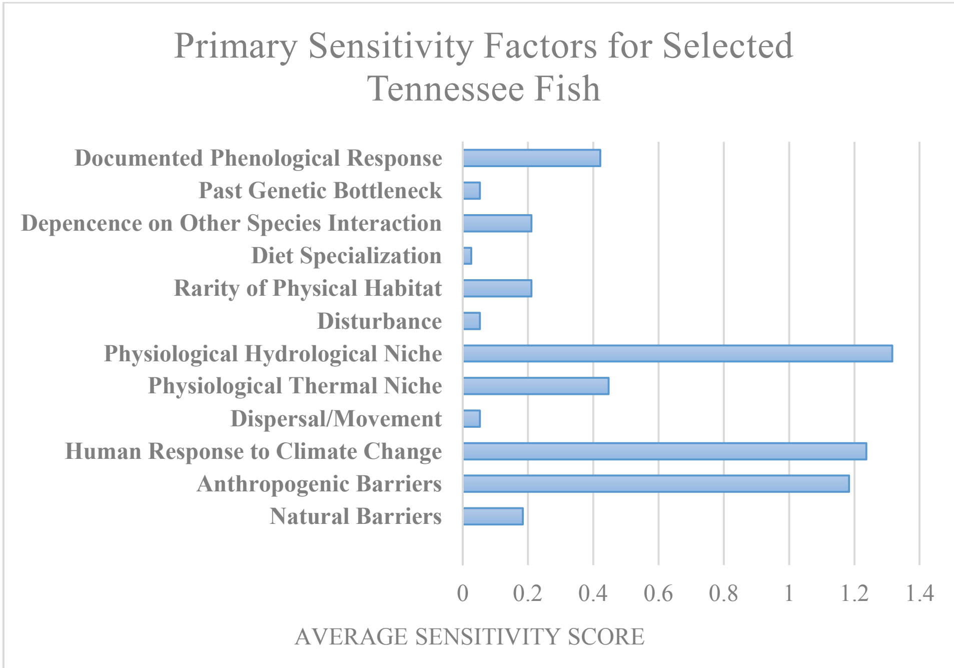


Figure 12. Primary CCVI sensitivity factors for selected Tennessee fish. The x-axis indicates the average CCVI score for relevant indirect exposure and sensitivity factors among all fish assessed (see Tables 13 and 14 in Appendix A for detailed descriptions). Negative numbers indicate factors that decrease vulnerability, positive scores reflect increased vulnerability. Factors with a 0 average score are not included in the chart, although it is important to recognize that these are average scores – in some cases, individual factors that contribute to vulnerability might be offset by factors that decrease vulnerability. Accordingly, this chart should be seen as supplemental to Table 22 in Appendix C.

4.1.2.2.6 Mussels and Crayfish

The assessment team selected 27 of Tennessee's freshwater mussels and eight crayfish species for inclusion in the CCVI analysis. Mussels in this taxonomic group show relatively high vulnerability to climate change. Among the mussels studied, 16 species ranked as Moderately Vulnerable, and six Highly Vulnerable (see Table 8). Just five species were Presumed Stable. For both Moderately and Highly Vulnerable species, the primary factors contributing to their vulnerability include anthropogenic barriers, implications from human response to climate change (e.g., dredging streams in response to drought conditions), limited dispersal ability given their sessile characteristic, and the dependence on other species (fish) for propagule dispersal, some species of which also may be vulnerable to climate change (see Figure 13, below, and Table 23 in Appendix C). For those species ranked as Presumed Stable, it appears that relative flexibility in terms of propagule dispersal is a primary factor.

Table 8. Conservation status and CCVI score for selected Tennessee GCN mussels

Scientific Name	Common Name	Relative Range	Global Rank	State Rank	CCVI Score
Fusconaia subrotunda	Longsolid	Southern edge	G3	S3	Highly Vulnerable
Villosa vanuxemensis	Mountain creekshell	Center of range	G4	S4	Highly Vulnerable
Villosa taeniata	Painted creekshell	Center of range	G3	S3S4	Highly Vulnerable
Toxolasma lividus	Purple lilliput	Center of range	G3	S1S2	Highly Vulnerable

Table 8. Conservation status and CCVI score for selected Tennessee GCN mussels

Scientific Name	Common Name	Relative Range	Global Rank	State Rank	CCVI Score
Obovaria subrotunda	Round hickorynut	Center of range	G4	S2S3	Highly Vulnerable
Pleurobema oviforme	Tennessee clubshell	Center of range	G2G3	S2S3	Highly Vulnerable
Strophitis connasaugaensis	Alabama creekmussel	Northern edge	G3	S1	Moderately Vulnerable
Villosa nebulosa	Alabama rainbow	Northern edge	G3	S2	Moderately Vulnerable
Medionidus conradicus	Cumberland moccasinshell	Center of range	G3G4	S3	Moderately Vulnerable
Alasmidonta marginata	Elktoe	Southern edge	G4	S4	Moderately Vulnerable
Pleurobema hanleyianum	Georgia pigtoe	Northern edge	G1	S1	Moderately Vulnerable
Obovaria olivaria	Hickorynut	Northern edge	G4	S2	Moderately Vulnerable
Villosa lienosa	Little spectaclecase	Entire range	G5	S4	Moderately Vulnerable
Pleurobema cordatum	Ohio pigtoe	Entire range	G4	S3	Moderately Vulnerable
Actinonaias pectorosa	Pheasantshell	Center of range	G4	S4	Moderately Vulnerable
Pleurobema rubrum	Pyramid pigtoe	Southern edge	G2	S1	Moderately Vulnerable
Quadrula cylindrica	Rabbitsfoot	East/west edge	G3	S3	Moderately Vulnerable
Pleuronaia dolabelloides	Slabside pearlymussel	Entire range	G2	S2	Moderately Vulnerable
Alasmidonta viridis	Slippershell mussel	Southern edge	G4G5	S3S4	Moderately Vulnerable
Cumberlandia monodonta	Spectaclecase	Center of range	G3	S2	Moderately Vulnerable
Lasmigona holstonia	Tennessee heelsplitter	Center of range	G3	S2	Moderately Vulnerable
Pleuronaia barnesiana	Tennessee pigtoe	Center of range	G2G3	S2S3	Moderately Vulnerable
Ligumia recta	Black sandshell	East/west edge	G4	S5	Presumed Stable
Strophitus undulatus	Creeper	Southern edge	G5	S5	Presumed Stable
Pleurobema sintoxia	Round pigtoe	Southern edge	G4	S4	Presumed Stable
Villosa vibex	Southern rainbow	Southern edge	G5	S2	Presumed Stable
Lasmigona complanata	White heelsplitter	Entire range	G5	S?	Presumed Stable

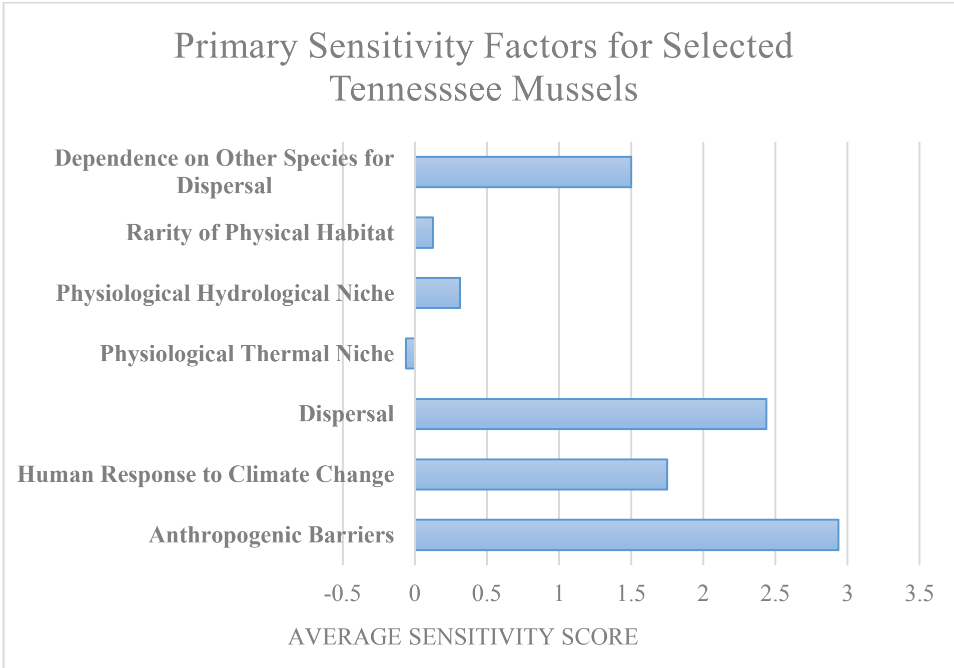


Figure 13. Primary CCVI sensitivity factors for selected Tennessee mussels. The x-axis indicates the average CCVI score for relevant indirect exposure and sensitivity factors among all mussels assessed (see Tables 12 and 13 in Appendix A for detailed descriptions). Negative numbers indicate factors that decrease vulnerability, positive scores reflect increased vulnerability. Factors with a 0 average score are not included in the chart, although it is important to recognize that these are average scores – in some cases, individual factors that contribute to vulnerability might be offset by factors that decrease vulnerability. Accordingly, this chart should be seen as supplemental to Table 23 in Appendix C.

The crayfish species assessed (Table 9) were all ranked Presumed Stable, although several species, including stateline crayfish (*Orconectes alabamensis*), Hardin County crayfish (*Orconectes wrighti*), Hatchie burrowing crayfish (*Fallicambarus hortoni*), and Tennessee cave crayfish (*Orconectes incomptus*) are sensitive to changing hydrologic conditions, and species with relatively limited distributions are likely to be more vulnerable than those with broader latitudinal ranges (see Figure 14, below, and Table 23 in Appendix C). Confidence in index results for all species was very high for all species assessed in this category.

Table 9. Conservation status and CCVI score for selected Tennessee GCN crayfish

Scientific Name	Common Name	Relative Range	Global Rank	State Rank	CCVI Score
Orconectes pagei	Big Sandy crayfish	Northern edge	G2	S1	Presumed Stable
Cambarus bouchardi	Big southfork crayfish	Southern edge	G2G3	S1	Presumed Stable
Orconectes burri	Blood River crayfish	Northern edge	G2	S2	Presumed Stable
Barbicambarus cornutus	Bottlebrush crayfish	Southern edge	G4	S2	Presumed Stable
Orconectes wrighti	Hardin County crayfish	Center of range	G2	S1	Presumed Stable

Table 9. Conservation status and CCVI score for selected Tennessee GCN crayfish					
Scientific Name	**Common Name**	**Relative Range**	**Global Rank**	**State Rank**	**CCVI Score**
Fallicambarus hortoni	Hatchie burrowing crayfish	Center of range	G1	S1	Presumed Stable
Orconectes alabamensis	Stateline crayfish	Center of range	G5	S2	Presumed Stable
Orconectes incomptus	Tennessee cave crayfish	Center of range	G2G2	S1	Presumed Stable

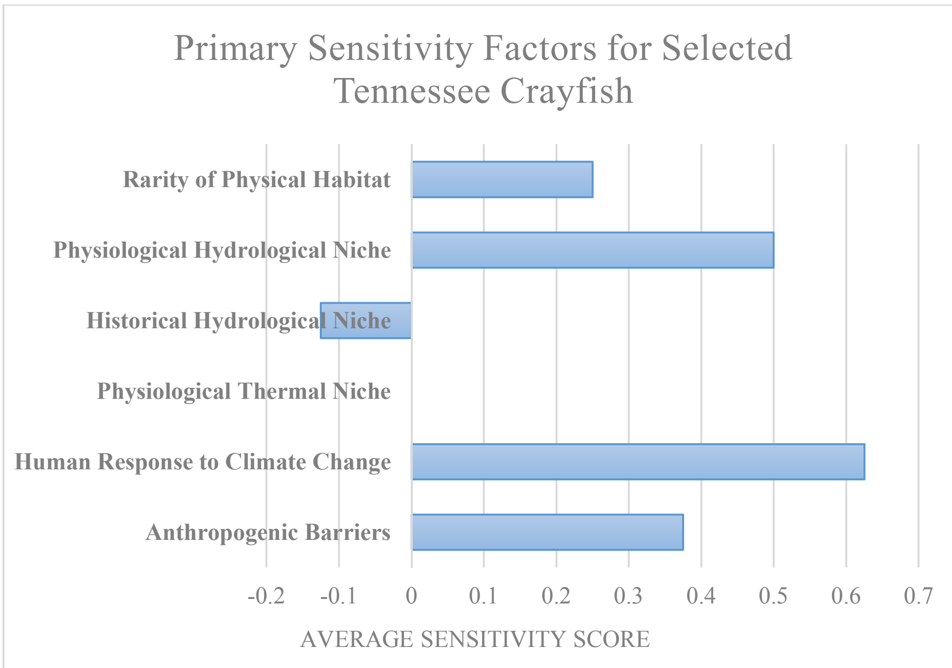


Figure 14. Primary CCVI sensitivity factors for selected Tennessee crayfish. The x-axis indicates the average CCVI score for relevant indirect exposure and sensitivity factors among all crayfish assessed (see Tables 13 and 14 in Appendix A for detailed descriptions). Negative numbers indicate factors that decrease vulnerability, positive scores reflect increased vulnerability. Factors with a 0 average score are not included in the chart, although it is important to recognize that these are average scores – in some cases, individual factors that contribute to vulnerability might be offset by factors that decrease vulnerability. Accordingly, this chart should be seen as supplemental to Table 23 in Appendix C.

4.1.2.2.7 Plants

The team chose 26 of the state's 552 GCN plant species for the CCVI assessment. More than half of the plants assessed ranked as Extremely Vulnerable or Highly Vulnerable (see Table 10). All eight of the plant species that ranked as Extremely Vulnerable, including American hart's-tongue (*Asplenium scolopendrium var. americanum*), Pyne's ground-plum (*Astragalus bibullatus*), rock gnome lichen (*Gymnoderma lineare*), Roan Mountain bluet/Venus' pride (*Hedyotis purpurea var. montana*), whorled sunflower (*Helianthus verticillatus*), Spring Creek bladderpod (*Paysonia perforata*), Ruth's golden aster

White fringeless orchid (*Platanthera integrilabia*) – FWS

(*Pityopsis ruthii*), and Tennessee yellow-eyed grass (*Xyris tennesseensis*) are also ranked in Tennessee as critically imperiled (S1), and all but American hart's-tongue and Roan Mountain bluet ranked as either very rare or imperiled globally (G3, G2, G1).

The primary sensitivity factors for vulnerability of selected plants is their dependence on a narrowly-defined precipitation/hydrologic conditions, limited dispersal abilities, and the presence of natural and anthropogenic barriers to dispersal (see Figure 15, below, and Table 24 in Appendix C). For instance, species such as American hart's tongue fern and rock gnome lichen, which depend on high humidity, are vulnerable to drier conditions. Conversely, two species that generally rank as rare (G3 and S3), Eggert's sunflower (*Helianthus eggertii*) and ginseng (*Panax quinquefolius*) scored as Increase Likely from a climate change perspective, as they are not considered sensitive to most of the CCVI risk factors. Confidence in CCVI scores was low for Short's bladderpod (*Physaria globose*), moderate for spreading avens (*Geum radiatum*), and very high for all other species assessed.

Table 10. Conservation status and CCVI score for selected Tennessee GCN plants

Scientific Name	Common Name	Relative Range	Global Rank	State Rank	CCVI Score
Asplenium scolopendrium var. americanum (syn. *Phyllitis scolopendrium var. americana*)	American hart's-tongue	Center of range	G4T3	S1	Extremely Vulnerable
Astragalus bibullatus	Pyne's ground-plum	Entire range	G1	S1	Extremely Vulnerable
Hedyotis purpurea var. montana (syn. *Houstonia montana*)	Roan Mountain bluet/ Venus' pride	Center of range	G5T2	S1	Extremely Vulnerable
Gymnoderma lineare	Rock gnome lichen	East/west edge of range	G3	S1	Extremely Vulnerable
Pityopsis ruthii	Ruth's golden aster	Entire range	G1	S1	Extremely Vulnerable
Paysonia perforata (syn. *Lesquerella perforata)*	Spring Creek bladderpod	Entire range	G1	S1	Extremely Vulnerable
Xyris tennesseensis	Tennessee yellow-eyed grass	Northern edge of range	G2	S1	Extremely Vulnerable
Helianthus verticillatus	Whorled sunflower	Northern edge of range	G1Q	S1	Extremely Vulnerable
Solidago spithamaea	Blue Ridge goldenrod	Northern edge of range	G2	S1	Highly Vulnerable

Table 10. Conservation status and CCVI score for selected Tennessee GCN plants					
Scientific Name	**Common Name**	**Relative Range**	**Global Rank**	**State Rank**	**CCVI Score**
Boechera perstellata (syn. *Arabis perstellata*)	Braun's rockcress	Southern edge of range	G2	S1	Highly Vulnerable
Physaria globosa (syn. *Lesquerella globosa*)	Short's bladderpod	Southern edge of range	G2	S2	Highly Vulnerable
Geum radiatum	Spreading avens/ Appalachian avens	East/west edge of range	G2	S1	Highly Vulnerable
Spiraea virginiana	Virginia spiraea/ Virginia meadowsweet	East/west edge of range	G2	S2	Highly Vulnerable
Platanthera integrilabia	White fringeless Orchid/monkey-face orchid	Center of range	G2G3	S2S3	Highly Vulnerable
Conradina verticillata	Cumberland rosemary	Center of range	G3	S3	Moderately Vulnerable
Dalea foliosa	Leafy prairie-clover	Center of range	G2G3	S2S3	Moderately Vulnerable
Echinacea tennesseensis	Tennessee purple coneflower	Entire range	G2	S2	Moderately Vulnerable
Hottonia inflate	American featherfoil	Center of range	G4	S2	Presumed Stable
Minuartia cumberlandensis (syn. *Arenaria cumberlandensis*)	Cumberland sandwort/ Cumberland stitchwort	Center of range	G2G3	S2	Presumed Stable
Scutellaria montana	Large-flowered skullcap	Northern edge of range	G4	S4	Presumed Stable
Clematis morefieldii	Morefield's leatherflower	Northern edge of range	G2	S2	Presumed Stable
Buckleya distichophylla	Pirate bush	Southern edge of range	G3	S2	Presumed Stable
Apios priceana	Price's potato bean	Center of range	G3	S3	Presumed Stable
Isotria medeoloides	Small whorled pogonia/little five leaves	Southern edge of range	G2	S1	Presumed Stable
Helianthus eggertii	Eggert's sunflower	Center of range	G3	S3	Increase Likely
Panax quinquefolius	Ginseng	Center of range	G3G4	S3S4	Increase Likely

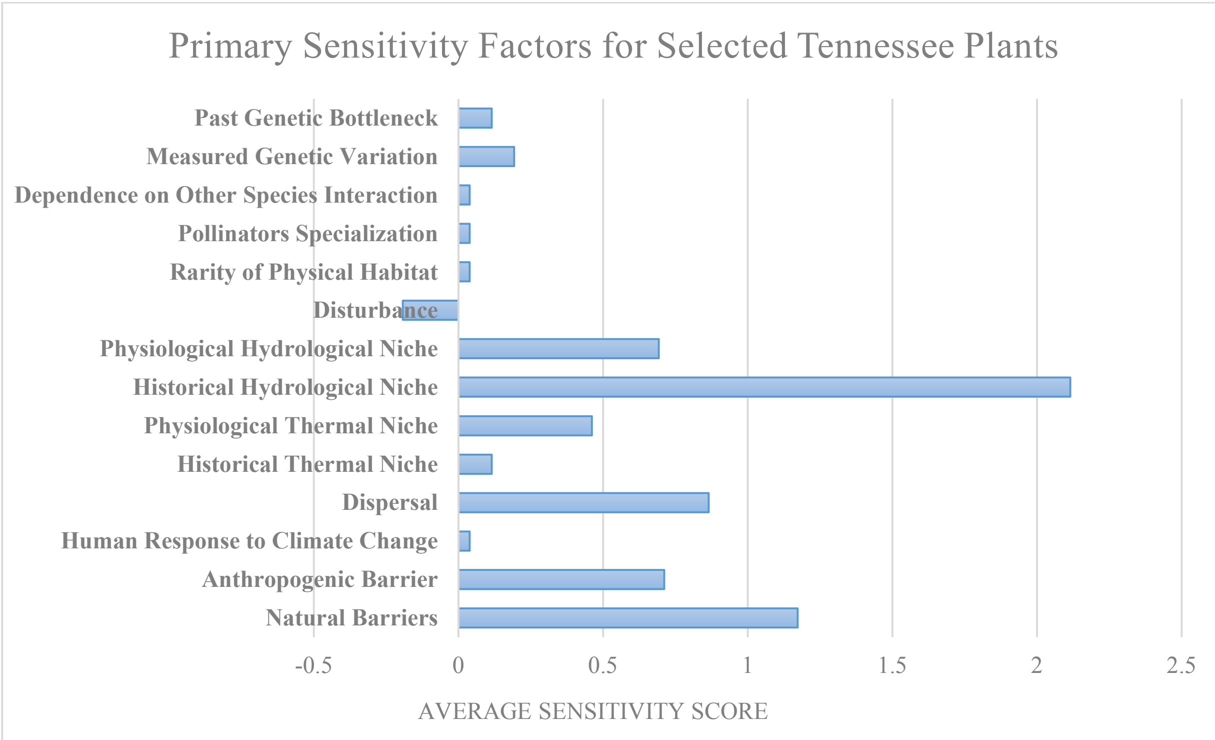


Figure 15. Primary CCVI sensitivity factors for selected Tennessee plants. The x-axis indicates the average CCVI score for relevant indirect exposure and sensitivity factors among all plants assessed (see Tables 13 and 14 in Appendix A for detailed descriptions). Negative numbers indicate factors that decrease vulnerability, positive scores reflect increased vulnerability. Factors with a 0 average score are not included in the chart, although it is important to recognize that these are average scores – in some cases, individual factors that contribute to vulnerability might be offset by factors that decrease vulnerability. Accordingly, this chart should be seen as supplemental to Table 24 in Appendix C.

4.1.2.3 Some Cautions When Interpreting CCVI Results

As with all vulnerability assessment approaches, users should exercise caution when interpreting results. For instance, with tools such as the CCVI that provide rankings among a number of target species or systems, it is tempting to prioritize conservation efforts toward the species or systems that rise to the top as being among the most vulnerable. Yet, the results are likely to be most useful if managers consider the full range of climate change vulnerability rankings and not just focus on those species likely to be adversely affected. Certainly, identifying the most-vulnerable species and the factors underlying that vulnerability will help managers set priorities and identify strategies that might more effectively reduce the multitude of stressors, including climate change, to those species of concern. In some cases, however, managers may choose to focus actions on those species likely to persist or perhaps even thrive under climate change (i.e., those ranked as Presumed Stable or Increase Likely). For example, if an important keystone species is considered extremely vulnerable and likely to be extirpated from a region under climate change, managers may choose to place greater emphasis on a non-vulnerable species that could play a similar role in the ecosystem.

Another factor that warrants attention is the spatial scale at which the relevant species are assessed. The CCVI is designed to work best at a *relatively* small scale, such as a national park, wildlife refuge, or state (Young et al. 2011). At larger (e.g., regional or national) scales, variations in climatic variables, topographic diversity, and other factors can make assessments of both the direction and magnitude of species' responses more difficult. Of course, this does not mean that vulnerability assessments across a broader landscape are unimportant or unnecessary. Rather, climate change requires managers to consider a broader-landscape context to account for likely shifts in species distributions, to sustain ecological processes, and promote cross-institutional collaboration.

It is also important to recognize that there may be considerable complexities associated with species' vulnerability to climate change that are not captured by the CCVI. For example, as noted in Young et al. (2014), climate change can indirectly threaten species through factors (such as changes in disease transmission patterns and shifts in the population dynamics of natural enemies or invasive species) that can be difficult to predict and are not explicitly included as elements of indirect exposure or sensitivity in the CCVI. For some species, climate-related factors such as seasonal timing of maximum stream flows or greater swings in temperature extremes are more important than average annual temperature or annual moisture, which are the data points used in typical CCVI assessments. Supplemental information from additional modeling, expert input, and other sources may be warranted to provide a more-thorough analysis of potential vulnerability (Butler et al. 2014).

Finally, as noted previously, climate change does not occur in a vacuum but rather acts synergistically with many other factors that are of concern for conservation of Tennessee's GCN species. In some cases, climate change may not pose a major risk for a species, but that does not necessarily mean that the species is not otherwise imperiled. For example, a species assessed as Presumed Stable under the CCVI may still be impacted by other stressors unrelated to climate change, such as overharvest. In other cases, climate change might benefit a species, reducing the need to address some other threats. An increase in wildfire, for example, may favor species that rely on early-successional habitat. Ultimately, managers will need to consider the broad context of conditions in which species and associated habitats exist, both now and in the future, in order to develop effective conservation strategies.

These cautions notwithstanding, the CCVI provides useful tool for managers to begin to look at their conservation targets through a climate change lens – a necessary step for effective climate change adaptation (Stein et al. 2014).

4.2 VULNERABILITY OF TENNESSEE HABITATS

Some of the most-significant impacts of climate change on Tennessee's fish and wildlife species will be associated with changes to their terrestrial and aquatic habitats. This section provides a brief summary of habitat vulnerabilities based on a review of the scientific literature. More in-depth assessments of regional scale habitat impacts are provided by the following sources: EPRI (2009), TWRA (2009), and McNulty et al. (2013).

4.2.1 Terrestrial Habitats

4.2.1.1 Shifts in Vegetation

Climate change is projected to contribute to significant changes in the composition of associated plant species in both forest and grassland systems across Tennessee due to direct changes in suitable climate conditions (e.g., increasing temperatures and changes in precipitation patterns), indirect changes (e.g., altered disturbances such as wildfire and insect outbreaks), and an increase in the atmospheric concentration of carbon dioxide (CO_2). Some impacts will occur in the near term, while others are likely to take decades. For example, although direct impacts of higher temperatures and changes in moisture on terrestrial habitats may be gradual, more-extreme disturbances such as wildfires could lead to dramatic changes in habitat within a relatively short period (Dale et al. 2000). In addition, changing CO_2 levels put certain types of plants at either a relative growth advantage or disadvantage, depending on the type of photosynthetic pathway they have (Poorter and Navas 2003, McNulty et al. 2013). This will likely have an effect on both species competition and regeneration.

Prairie vegetation in Tennessee – TWRA

It is important to recognize that the projected changes in vegetation types differ depending on the particular climate and vegetation change models, greenhouse gas emissions scenarios, and the data and assumptions used for the respective analyses. Several studies project a decline in floodplain-associated species such as cottonwoods and ash and an increase in oak-hickory forest in the Mississippi Alluvial Plain by the end of this century (Prasad et al. 2007, EPRI 2009). Oak-hickory forest is expected to persist in the Interior Low Plateau and Cumberland Plateau regions, although Iverson and Prasad (2002) suggest that there is likely to be encroachment from loblolly and shortleaf pines under some scenarios. Other studies (e.g., Iverson and Prasad 2001, Iverson et al. 2008, TWRA 2009) project a decline in loblolly/shortleaf pine forests and maple/beech/birch forests in Tennessee by 2100. Trees and forest systems adapted to more-northern latitudes, including eastern hemlock, spruce-fir forest, and northern hardwood forest, could be eliminated entirely from higher-elevation areas of the Southern Blue Ridge by the end of the century (Prasad et al. 2007, EPRI 2009). Research also indicates the potential for significant "savannafication" across the Southeast, in which forests are converted into more-open woodlands due to a combination of hotter and drier conditions (Hansen et al. 2001, McNulty et al. 2013).

Bachelet et al. (2003) project that winter deciduous forest could be replaced by coniferous forest or grassland in the western part of Tennessee by 2030, with expansion of savanna throughout the state by 2095.

4.2.1.2 Altered Disturbances

Forest and grassland systems in Tennessee are naturally exposed and adapted to a certain degree of disturbances such as wildfires, droughts, and insect and disease outbreaks. Changes in the frequency and severity of many these disturbances, however, are expected to contribute to shifts in habitat quality and composition (Dale et al. 2001). For example, higher air temperatures are projected to increase regional drying through increased forest water use via evapotranspiration, regardless of changes in precipitation. This drying is likely to increase wildfire risk across southeastern forests (McNulty et al. 2013). Studies indicate that the South's spring and fall wildfire seasons will be extended (Stanturf and Goodrick 2013) and that the area burned by wildfire will increase (Flannigan et al. 2000).

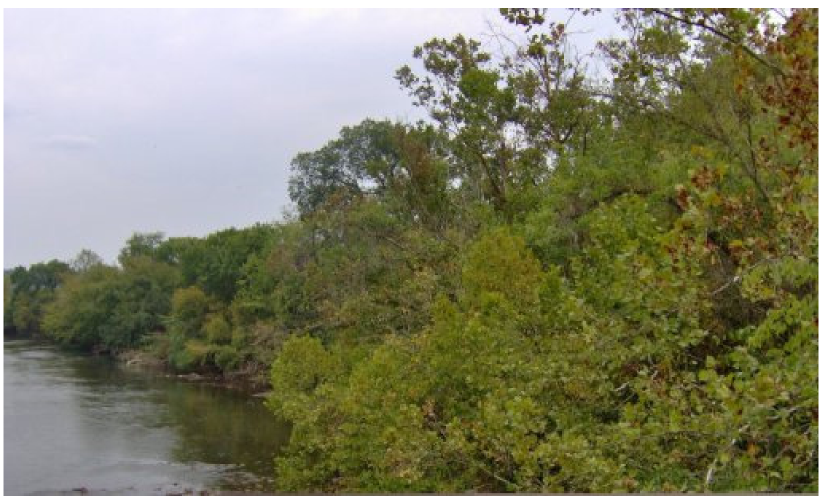
Prescribed burn, Great Smoky Mountains National Park – NPS

The implications of changes in wildfires for the region are likely to be complex. In principle, an increase in the frequency of wildfires could enhance some habitats, such as calcareous glades and barrens, which have historically relied on fire and grazing by megafauna but have declined in the region due in part to historical fire-suppression practices (NWF and NatureServe 2014). On the other hand, in areas with currently-high fuel loads, such as the southern Appalachian and Blue Ridge forests, drier conditions could lead to high-severity, stand-replacing fires and the potential conversion from one habitat type to another (Flannigan et al. 2000, Lenihan et al. 2008). As conditions become more favorable for wildfires in the state, managers will increasingly need to weigh the potential ecological benefits of allowing some fires to burn, where and when prescribed burns will be appropriate to manage fuels or restore ecosystems, and the need to suppress fires for purposes such as improved air quality and protection of property (Stanturf and Goodrick, 2013, Mitchell et al. 2014).

Climate change is also expected to increase the extent and frequency in outbreaks of both native and non-native forest insects and disease pathogens across the southeastern United States (McNulty et al. 2013). Not only does climate change affect the viability and spread of insects and pathogens directly, for instance by allowing greater winter survival, but it also can increase the susceptibility of host trees to outbreaks due to drought stress and other factors (Dale et al. 2001). Several insect species, including southern pine beetle (*Dendroctonus frontalis*) and hemlock wooly adelgid (*Adelges tsugae)*, have already caused considerable forest damage in parts of Tennessee (Duerr and Mistretta 2013). Higher average temperatures are expected to enhance winter survival and exacerbate outbreaks of both species, as well as contribute to their expansion northward (Gan 2004, Paradis et al. 2008). Indeed, studies suggest that climate change could increase the risk of southern pine beetle infestations across the Southeast by 2.5-5 times and could result in 4-7.5 times the current annual mortality of pines (Gan 2004). Persistence of the hemlock wooly adelgid is projected to lead to a complete loss of eastern hemlock from the Cumberland Plateau and Mountains region by the end of the century (Paradis et al. 2008, Evans and Gregoire 2007, Dale et al. 2009).

4.2.1.3 Altered Ecological Processes

The impacts of climate change on forest structure and functions could have a considerable impact on important ecological processes, such as regulation of water quality and quality, by altering key hydrologic fluxes (including precipitation and evapotranspiration) and biochemical processes. For example, under most climate scenarios analyzed, increasing temperatures and decreasing precipitation are projected to result in a greater uptake of soil water by forests and lead to reductions in streamflow, with associated impacts on aquatic fish and wildlife (Sun et al. 2011, McNulty et al. 2013). These changes are likely to be exacerbated by other stressors, such as ground-level ozone pollution, the concentration of which is expected to increase as temperatures rise given the relationship between heat and the chemical reactions between oxides of nitrogen and volatile organic compounds (Jacob and Winner 2009). A study modeling the effects of ozone exposure and climate change on tree transpiration in Tennessee suggests that ozone at near ambient concentrations can reduce stomatal control of leaf transpiration and increase water use (Sun et al. 2012). Increases in evapotranspiration and associated streamflow reductions in response to ambient ozone exposures are expected to episodically increase the frequency and severity of drought and affect flow-dependent aquatic biota in forested watersheds.



Drought-stressed vegetation along the Nolichucky River in 2007 – NOAA

4.2.1.4 Implications for Wildlife

The impacts of climate change on terrestrial habitats will have positive effects on some species and negative effects on others. For example, if climate change contributes to a widespread decline in the less-adapted trees that currently comprise the overstory, there will be an increase in canopy gaps of varying sizes (TWRA 2009). This would likely result in more understory vegetation and more early-successional wildlife habitat until better-adapted tree species become established. When overstory declines, however, invasive exotic vegetation, especially plants that benefit from higher temperatures and CO_2 levels, may gain a foothold (Simberloff 2000). The predicted modest expansion of oak-hickory forest type in some areas could benefit species that rely on the cover and structure provided by forest interiors as well as those that depend on hard mast for food. Where tree mortality is greatest, such as is projected for the elm-ash-cottonwood systems, the disappearance of areas of later-successional forest would adversely affect interior forest wildlife species.

Given the complexities and uncertainties in climate projections and associated impacts, the general challenge for managers is to consider how to define desired conservation outcomes and maintain Tennessee's high biodiversity values in the context of overall terrestrial habitat changes (Joyce et al. 2008). The state's upland forest systems, for instance, support a great diversity of wildlife due in part to the variety of different habitats and niches found within a structurally diverse forest system (TWRA 2014). Managing for a diversity of habitat types, even if the composition of associated vegetation changes, may still support desired conditions for valued fish and wildlife.

4.2.2 Aquatic Habitats

Tennessee's rivers, streams, lakes, and wetlands support a tremendous diversity of fish and wildlife species. Indeed, the state's rivers and streams are home to more species of fish, mussels, and crayfish than any other state in the country (TWRA 2014). Climate change is expected to have a considerable impact on aquatic habitats in Tennessee and across the Southeast (Anderson et al. 2013, McNulty et al. 2013). Higher temperatures and changes in precipitation patterns, in particular, will affect water temperatures and water quality and alter hydrological conditions to which many species of fish and wildlife have adapted.

4.2.2.1 Higher Water Temperatures and Altered Water Quality

Higher average air temperatures are likely to have a direct effect on water temperatures, although the localized impacts will depend on factors such as groundwater inflow and riparian cover (Marion et al. 2014). In addition, human-related factors that affect water temperature may include runoff from impervious surfaces and releases of water from reservoirs. In some areas, higher water temperatures could put organisms closer to the threshold for their thermal tolerance and exacerbate low dissolved oxygen conditions (Hopkinson et al. 2013). In general, higher water temperatures are expected to have an adverse impact on coldwater fish habitat throughout the Appalachians (Sun et al. 2013), although the impacts will vary geographically. Streams and rivers generally transition to higher average temperatures as water travels downstream. For example, while the headwaters of the Tellico River have cold water that support trout populations, downstream it warms to become warmwater habitat that supports

Brook trout (*Salvelinus fontinalis*) thrive in water temperatures of 65°F or lower – FWS smallmouth bass (*Micropterus dolomieu*) (TWRA 2009). Between these reaches, there is a transition zone that is not well suited for either species due to temperature (TWRA 2009).

In a warming scenario, warmwater species are likely to migrate upstream as water temperatures in the transition zone become more favorable. Ultimately, there is likely to be a loss of coldwater habitat in the upper reaches. The ability for species to migrate upstream will also be affected by the existence of natural and/or anthropogenic barriers such as dams and culverts. Much of the riverine habitat in the Tennessee and Cumberland Rivers was converted to reservoirs in the early 20th century, and many dams and culverts continue to limit movement of species and reduce water quality (TWRA 2014).

Given that reservoirs also support some of Tennessee's aquatic species, impacts of climate change on those systems are also likely to be a factor in their management. In large tributary reservoirs, for example, an increase in water temperatures will negatively affect cool- to coldwater fish habitat, while benefiting warmwater species (TWRA 2009). Some species may be able to retreat to deeper cool water associated with stratification, although excess nutrients may lead to hypoxic or anoxic conditions in those zones. Warmer water may also make rivers and reservoirs more suitable to non-native species that already inhabit waters to the south (TWRA 2009). For example, warmer waters are projected to facilitate the spread of invasive zooplankton such as *Daphnia lumholtzi* in lakes and reservoirs, altering the aquatic food web (Lennon et al. 2001, Fey and Cottingham 2011).

4.2.2.2 Changes in Hydrology

Coupled with other stressors such as water withdrawals and dams, climate change is expected to have a significant impact on the hydrology of Tennessee's lakes, rivers, and streams. Although droughts are historically common in Tennessee and are an important part of interannual habitat variability in rivers, severe droughts could adversely affect already-stressed species by reducing invertebrate production, disrupting fish migrations, and exposing aquatic species to higher water temperatures and lower dissolved oxygen. (TWRA 2009). More-frequent droughts are likely to contribute to more-frequent stream drying events, even in those systems that are considered perennial (Hopkinson et al. 2013). This, in turn, may increase the frequency of local species extirpations. Alternately, changes in the intensity of rainfall events are expected to contribute to higher runoff, erosion, and excessive sedimentation in rivers and streams, particularly in areas where riparian vegetation is limited (Treasure et al. 2008, Sun et al. 2013). In addition, high flows can scour nests and reduce habitat for species such as brook trout (TWRA 2009).

Changes in the timing and magnitude of streamflows affect important and habitat for a number of aquatic species (TWRA 2009). For example, recent research in the Tennessee River basin has found that even small deviations in streamflow can significantly reduce the diversity of fish species within that system (Knight et al. 2014). Climate change is likely to exacerbate other anthropogenic factors, such as water withdrawals, that influence streamflows in Tennessee. The state will need to address significant tradeoffs among competing water uses as climate change contributes to greater variability and extremes in water resources and associated hydrological conditions across the region. If drought conditions become more persistent, as some studies suggest, there is likely to be increased demand for water for municipal, agricultural, and industrial consumption. These uses may increasingly be at odds with maintaining instream flows for navigation, recreation, habitat, and other purposes (EPRI 2009).

4.2.2.3 Wetland Habitat Loss

More than 90% of Tennessee's historic wetlands have been lost, largely due to draining for agriculture or development (TWRA 2014). This includes 80% of the bottomland hardwood wetland forests in the Mississippi Alluvial Plain in Tennessee and other southern states. Freshwater marshes and swamps are highly vulnerable to warming, changes in precipitation and severity of storms, and the frequency and severity of drought (Hopkinson et al. 2013). The combined effects of higher temperatures and changes in precipitation are expected to increase evapotranspiration and reduce stream base flows, which could lead to drying of isolated wetland systems that are important habitat for a variety of plants and animals. Vernal pools are especially vulnerable to climate change since their hydrology is strongly dependent on precipitation and evaporation (Keely and Zedler 1998). Climate change may affect the size of pools as well as the timing under which they fill and dry up, all of which are likely to affect species that rely on these systems for part or all of their life cycle (Graham 2013). Furthermore, because wetlands can play an important role in absorbing floodwaters, the loss of these habitats in some areas may also serve to exacerbate flooding events associated with an increase in the intensity of heavy downpours.

Gum Swamp at Cades Cove when dry – USGS

4.2.2.4 Implications for Wildlife

As with terrestrial species, the impacts of climate change on Tennessee's aquatic fish and wildlife will be considered favorable for some species but adverse for others. For example, as noted above, some cool- and warmwater fish could see an increase in suitable stream and reservoir habitat across parts of the state as average temperatures increase. Conversely, coldwater species are likely to face a loss of habitat.

With many of Tennessee's highly-diverse aquatic species already considered at-risk for a variety of reasons, the additional threat from climate change is likely to exacerbate conservation concerns (TWRA 2009). Indeed, it is the combination of climate change and other stressors such as polluted runoff and barriers to stream connectivity that will have the greatest impact on aquatic habitats and the species that depend on them (Sun et al. 2013). An integrated approach to managing aquatic species and habitats that takes into account multiple stressors, including climate change, will be important to help the state meet is short- and long-term wildlife conservation goals.

4.3 KEY VULNERABILITIES

Drawing from the vulnerabilities for species and habitats highlighted in this section, the Tennessee team undertook a process to winnow down the broad array of concerns to a set of "key vulnerabilities" (see Table 11). Essentially, the key vulnerabilities are those vulnerabilities considered to be the most critical for managers to address given the particular risk they pose to achieving Tennessee's conservation goals and objectives (Stein et al. 2014). In the face of many possible targets for adaptation actions, identification of key vulnerabilities provides a structured means for setting priorities in the development, evaluation, and selection of adaptation strategies and measures.

Table 11. Key vulnerabilities of Tennessee species and habitats

Climate Change Drivers	Potential Impacts	Key Vulnerabilities
Changes in precipitation timing and duration	• Increased frequency, duration, and intensity of drought • Changes to seasonal timing, frequency, and magnitude of moderate and extreme flood events • Changes to habitat availability for different life history stages • Interactions with water quality conditions • Instream flow management response issues	• Low flow/extreme low flow and base flow alteration could result in reduced habitat quality and connectivity for aquatic species. • More-extreme flood events could lead to habitat destabilization (especially in headwater/smaller order streams), affect spawning cues for some species, and interrupt the availability of feeding and nursery grounds. • Increases in stormwater runoff are likely to exacerbate input of excess nutrients and toxicity loading and contribute to altered pH and dissolved oxygen levels. • Extreme droughts could alter habitat availability, including breeding habitat and food sources for birds, spawning habitat for mussels and fish, and vernal pools for amphibians.
Increasing temperatures	• Contributions to terrestrial habitat shifts • Relationship to pest and pathogen spread • Changes to freshwater and cave habitat suitability • Interactions with water quality conditions • Contributions to phenological mismatch	• Thermal habitat suitability is likely to be reduced for a number of aquatic species, especially brook trout, hellbender, and some mussel species. • Increased evaporation is expected to cause drying of vernal pool habitats. • Higher temperatures in caves could harm certain cave fish and bat hibernacula. • Significant shifts in forest habitat types are projected, particularly at higher elevations and in the western portion of the state. • Negative impacts are expected among high-elevation habitat-dependent species such as southern rock vole and Carolina northern flying squirrel. • Spread of pests and pathogens are likely to affect plant and animal species both directly and indirectly. • Phenological mismatch could lead to disruptions in species interactions and mutualisms (e.g., timing of insect emergence and other food sources for birds, fish, and other species).
Altered disturbances (i.e., fire, wind damage, ice storms)	• Contributions to terrestrial habitat shifts • Relationship to spread of invasive species • Damage to habitat	• Increasingly extreme events could have adverse effects on habitat quantity and quality, especially in forest communities. • Altered fire regimes could pose significant challenges for fire management practices.

4.4 SPATIAL VULNERABILITY ANALYSIS FOR TENNESSEE

4.4.1 Overview of Spatial Vulnerability Assessments

Spatial, or geographic, analyses can be useful tools to assess the vulnerability of relevant conservation targets to climate change and associated impacts. Such information can help managers identify priority areas for conservation and can help inform specific management actions based on the underlying factors that contribute to vulnerability (Steel et al. 2011).

There are many ways of assessing vulnerability to climate change across the landscape. Some of the more-common approaches use models to identify potential spatial distribution of species or habitat types based on specific biophysical attributes, ecological processes, and/or other factors that determine where “suitable” climatic conditions for those species or systems may exist in the future. These models range in complexity, from climate envelope models to dynamic ecological models (Hayhoe et al. 2011). Another approach is to use a spatial vulnerability index, a tool that is designed to calculate and display various indicators of vulnerability across a geographical area (Joyce et al. 2008, Anderson et al. 2014, USAID 2014). Often, a combination of approaches will be appropriate.

One way to visualize potential vulnerability of species and habitats of conservation concern is to develop geographic information system (GIS) overlay maps, or “blueprints.” A relatively straight-forward approach is to identify the exposure of existing priority conservation areas to various elements of climate change and associated impacts (e.g., exposure to increasing temperatures, changes in vegetation, or inundation from rising sea levels). For example, Kershner and Mielbrecht (2012) have developed a *Climate-informed Conservation Blueprint* for the Greater Puget Sound ecoregion in Washington State. Their approach combines GIS maps showing areas of predicted future vegetation change (based on MC1 dynamic vegetation model from Bachelet et al. [2001]), areas of biodiversity significance (based on TNC’s ecoregional assessments for Washington), core landscape integrity areas (based on the Washington Wildlife Habitat Connectivity Working Group [WHCWG] Connected Landscapes Project [Washington WHCWG 2010]), and areas with concentrations of focal species (also based on the Washington WHCWG Connected Landscapes Project). With this information, the team was able to identify areas of land that they consider as providing the best opportunities for species and habitats to persist under changing climate conditions, and areas where habitat connectivity could be restored or maintained to facilitate species movements.

As with the CCVI, some caution is warranted when interpreting these types of overlay maps. For example, there often are inconsistencies in the spatial resolution used in the various maps being compared, so the degree to which focal areas across different maps overlap are likely to be inexact. In addition, uncertainties can exist in the underlying data, ranging from the various levels of accuracy and resolution of the maps to the complexity, assumptions, and uncertainties associated with climate and ecological response models. As such, these maps may be most appropriate for planning at a relatively-coarse scale (Kershner and Mielbrecht 2012).

The following is a preliminary analysis for Tennessee that draws from the approaches used by Joyce et al. (2008), Kershner and Mielbrecht (2012), and Anderson et al. (2014), with a focus on terrestrial habitats and associated species. The assessment is based on several existing datasets and maps, including:

- Terrestrial Habitat Priority areas in Tennessee (TWRA 2015);
- Areas in Tennessee predicted to experience vegetation change using the MC2 dynamic vegetation model (Bachelet et al. 2014);
- Areas rated using the Terrestrial Climate Stress Index (USDA Forest Service *in press*, Joyce and Flather *personal communication*); and
- Areas rated using the Resilient Sites for Terrestrial Conservation approach (Anderson et al. 2014).

4.4.2 Foundational Maps for Tennessee

This section describes the spatial analyses created for understanding different attributes of Tennessee's landscape. These separate analyses were then overlaid in a "blueprint" fashion to ascertain landscape-level patterns that provide important context for decision-making on desired conservation outcomes and potential climate adaptation strategies.

4.4.2.1 Terrestrial Habitat Priority Areas

TWRA and TNC, with input from a variety of technical experts, developed a methodology for mapping priority habitat areas for all GCN species in the state (TWRA 2015). For terrestrial species, the methodology included the following basic steps:

1) Assignment of expert-derived habitat preference ratings for each GCN species to NatureServe ecological systems, as mapped by the 2008 Southeast Gap Analysis Project (http://www.basic.ncsu.edu/segap (accessed September 8, 2015);
2) Calculation of a priority score for each GCN species using data on how recently the species were recorded in each location combined with relevant rarity designations (e.g., G- and S-Rank and federal and state legal listing status); and
3) Modeling potential habitat occupancy based on species observation records and NatureServe information on relative dispersal abilities to calculate that species' footprint.

To develop the habitat priority maps, the GCN prioritization scores were combined with the species footprint and their habitat preference scores. For more information on this methodology, see TWRA 2015 and Palmer and Wisby 2015.

Figure 16 shows the Terrestrial Habitat Priority areas for Tennessee. The darker-green colors indicate higher habitat priority areas, while the yellow-green colors indicate the lower habitat priorities. Areas shaded dark gray denote developed/urbanized land. Identification of these habitat priorities was a key step in the selection of locations defined as Conservation Opportunity Areas (COAs), which has become a valuable step for many states as they revise and implement their SWAPs (AFWA 2012). Essentially, COAs are areas that represent the greatest potential for conservation of GCN species, as determined by the state. They are intended to help guide and improve the outcomes of species and habitat conservation efforts and facilitate outreach and coordination with relevant partners across the state. The concept for identification of COAs in Tennessee has been to find important intersections between habitat priority areas, the types and severity of stressors affecting those habitats, and key opportunities to act (TWRA

2015). As Tennessee continues to integrate climate change into its conservation efforts, the information presented in the report should serve as a useful tool to inform the COA management process.

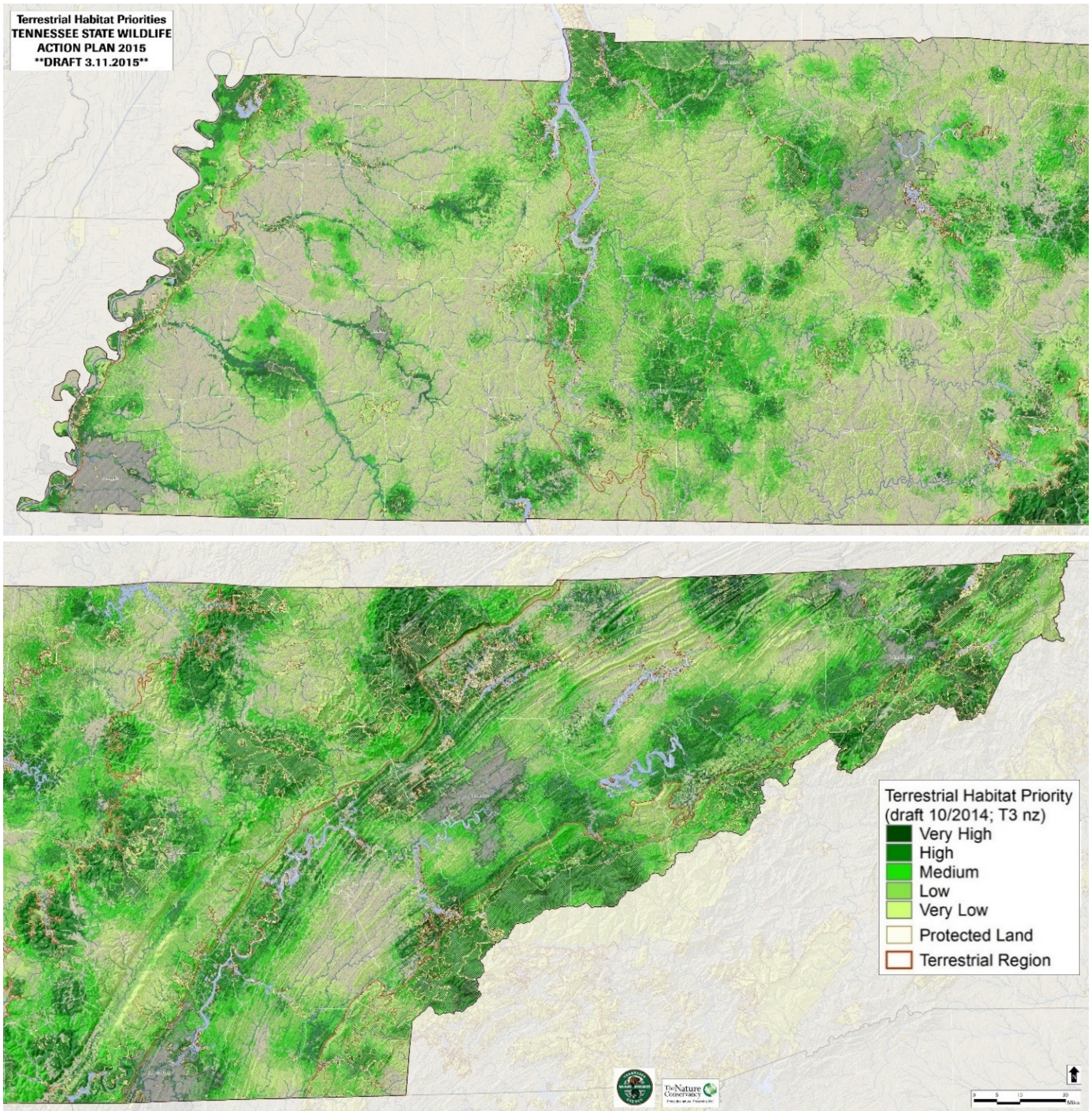


Figure 16. Terrestrial Habitat Priorities for western (upper map) and eastern (lower map) Tennessee (TWRA 2015). The areas shaded in the darkest green scored as Very High habitat priorities, while the areas shaded in yellow-green scored as Very Low priorities. Areas in dark gray denote developed/urbanized land.

4.4.2.2 Vegetation Change Analysis using the MC2 Dynamic Vegetation Model

As discussed previously, climate change is expected to contribute to changes in the composition of major vegetation types across the state. One model used to assess such changes is MC2 dynamic global vegetation model, which simulates potential changes in the distribution of dominant vegetation types (i.e., deciduous-evergreen trees and C3-C4 grasses) across biogeographical regions based on projected changes in climate and associated variables (Bachelet et al. 2001, Bachelet et al. 2014). Specifically, the model identifies areas in which certain vegetation types are likely to reach ecological thresholds that lead to shifts from one functional vegetation type (e.g., Temperate Deciduous Broadleaf Forest) to another (e.g., Temperate Warm Mixed Forest) by simulating biochemical processes associated with carbon and nutrient dynamics including plant production, solid organic matter decomposition, and water and nutrient cycling, and the occurrence, behavior, and impacts of severe fire. The model can be run with or without a fire suppression algorithm to identify potential changes under alternative fire management scenarios.

Researchers at the U.S. Forest Service Rocky Mountain Research Station have applied MC2 across the United States (Joyce and Flather *personal communication*, USDA Forest Service *in press*). For this assessment, the authors have parsed out data for the Tennessee (Joyce and Flather *personal communication*). MC2 was run using climate projections from three global climate models (UKMO HadCM3, CSIRO-MK3.0, and MIROC) from the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC 2007) under three Special Report on Emissions Scenarios (SRES)[1]: A1B, A2, and B1. The specific projections for vegetation changes (e.g., areas where vegetation shifts from Temperate Deciduous Broadleaf Forest to Temperate Warm Mixed Forest or Temperate Evergreen Needleleaf Forest) vary across models and emissions scenarios due to differences in model projections for temperature and precipitation changes for the region.

Figure 17 shows results of the vegetation change projections for the period 2050-2099, compared to the baseline period 1950-1999, with an assumption of no fire suppression efforts (USDA Forest Service *in press*, Joyce and Flather *personal communication*). The scale here is an equal area hexagon grid with each cell approximating an area of approximately 69 km^2. The map highlights the number of times the vegetation changes from the historical type across nine projections using the three climate models and three emissions scenarios. The warmer colors (reds) show areas where vegetation changes under most or all of the models and scenarios run (i.e., areas that more likely to undergo a shift in dominant vegetation type under climate change), while the cooler colors indicate areas where little or no change in vegetation occurs. From this, one may infer that vegetation types in the northeastern portion of Tennessee are generally less vulnerable to change under future climate conditions than those in the southern and southwestern portions of the state.

[1] The suite of climate change scenarios on which many projections are based come from a set of scenarios developed by the IPCC SRES (Nakicenovic and Swart 2000). The scenarios span a range of possibilities for future greenhouse gas emissions based on estimates for things like population growth, economic activity, technological advances, and policy measures (with A1T, B1, and B2 suggesting a lower-range of emissions and A1B, A2, and A1FI suggesting higher emissions). Importantly, given current and near term emissions projections, the lowest emissions scenarios are looking to be less-plausible. In fact, recent emissions trajectories have been higher than those in the IPCC's highest emissions scenario, A1FI. Strong international emissions reductions initiatives would allow for more moderate trajectories such as the IPCC's A2 and A1B scenarios.

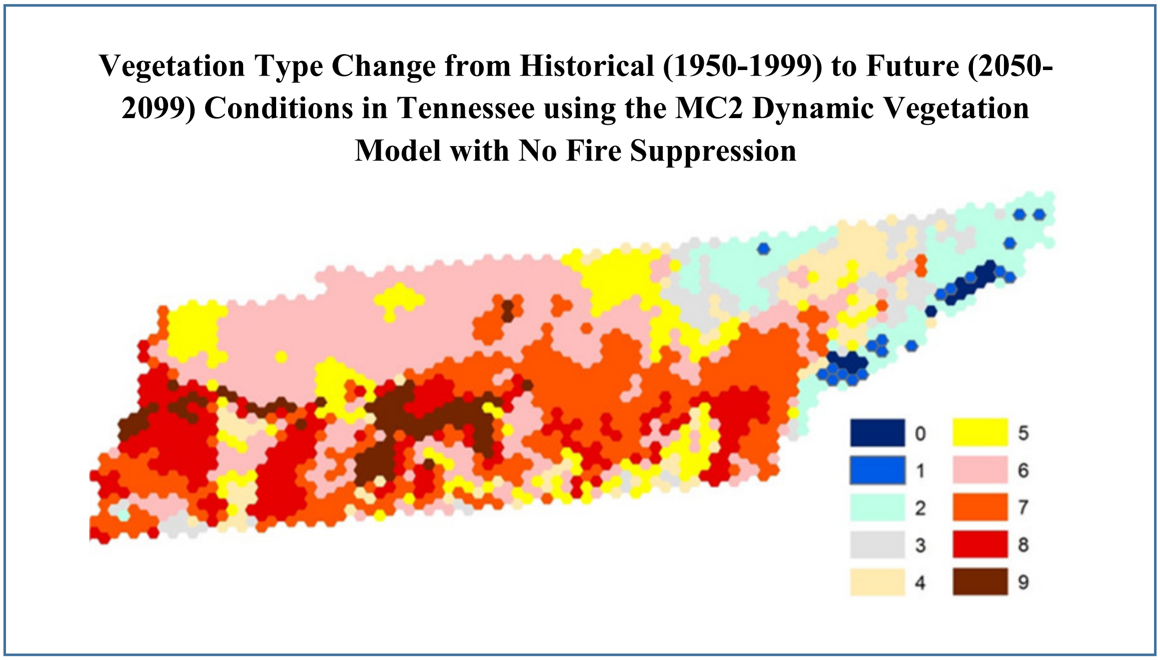


Figure 17. Results of the analysis of vegetation type change in Tennessee using the MC2 model (Joyce and Flather *personal communication*). The colors indicate the number of times vegetation changed from the historical (1950-1999) type to the future (by 2050-2099) across nine projections (three GCMs and three emission scenarios: A2, A1B, and B1), with a model assumption of no suppression of fire. The dark blue (0) = future vegetation types remained unchanged from historical under all scenarios; brownish-red (9) = future vegetation always changed from historical.

When interpreting the model results for management decisions, it is important to recognize some limitations. One is that the vegetation change analysis does not incorporate land use as a factor in determining availiability of habitat. In many areas, including Tennessee, land use for agriculture and development are likely to have a significant impact on the ability for both plants and animals to disperse across the landscape (USDA Forest Service 2012). Furthermore, the MC2 model does not simulate changes in wetland vegetation types, which are important habitat for a range of species and may be especially vulnerable under warmer, drier conditions. Supplementing analyses such as this with additional information, where available, will enhance relevant decisions-making processes.

4.4.2.3 The Terrestrial Climate Stress Index (TCSI)

The Terrestrial Climate Stress Index (TCSI) identifies areas of stress across target geographical areas based on a sum of separate terms that reflect projected changes in mean annual temperature and precipitation (the climate regime), associated changes in biomass production (an indicator of habitat quality), and climate-induced distribution shifts in broad vegetation types (an indicator of habitat area) across target geographical areas (Joyce et al. 2008, USDA Forest Service 2012, USDA Forest Service *in press*). The projected changes in biomass and vegetation were obtained from an application of the dynamic global vegetation model MC2, described above.

The TCSI is an indication of the degree of change in these key factors between recent history and the projected future (Joyce et al. 2008, USDA Forest Service 2012, USDA Forest Service *in press*). Mean scores are estimated for each grid cell in the target area across a set of various emissions scenarios, climate models, and assumptions about the effects of CO_2 on plant growth. The mean TCSI score represents the average result across the range of potential alternative futures.

In its applications to date, the index scores have been ranked using a percentile approach to indicate areas with the greatest change under future climate change (2050-2099) when compared to the baseline period (1950-1999). High stress is defined as the top 20 percent highest scoring grids in the TCSI over the study area, while low stress areas are the 20 percent grids with lowest scores. The areas are then mapped across the relevant study region according to the relative scores.

For this analysis (hereafter called the modified TCSI), the mapping methodology was revised from the percentile approach to a normalized approach that takes the average of: 1) percentile rank, and 2) normalized TCSI value. The resulting index is on a 0-100 scale, as both input scores and percentages. The TCSI scores were then categorized using ArcGIS's Natural Breaks (i.e., Jenk's Optimization) classification. This is the same approach used for the habitat priority stratification (highlighted above) and is closer to the approach used for the Resilient Sites analysis (described below), making the associated maps more comparable. Figure 18 shows the modified TCSI results for Tennessee under the A1B emissions scenario. Areas in green reflect the low stress scores, and areas in red high scores.

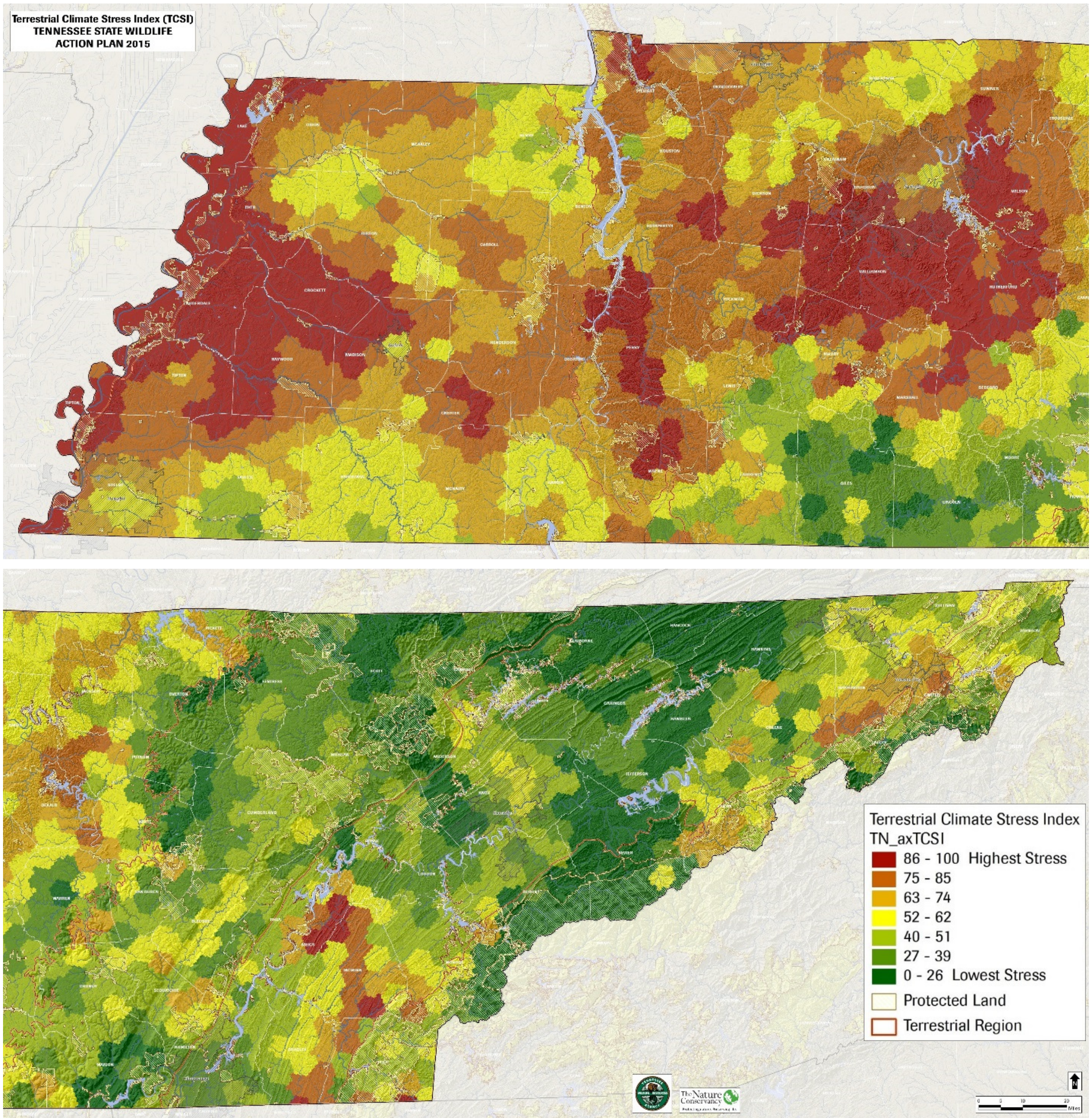


Figure 18. Results of the modified Terrestrial Climate Stress Index (TCSI) application for western (upper map) and eastern (lower map) Tennessee. Areas in green reflect low stress scores, and areas in red high stress scores (adapted from Joyce and Flather *personal communication*).

4.4.2.4 Resilient Sites for Terrestrial Conservation

The Resilient Sites for Terrestrial Conservation was developed to facilitate the identification of terrestrial areas that are expected to continue to support high levels of biodiversity under changing climate conditions given a variety of ecologically-relevant physical landscape features (Anderson et al. 2014).

This approach is drawn from the strong correlation between species diversity and geographical diversity in the eastern United States (Anderson and Ferree 2010). In topographically-complex landscapes, for example, species may be able to take advantage of micro-climates that either remain or become suitable as ambient climate conditions change (Weiss et al. 1988). Species may also be able to physically move to adjust to climatic changes if the landscape features of an area are permeable and connected. Accordingly, ratings of resilience are based on factors associated with physical complexity of the area (i.e., landform variety, elevation range, and wetland density) and its permeability (local connectedness and regional flow patterns, based on existence and extent of both anthropogenic and natural barriers).

Under this framework, resilience to climate change and its converse, vulnerability, are relative concepts, not absolute thresholds. Relative vulnerability scores are stratified across the various geophysical settings within natural ecoregions. In its application of the Resilient Sites framework for the Southeast Region (Anderson et al. 2014), TNC used the ecoregions identified in Figure 19. This ecoregional stratification process is important because natural landscape features vary greatly ecoregion by ecoregion; therefore, the potential resilience of an area should be compared relative to similar areas within the same ecoregion. Sites are considered more or less resilient as represented by standard deviations from the average overall resilience score for their ecoregion. More-resilient sites identified by this analysis are hypothesized to offer greater adaptive capacity by providing features such as more-diverse microclimates and greater overall habitat. Less-resilient sites are already highly fragmented or have a lower potential for providing a diversity of microhabitats over time.

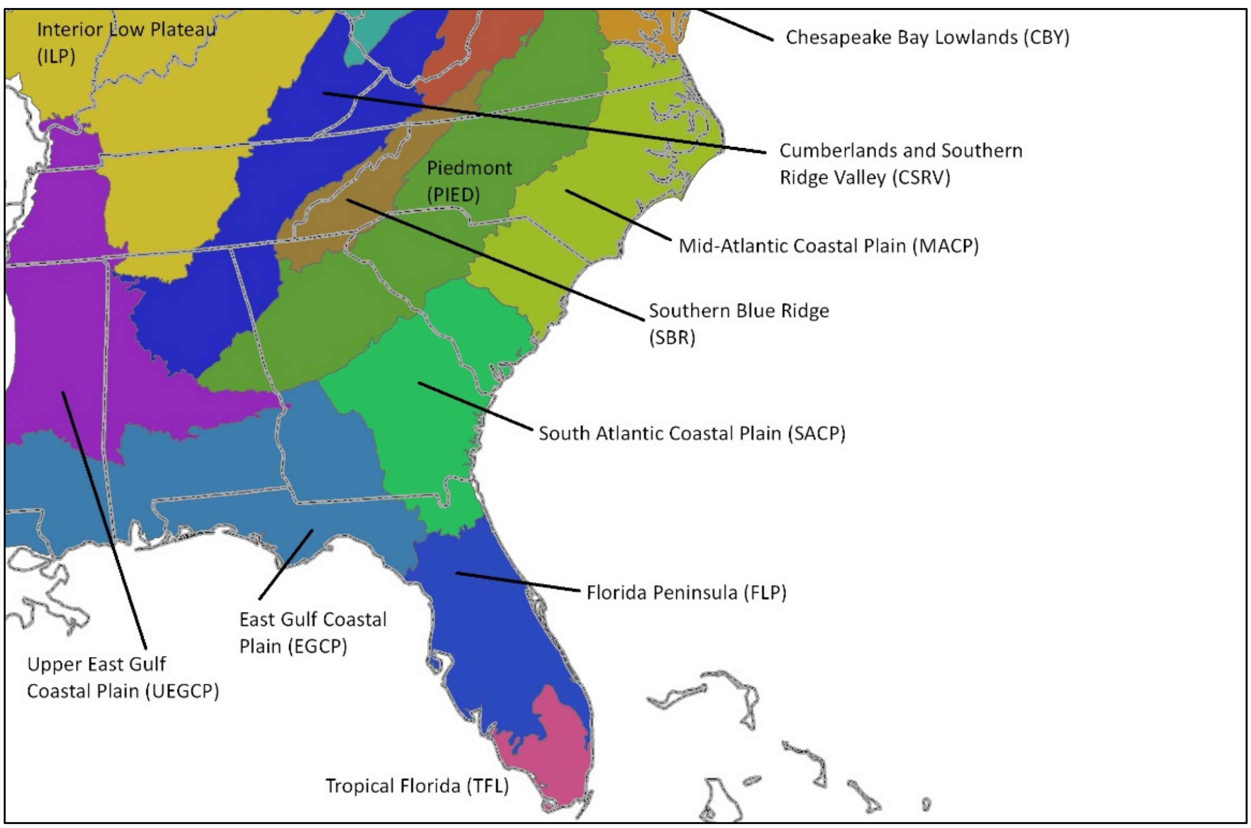


Figure 19. Southeastern ecoregions (https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/PublishingImages/ED_rotator_Ecoregions.jpg, accessed June 18, 2015).

Figure 20 shows estimated resilience of sites for Tennessee stratified by ecoregion. For this analysis, the geophysical settings were assessed at 30-meter resolution and interpreted as 100-acre hexagons. Areas whose score is far below the average (shown in dark brown) are considered more vulnerable relative to the average for the ecoregion, and those far above average (in dark green) are more resilient relative to other sites containing that geophysical setting within the same ecoregion.

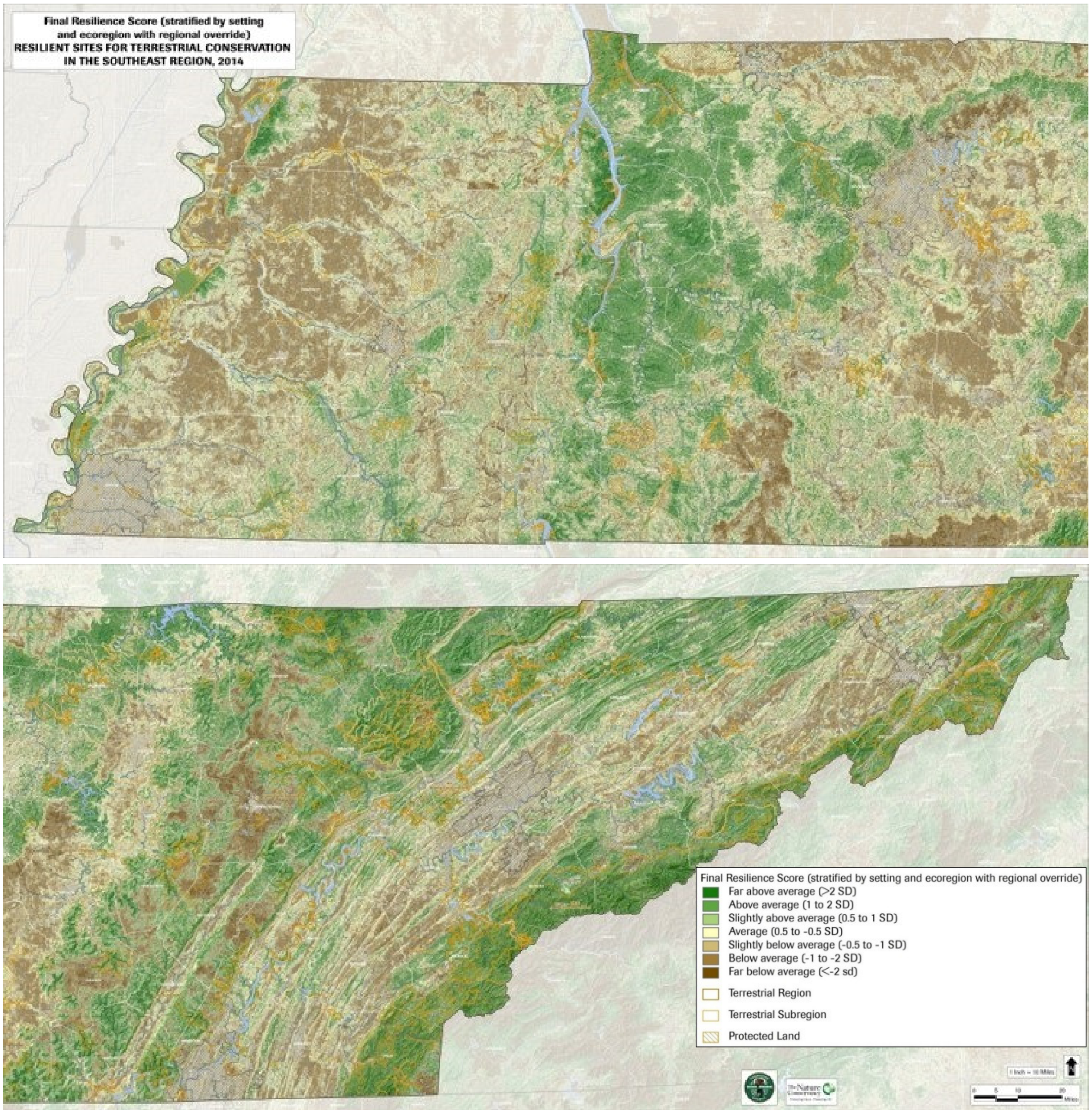


Figure 20. Resilient Sites for Terrestrial Conservation scores for western (upper map) and eastern (lower map) Tennessee, stratified by geophysical setting and ecoregion. Areas whose score is far below the average (shown in dark brown) are considered most vulnerable, and those far above average (in dark green) are most resilient (adapted from Anderson et al. 2014).

4.4.3 Overlay Maps for Tennessee

The maps that follow are intended to provide landscape-scale information for managers as they define conservation outcomes and identify climate adaptation options within the SWAP and other resource management planning efforts. The maps identify where projected changes in major vegetation types coincide with areas currently providing high-priority terrestrial habitat for GCN species, as well as helping discern which regions provide more or less landscape resilience and potential adaptive capacity.

4.4.3.1 Overlay of Terrestrial Habitat Priority Areas and the Modified Terrestrial Climate Stress Index (TCSI)

Figure 21 presents an overlay of the state-level modified TCSI results and Tennessee's Terrestrial Habitat Priority areas. Here, high priority habitats showing high TCSI risk are shown in darker red; medium priority habitats at moderate TCSI risk are darker yellow, and so forth (as indicated in the legend). Darker green areas are those considered to be high habitat priority but have lower TCSI risk.

In general, Southern Floodplain Hardwood Forest areas along the Mississippi River Alluvial Plain and parts of the Upper Gulf Coastal Plain, and areas of Southern Central Mixed Deciduous Evergreen Broadleaf Forest, Central Oak Hardwood and Pine Forest, and glade and barrens habitats in the Interior Low Plateau have the greatest concentration of high priority habitat areas overlapping with those scoring as high stress under TCSI. The forested areas of the Cumberland and Southern Ridge and Valley and Southern Blue Ridge ecoregions encompass most of the high habitat priority areas with lower TCSI scores.

This information may help inform a variety of different management choices. For example, those areas identified as high terrestrial habitat priorities projected to experience relatively low climate-induced stress (dark green on the map) could point to possible refugia, where terrestrial vegetation and other conditions may continue to provide favorable habitat for associated GCN species over time. In habitat priority areas that face higher relative climate stress, managers may need to tailor conservation actions to reduce factors associated with that climate stress, such as reducing vulnerability to fire or other disturbances that may accelerate changes in associated vegetation types, or placing greater emphasis on supporting desired ecological functions rather than specific species assemblages.

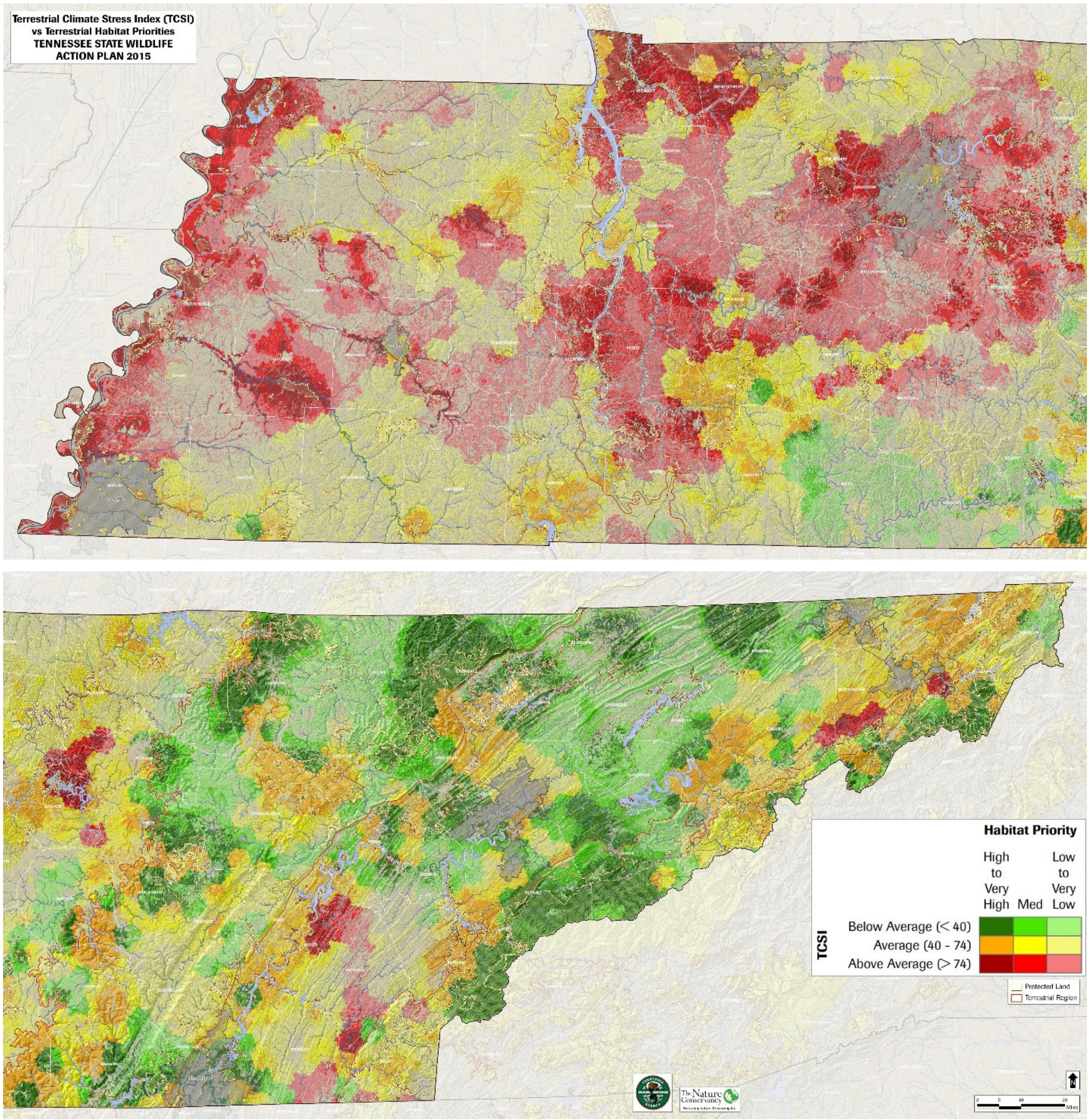


Figure 21. Overlay of the modified TCSI and Terrestrial Habitat Priorities for western (upper map) and eastern (lower map) Tennessee. High priority habitats also ranked as high TCSI risk are shown in darker red; high priority habitats ranked as low TCSI risk are in darker green.

4.4.3.2 Overlay of Terrestrial Habitat Priority Areas and Resilient Sites for Terrestrial Conservation

Figure 22 shows an overlay of the Resilient Sites for Terrestrial Conservation and the Terrestrial Habitat Priority areas for Tennessee. Here, areas highlighted in darker green are high habitat priorities that coincide with relatively-high (above-average) landscape resilience scores. Areas in yellow to light orange are medium- to high-priority habitats with average resilience scores. Areas in darker red indicate places of high habitat priority currently, but that have below-average landscape resilience and therefore may be more vulnerable to change over time.

As with the modified TCSI and Terrestrial Habitat Priorities comparison, these maps can provide insights as to how climate change might influence conservation priorities and actions. There are a number of areas that are identified as both high habitat priorities and resilient sites (the darkest green), which indicates that these sites may continue to be important areas to maintain for biodiversity moving forward. Implementing conservation efforts across a diverse portfolio of these sites is likely to increase the probability of their persistence over time (Anderson et al. 2014).

However, there also are a number of areas that have been identified as high habitat priorities but appear more vulnerable. In these cases, managers may need to investigate some of the underlying reasons for that vulnerability, such as low connectedness, for which specific conservation actions such as elimination of anthropogenic barriers or expansion of open space might be useful. Similarly, there are areas currently identified as very low habitat priorities but that score far above average on the resilience scale (light green). Ultimately, some of these areas may warrant reconsideration as a focus of conservation efforts depending on a variety of factors including (but not limited to) local site conservation objectives or regional connectivity goals (Anderson et al. 2014).

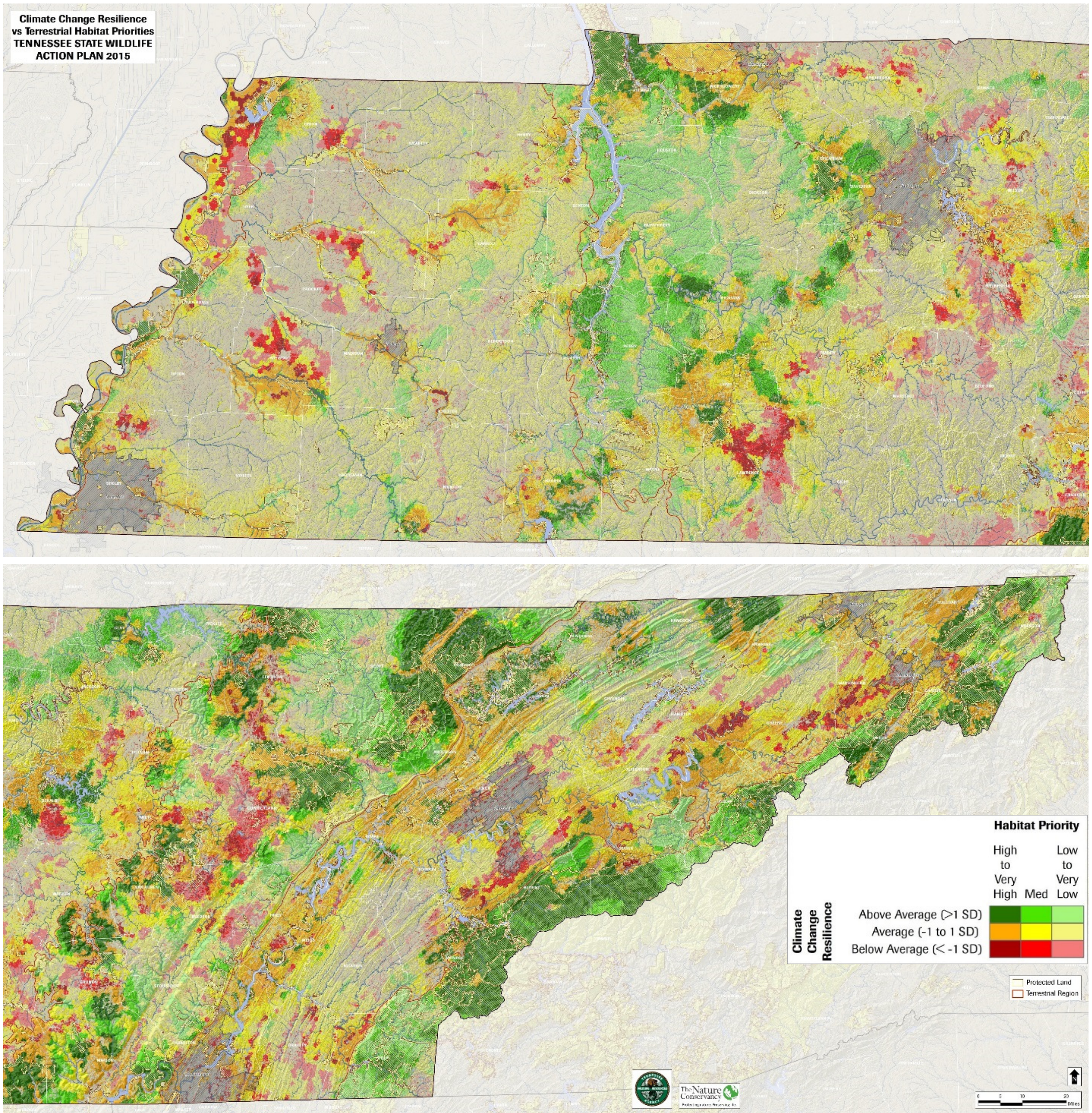


Figure 22. Overlay of Resilient Sites for Terrestrial Conservation with Terrestrial Habitat Priority areas for western (upper map) and eastern (lower map) Tennessee. The darkest green areas are those identified as both high habitat priorities and resilient sites, while areas shaded in pink are low resilience and low habitat priority.

4.4.3.3 Overlay of the Modified Terrestrial Climate Stress Index and Resilient Sites for Terrestrial Conservation

Figure 23 compares areas where relative changes in vegetation types and biomass production are expected under future climate conditions, as indicated by the modified TCSI, with their resilience scores calculated by the Resilient Sites for Terrestrial Conservation approach. Areas with low landscape resilience scores and high TCSI ranking are shown in dark red. The dark green areas indicate high landscape resilience and low TCSI scores.

The Mississippi Alluvial Plain and central portions of the Interior Low Plateau surrounding Nashville show both low landscape resilience and high TCSI scores, indicating that vegetation types and biomass production are likely to change in these regions and the characteristics of the surrounding landscapes do not necessarily provide a high level of connectivity or geophysical diversity. On the other hand, areas with lower TCSI scores and higher resilience are found in the Blue Ridge Mountains, Cumberland Mountains, and sections of the Cumberland Plateau and northern Ridge and Valley. These regions of the state are generally forested landscapes with a high degree of landscape complexity and connectivity, and the TCSI results indicate they may be less at risk for major vegetation type changes in the coming decades.

Areas in yellow demonstrate interesting differences in the information provided by the TCSI and landscape resilience scores. For example, forested areas along the Western Highland Rim of the Interior Low Plateau ecoregion score relatively high on landscape resilience (for detailed reference, see Figure 20), but according to the TCSI are projected to experience a higher risk of major vegetation type change. Further consideration of this information in conjunction with more local site and field monitoring data may help resource managers develop strategies to protect the current intactness of the landscape, but deploy management activities that help facilitate species and habitat transitions and utilization of potentially-available microhabitats.

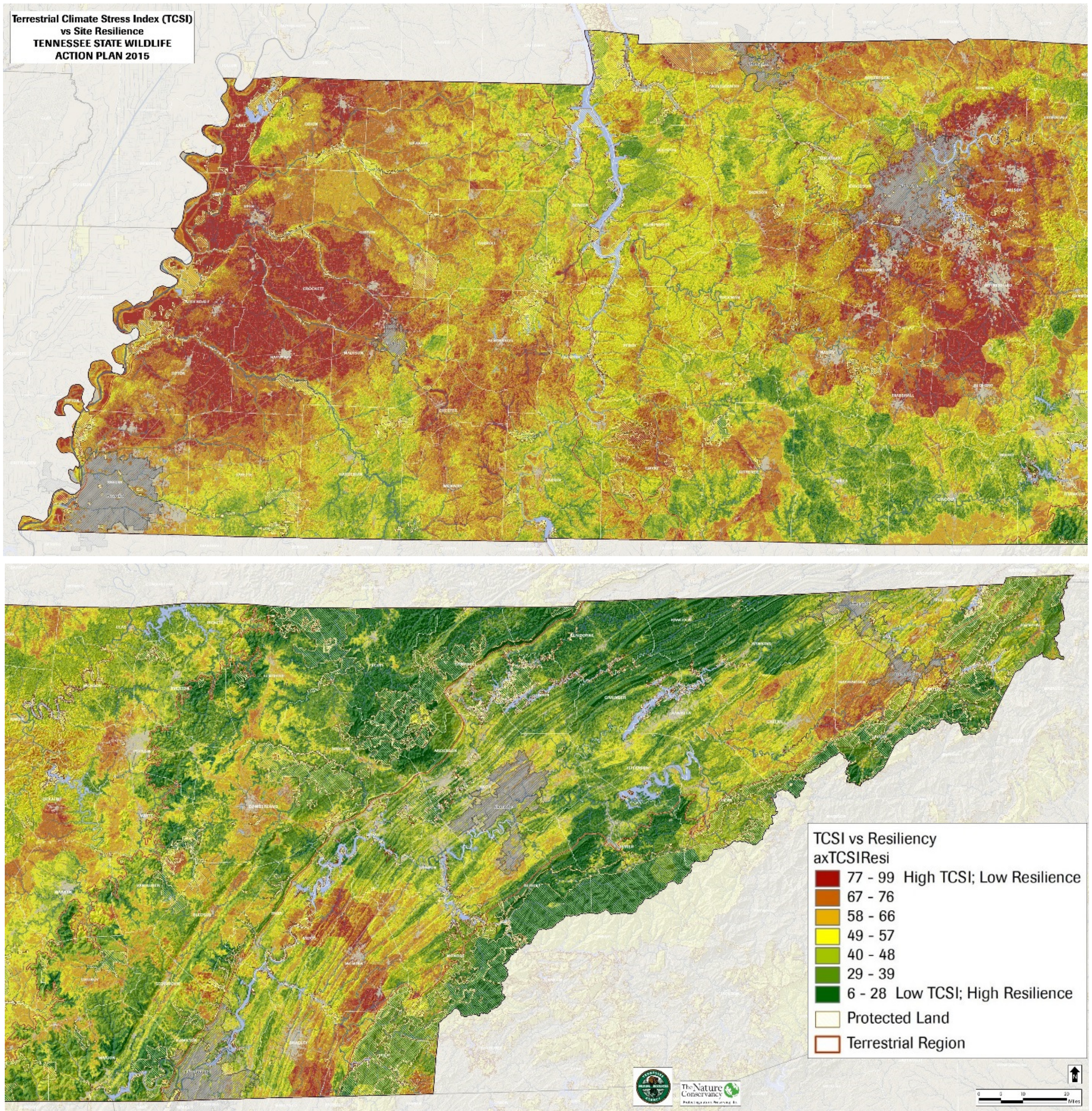


Figure 23. Overlay of the modified TCSI and Resilient Sites for western (upper map) and eastern (lower map) Tennessee. The darkest red areas are those identified as having low resilience and high TCSI scores, while areas shaded in dark green are areas with high resilience and low TCSI scores. The yellow areas indicate places where there are either contradictory scores (e.g., high TCSI and high resilience) or where both scores are in the mid-range of their respective values.

4.4.3.4 Overlay of Terrestrial Habitat Priorities, the Modified Terrestrial Climate Stress Index, and Resilient Sites for Terrestrial Conservation

Figure 24 compares the results of the modified TCSI and Terrestrial Habitat Priorities overlay analysis for Tennessee with the Resilient Sites and Terrestrial Habitat Priorities overlay. Dark red indicates high-priority terrestrial habitat in areas identified as having low potential landscape resilience and face high ratings of TCSI stress. These include habitats in far western Tennessee along the Mississippi Alluvial

Plain and parts of central Tennessee in the Interior Low Plateau, but there are also several such areas in agriculturally-fragmented parts of eastern Tennessee. These results suggest that current areas of high-priority terrestrial habitat in some regions of the state may face greater degrees of stress and change. On the other hand, places that are identified as resilient and face relatively low TCSI stress (shaded in dark green), such as the forests of the Cumberland and Smoky Mountains, appear especially promising as refugia.

This type of information is significant, as managers must make informed choices about what conservation outcomes may be feasible in different locations and what types of management and monitoring activities are likely to be most useful for managing change given longer-term and larger-scale regional projections.

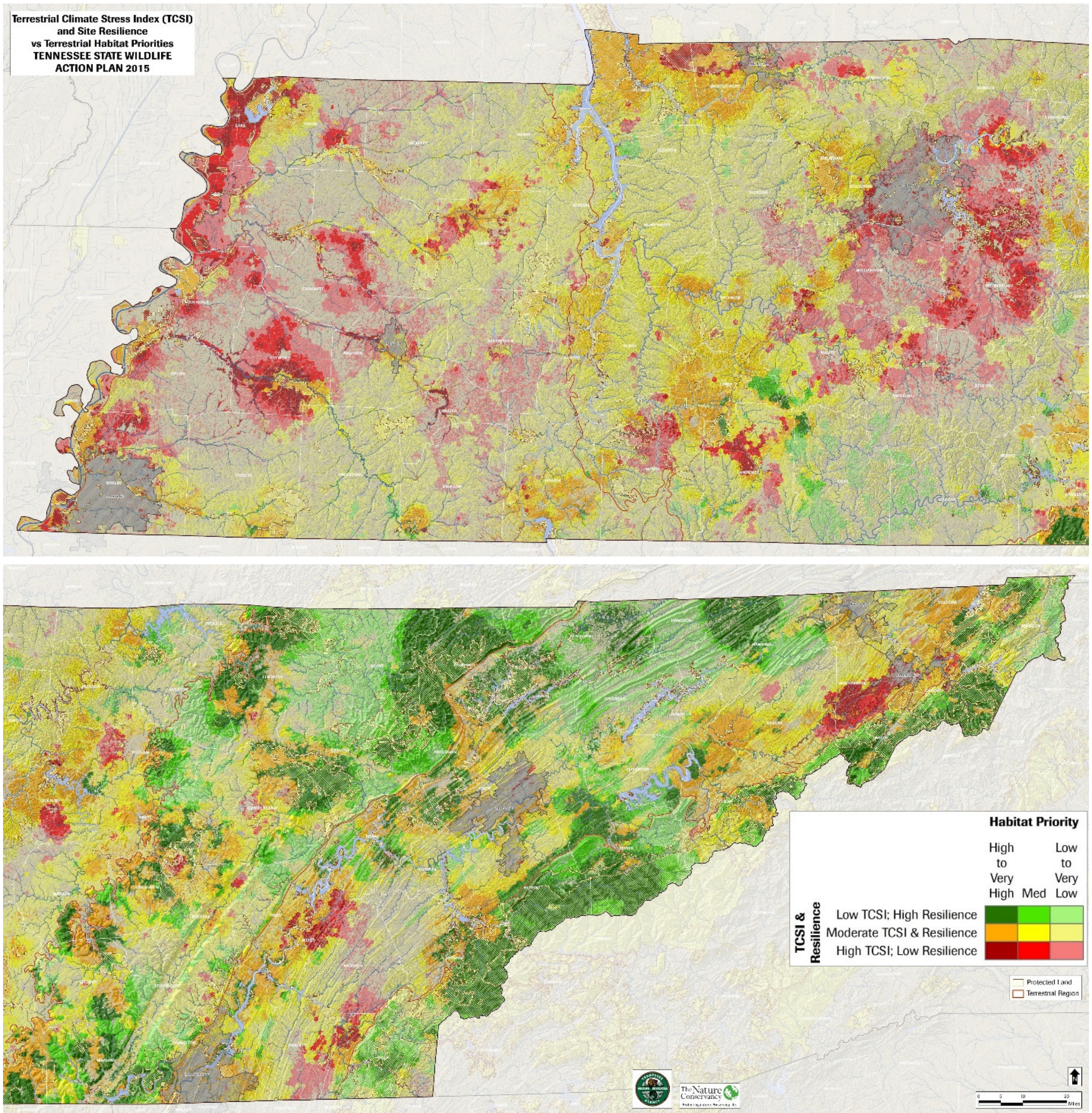


Figure 24. Overlay of Climate Change Resilience/Terrestrial Habitat Priority sites with modified TCSI/Terrestrial Habitat Priority areas for western (upper map) and eastern (lower map) Tennessee. The darkest green areas are those identified as high habitat priorities, resilient sites, and having low TCSI scores, while areas shaded in dark red are high habitat priorities and rank as having low resilience and high TCSI.

5 CONCLUSION

Tennessee's fish and wildlife are treasured by the millions of people who call the state home or visit each year. With the growing recognition that climate change is playing an increasingly-significant role in the fate of the region's ecological systems, the state has an important opportunity to build on its conservation successes to date as well as incorporate new information that might affect its conservation goals.

The results of the climate change vulnerability assessment highlighted in this report will play a crucial role in helping Tennessee shape meaningful strategies to address the additional conservation challenges posed by climate change in its ongoing efforts to protect the state's rich biodiversity. Ultimately, addressing climate change will help improve the forecast for Tennessee's species and habitats and ensure that the many benefits they provide for society will endure for generations to come.

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APPENDIX A. DESCRIPTIVE TABLES FOR THE CLIMATE CHANGE VULNERABILITY INDEX (CCVI)

The CCVI uses a scoring system that integrates projected direct exposure to climate change (Table 12) with three sensitivity factors: 1) indirect exposure to climate change (Table 13); 2) species-specific sensitivity factors (Table 14); and, where available, 3) documented responses to climate change (Table 15). A numeric sum of the scores for each component is then converted into a categorical score by comparing it to threshold values (Table 16).

Table 12. CCVI direct exposure factors

This category allows for analysis of the percentage of a species' range that is likely to be associated with specific changes in temperature or precipitation/moisture conditions under scenarios of modeled future climate change. Typically, this data is at a relatively-coarse scale using data from the tool ClimateWizard.

Temperature	The percent of a species' range in five categories of increasing temperature based on ClimateWizard projections for 2050. Typically, assessments are based on the results of the Model Ensemble Average for the IPCC SRES A1B emissions scenario.	>5.5° F (3.1° C) warmer (compared to 1961-1990 baseline)
		5.1-5.5° F (2.8-3.1° C) warmer
		4.5-5.0° F (2.5-2.7° C) warmer
		3.9-4.4° F (2.2-2.4° C) warmer
		<3.9° F (2.2° C) warmer
Moisture	The percent of species' range in six categories of changing moisture regime based on ClimateWizard projections for 2050. These figures represent the predicted change in annual moisture based on the Hamon AET:PET Moisture Metric (the ratio of actual evapotranspiration, or AET, to potential evapotransporation, PET), rather than changes in precipitation. Negative values indicate net drying: no areas of the contiguous U.S. are predicted to increase in annual moisture.	<-0.119 (a significant change)
		-0.097 - -0.119
		-0.074 - -0.096
		-0.051 - -0.073
		-0.028 - -0.050
		>-0.028 (an insignificant change)

Table 13. CCVI indirect exposure factors

Within the CCVI framework, indirect exposure factors are those changes that are not directly associated with changing climate conditions (e.g., temperature and precipitation) but, rather, those that may result from such direct changes. This category also includes several factors that one might consider elements affecting the adaptive capacity of a particular species (e.g., physical barriers to dispersal). This is also where one might consider any ancillary effects that human response to climate change might create. These may be positive, such as protection of forests or other natural areas to enhance carbon sequestration, or negative, such as developing wind farms in important bird or bat migration corridors or damming rivers for new freshwater reservoirs.

Exposure to sea-level rise	This factor comes into play only in the case that all or a portion of the range within the assessment area may be subject to the effects of a 0.5-1m sea-level rise and the consequent influence of storm surges.

Distribution relative to natural barriers	This factor assesses the degree to which natural (e.g., topographic, geographic, ecological) barriers limit a species' ability to shift its range in response to climate change. Species for which barriers would inhibit distributional shifts with climate change-caused shifts in climate envelopes likely are more vulnerable to climate change than are species whose movements are not affected by barriers.
Distribution relative to anthropogenic barriers	This factor assesses the degree to which anthropogenic barriers (e.g., roads, urban areas or agricultural areas, seawalls, dams, and culverts) limit a species' ability to shift its range in response to climate change. Species for which barriers would inhibit distributional shifts with climate change-caused shifts in climate envelopes likely are more vulnerable to climate change than are species whose movements are not affected by barriers. NatureServe suggests assessing the intensity of landuse in the assessment area and in the direction of expected species movements using the Wildland-Urban Interface of the Silvis Lab. Users can also use the National Land Cover Dataset from the Multi-Resolution Land Characteristics Consortium.
Predicted impacts of land use changes due to human response to climate change	Strategies designed to mitigate or adapt to climate change have the potential to affect very large areas of land, and the species that depend on these areas, in both positive and negative ways. This factor is not intended to capture habitat loss or destruction due to other on-going human activities, which are already considered in existing conservation status ranks.

Table 14. CCVI sensitivity factors	
CCVI sensitivity factors refer to characteristics of the particular species being assessed. Some of the factors may, in fact, be considered elements of adaptive capacity as described previously, but here they are relevant to more "intrinsic" elements of adaptive capacity. Extrinsic factors (e.g., anthropogenic or natural barriers to dispersal) are considered in the previous category of assessment variables.	
Dispersal and movements	This pertains to known or predicted dispersal or movement capabilities and characteristics and ability to shift location in the absence of barriers as conditions change over time as a result of climate change. In general, species with poor dispersal ability are likely to be more vulnerable to climate change than those that regularly disperse or move long distances. Specific "barriers" to dispersal (both natural and anthropogenic) are considered as elements of indirect exposure (above).
Sensitivity to changes in temperature	This pertains to the breadth of temperature conditions within which a species is known to be capable of reproducing, feeding, growing, or otherwise existing. Factors evaluated include the **historical thermal niche** (exposure to past variations in temperature, as approximated by mean annual precipitation variation across occupied cells in the assessment area) and the current **physiological thermal niche**.
Sensitivity to changes in precipitation, hydrology, and moisture regime	This pertains to the breadth of moisture conditions within which a species is known to exist. Factors evaluated include the **historical hydrologic niche** (exposure to past variations in precipitation) and **current hydrologic niche** (which pertains to a species' dependence on a narrowly-defined precipitation/hydrologic regime, including strongly seasonal precipitation patterns and/or specific aquatic/wetland habitats or localized moisture conditions that might be vulnerable to loss or reduction with climate change).
Dependence on a specific disturbance regime likely to be affected by climate change	This pertains to a species' response to specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events. It includes disturbances that affect species directly as well as those that affect species via abiotic aspects of habitat quality.

Dependence on ice, ice-edge, or snow-cover habitats	This pertains to a species' dependence on habitats associated with ice or snow throughout the year or seasonally.
Restriction to uncommon geological features or derivatives	This pertains to a species' need for a particular soil/substrate, geology, water chemistry, or specific physical feature (e.g., caves, cliffs) for reproduction, feeding, growth, or otherwise existing for one or more portions of the life cycle. It focuses on the commonness of suitable conditions for the species on the landscape, as indicated by the commonness of the features themselves combined with the degree of the species' restriction to them.
Dependence on other species to generate habitat	Habitat here refers to any habitat (e.g., for reproduction, feeding, hibernation, seedling establishment, etc.) necessary for completion of the life cycle, including those only used on a seasonal basis.
Dietary versatility (animals only)	This pertains to the diversity of food types consumed by animal species. Dietary specialists are more likely to be negatively affected by climate change than species that readily switch among different food types.
Pollinator versatility (plants only)	This pertains to the degree to which plants are dependent on one or multiple species for pollination.
Dependence on other species for propagule dispersal	This can be applied to plants or animals (e.g., fruit dispersal by animals). If the propagule-dispersing species is vulnerable to climate change, the dependent species is likely to be so as well.
Other interspecific interaction factors	This may include factors other than habitat, seedling establishment, diet, pollination, or propagule dispersal, such as mutualism, parasitism, predator-prey relationships, etc.
Measured genetic variation	Species with less standing genetic variation will be less able to adapt because the appearance of beneficial mutations is not expected to keep pace with the rate of 21st century climate change.
Occurrence of bottlenecks in recent evolutionary history	In the absence of range wide genetic variation information, this factor can be used to infer whether reductions in species-level genetic variation that would potentially impede its adaptation to climate change may have occurred.
Phenological response to changing seasonal temperature or precipitation dynamics	Recent research suggests that some phylogenetic groups are declining due to lack of response to changing annual temperature dynamics (e.g., earlier onset of spring, longer growing season).

Table 15. Documented or modeled response to climate change	
This category allows for inclusion of information from supplemental studies, if available.	
Documented response to recent climate change	This addresses the degree to which a species is known to have responded to recent climate change based on published accounts in peer-reviewed literature. For example, some species have shifted ranges or shown phenological changes. Species already experiencing change are important sentinels for future impacts.
Modeled future (2050) change in range or population size	Models should be developed based on reasonably accurate locality data using algorithms that are supported by peer-reviewed literature. Relative vulnerability depends on the extent to which species distribution and/or population is projected to change relative to historic or current conditions.

Overlap of modeled future (2050) range with current range	If the range disappears or declines >70% within the assessment area, such that the previous factor is coded as Greatly Increase Vulnerability, this factor should be skipped to avoid double-counting in the scoring.
Occurrence of protected areas in modeled future distribution	"Protected area" refers to existing parks, refuges, wilderness areas, and other designated conservation areas that are relatively invulnerable to outright habitat destruction from human activities and that are likely to provide suitable conditions for the existence of viable populations.

Table 16. The CCVI final score ranking	
Vulnerability rankings are based on numeric scores calculated from a combination of exposure and the individual risk factors (i.e., indirect exposure, sensitivity, and documented response), as described in detail in Young et al. (2011). For the individual risk factors, numeric values are applied as follows: Somewhat Increase (SI) = 1.0; Increase (Inc) = 2.0; Greatly Increase (GI) = 3.0; Somewhat Decrease (SD) = -1.0; and Decrease (Dec) = -2.0. Factors for which there are no data or that are scored as neutral receive a zero. If a factor is scored at multiple levels (e.g., both Somewhat Increase" and Increase), the index uses an average of values for these levels. The value for each risk factor is then weighted by exposure to calculate a subscore for the factor. These subscores are then summed to determine a final score of relative vulnerability as follows:	
Extremely Vulnerable (EV)	Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.
Highly Vulnerable (HV)	Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.
Moderately Vulnerable (MV)	Abundance and/or range extent within geographical area assessed likely to decrease by 2050.
Not Vulnerable/Presumed Stable (PS)	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.
Not Vulnerable/Increase Likely (IL)	Available evidence suggests that abundance and/or range extent within the geographical area assessed is likely to increase by 2050.
Insufficient Evidence (IE)	Available information about a species' vulnerability is inadequate to calculate an Index score.

APPENDIX B. DIRECT EXPOSURE FACTORS FOR SELECTED TENNESSEE SPECIES

Projections for temperature and moisture changes across the state were derived from ClimateWizard (Girvetz et al. 2009, www.climatewizard.org) and are based on the IPCC Fourth Assessment Report (IPCC 2007) for a 16-model Ensemble Average under the IPCC medium emissions scenario A1B (the scenario recommended for use in the CCVI, Young et al. 2011). Projected temperatures calculated across Tennessee ranged from a 3.9 to 4.5°F increase by the 2050s, as shown in Figure 25. The predicted net change in moisture, which are derived from the Hamon AET:PET Moisture Metric (the ratio of actual evaporation, AET, to potential evapotranspiration, PET), showed net drying ranging from -0.119 to >-0.028 across the state, with the majority of the area falling within the -0.096 to -0.073 range (see Figure 26).

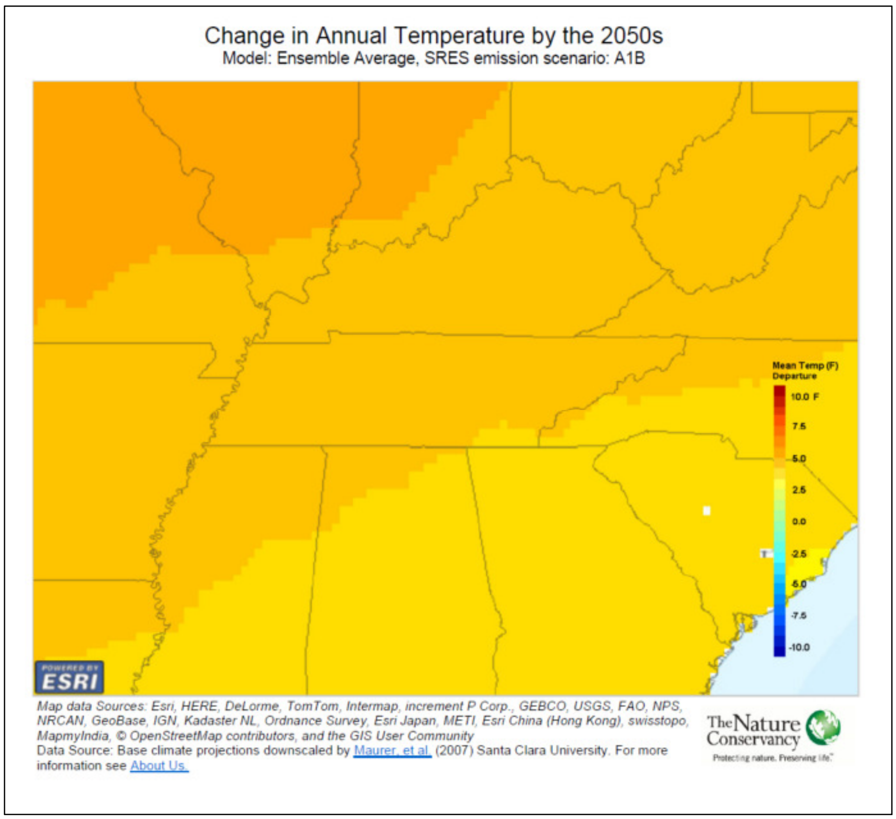

Figure 25. Regional map showing projected change in annual temperature by the 2050s (relative to the 1960-1991 reference period) based on the Ensemble Average under the SRES A1B emissions scenario. Map is based on data and analyses from ClimateWizard (www.climatewizard.org).

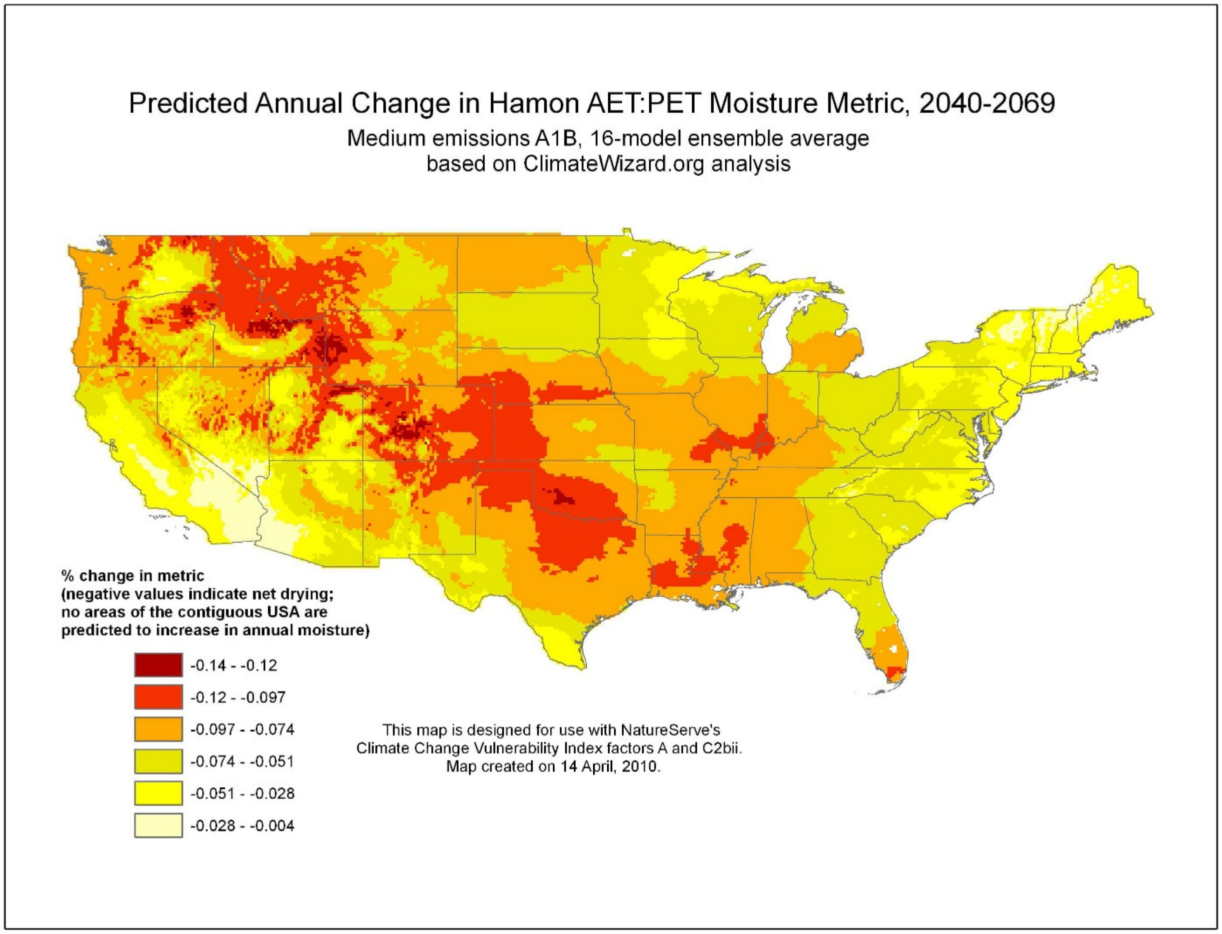

Figure 26. Continental map showing projected net-drying conditions by mid-century (relative to the 1960-1991 reference period) based on the Ensemble Average under the SRES A1B emissions scenario. Map is based on data and analyses from ClimateWizard (www.climatewizard.org).

Table 17 highlights the percentage of the particular species' range in Tennessee that is projected to be exposed to the various temperature and moisture changes, as calculated using ClimateWizard data. As reflected by the figures, there is greater variation in moisture changes across the state than temperature. The table is sorted by taxonomic group and common name.

Table 17. Direct CCVI exposure factors for selected Tennessee CGN species													
		Exposure to Temperature Variables					Exposure to Moisture Variables						
Scientific Name	Common Name	A >5.5F	A 5.1F	A 4.5F	A 3.9F	A <3.9F	< -0.119	-0.119	-0.096	-0.073	-0.05	>-0.028
Mammals													
Neotoma magister	Allegheny woodrat	0	0	0	100	0	0	0	0	100	0	0
Sorex palustris	American water shrew	0	0	0	100	0	0	0	0	100	0	0
Glaucomys sabrinus coloratus	Carolina northern flying squirrel	0	0	0	100	0	0	0	0	0	70	30
Myotis leibii	Eastern small-footed bat	0	0	0	100	0	0	0	60	40	0	0
Myotis grisescens	Gray bat	0	0	0	100	0	0	0	45	55	0	0
Parascalops breweri	Hairy-tailed mole	0	0	0	100	0	0	0	0	100	0	0
Myotis sodalis	Indiana bat	0	0	0	100	0	0	0	40	60	0	0
Mustela nivalis	Least weasel	0	0	0	100	0	0	0	0	100	0	0
Myotis septentrionalis	Northern myotis	0	0	0	100	0	0	0	50	50	0	0
Corynorhinus rafinesquii	Rafinesque's big-eared bat	0	0	0	100	0	0	0	60	40	0	0
Tamiasciurus hudsonicus	Red squirrel	0	0	0	100	0	0	0	0	0	70	30
Sorex fumeus	Smoky shrew	0	0	0	100	0	0	0	0	100	0	0
Microtus chrotorrhinus carolinensis	Southern rock vole	0	0	0	100	0	0	0	0	0	90	10
Condylura cristata	Star-nosed mole	0	0	0	100	0	0	0	0	95	5	0
Napaeozapus insignis	Woodland jumping mouse	0	0	0	100	0	0	0	0	100	0	0
Birds													
Botaurus lentiginosus	American bittern	0	0	100	0	0	0	0	100	0	0	0
Pluvialis dominica	American golden plover	0	0	100	0	0	0	0	80	20	0	0
Scolopax minor	American woodcock	0	0	100	0	0	0	0	80	20	0	0
Anhinga anhinga	Anhinga	0	0	100	0	0	0	0	100	0	0	0
Aimophila aestivalis	Bachman's sparrow	0	0	100	0	0	0	0	80	20	0	0
Riparia riparia	Bank swallow	0	0	100	0	0	0	0	80	20	0	0
Tyto alba	Barn owl	0	0	100	0	0	0	0	80	20	0	0
Vireo bellii	Bell's vireo	0	0	100	0	0	0	0	100	0	0	0
Thryomanes bewickii	Bewick's wren	0	0	100	0	0	0	0	100	0	0	0
Vermiforma pinus	Blue-winged warbler	0	0	100	0	0	0	0	80	20	0	0
Sitta pusilla	Brown-headed nuthatch	0	0	100	0	0	0	0	80	20	0	0
Tryngites subruficollis	Buff-breasted sandpiper	0	0	100	0	0	0	0	80	20	0	0
Setophaga cerulea	Cerulean warbler	0	0	100	0	0	0	0	80	20	0	0
Caprimulgus carolinensis	Chuck-will's-widow	0	0	100	0	0	0	0	80	20	0	0

Table 17. Direct CCVI exposure factors for selected Tennessee CGN species												
		Exposure to Temperature Variables					Exposure to Moisture Variables					
Scientific Name	**Common Name**	**A >5.5F**	**A 5.1F**	**A 4.5F**	**A 3.9F**	**A <3.9F**	**< -0.119**	**-0.119**	**-0.096**	**-0.073**	**-0.05**	**>-0.028**
Spiza americana	Dickcissel	0	0	100	0	0	0	0	80	20	0	0
Ammodramus savannarum	Grasshopper sparrow	0	0	100	0	0	0	0	80	20	0	0
Ardea alba	Great egret	0	0	100	0	0	0	0	80	20	0	0
Wilsonia citrina	Hooded warbler	0	0	100	0	0	0	0	80	20	0	0
Limosa haemastica	Hudsonian godwit	0	0	100	0	0	0	0	80	20	0	0
Oporornis formosus	Kentucky warbler	0	0	100	0	0	0	0	80	20	0	0
Rallus elegans	King rail	0	0	100	0	0	0	0	80	20	0	0
Chondestes grammacus	Lark sparrow	0	0	100	0	0	0	0	80	20	0	0
Ixobrychus exilis	Least bittern	0	0	100	0	0	0	0	80	20	0	0
Egretta caerulea	Little blue heron	0	0	100	0	0	0	0	80	20	0	0
Lanius ludovicianus	Loggerhead shrike	0	0	100	0	0	0	0	80	20	0	0
Seiurus motacilla	Louisiana waterthrush	0	0	100	0	0	0	0	80	20	0	0
Limosa fedoa	Marbled godwit	0	0	100	0	0	0	0	80	20	0	0
Ictinia mississippiensis	Mississippi kite	0	0	100	0	0	0	0	100	0	0	0
Parula americana	Northern parula	0	0	100	0	0	0	0	80	20	0	0
Icterus spurius	Orchard oriole	0	0	100	0	0	0	0	80	20	0	0
Passerina ciris	Painted bunting	0	0	100	0	0	0	0	100	0	0	0
Dendroica discolor	Prairie warbler	0	0	100	0	0	0	0	80	20	0	0
Protonotaria citrea	Prothonotary warbler	0	0	100	0	0	0	0	80	20	0	0
Calidris canutus	Red knot	0	0	100	0	0	0	0	80	20	0	0
Melanerpes erythrocephalus	Red-headed woodpecker	0	0	100	0	0	0	0	80	20	0	0
Passerculus sandwichensis	Savannah sparrow	0	0	100	0	0	0	0	80	20	0	0
Tyrannus forficatus	Scissor-tailed flycatcher	0	0	100	0	0	0	0	80	20	0	0
Accipiter striatus	Sharp-shinned hawk	0	0	100	0	0	0	0	80	20	0	0
Calidris himantopus	Stilt sandpiper	0	0	100	0	0	0	0	80	20	0	0
Limnothlypis swainsonii	Swainson's warbler	0	0	100	0	0	0	0	80	20	0	0
Elanoides forficatus	Swallow-tailed kite	0	0	100	0	0	0	0	80	20	0	0
Bartramia longicauda	Upland sandpiper	0	0	100	0	0	0	0	80	20	0	0
Pooecetes gramineus	Vesper sparrow	0	0	100	0	0	0	0	80	20	0	0
Calidris mauri	Western sandpiper	0	0	100	0	0	0	0	80	20	0	0
Numenius phaeopus	Whimbrel	0	0	100	0	0	0	0	80	20	0	0
Caprimulgus vociferus	Whip-poor-will	0	0	100	0	0	0	0	80	20	0	0
Vireo griseus	White-eyed vireo	0	0	100	0	0	0	0	80	20	0	0
Charadrius wilsonia	Wilson's plover	0	0	100	0	0	0	0	80	20	0	0

Table 17. Direct CCVI exposure factors for selected Tennessee CGN species												
		Exposure to Temperature Variables					Exposure to Moisture Variables					
Scientific Name	**Common Name**	**A >5.5F**	**A 5.1F**	**A 4.5F**	**A 3.9F**	**A <3.9F**	**< -0.119**	**-0.119**	**-0.096**	**-0.073**	**-0.05**	**>-0.028**
Hylocichla mustelina	Wood thrush	0	0	100	0	0	0	0	80	20	0	0
Helmitheros vermivorum	Worm-eating warbler	0	0	100	0	0	0	0	80	20	0	0
Coccyzus americanus	Yellow-billed cuckoo	0	0	100	0	0	0	0	80	20	0	0
Reptiles												
Macrochelys temminckii	Alligator snapping turtle	0	0	100	0	0	0	0	100	0	0	0
Glyptemys muhlenbergii	Bog turtle	0	0	100	0	0	0	0	0	100	0	0
Masticophis flagellum	Coachwhip	0	0	100	0	0	0	0	100	0	0	0
Plestiodon anthracinus	Coal skink	0	0	100	0	0	0	0	100	0	0	0
Terrapene carolina	Eastern box turtle	0	0	100	0	0	0	0	100	0	0	0
Herterodon platirhinos	Eastern hognose snake	0	0	100	0	0	0	0	100	0	0	0
Ophisaurus attenuatus longicaudus	Eastern slender glass lizard	0	0	100	0	0	0	0	100	0	0	0
Anolis carolinensis	Green anole	0	0	80	20	0	0	70	30	0	0	0
Clonophis kirtlandii	Kirtland's snake	0	0	100	0	0	0	0	100	0	0	0
Nerodia cyclopion	Mississippi green watersnake	0	0	100	0	0	0	0	100	0	0	0
Pituophis melanoleucus melanoleucus	Northern pine snake	0	0	100	0	0	0	0	100	0	0	0
Virginia striatula	Rough earthsnake	0	0	100	0	0	0	0	100	0	0	0
Apalone mutica	Smooth softshell turtle	0	0	100	0	0	0	0	100	0	0	0
Crotalus horridus	Timber rattlesnake	0	0	90	10	0	0	5	65	30	0	0
Sistrurus miliarius streckeri	Western pygmy rattlesnake	0	0	100	0	0	0	0	100	0	0	0
Thamnophis proximus	Western ribbonsnake	0	0	100	0	0	0	0	100	0	0	0
Nerodia erythrogaser flavigaster	Yellowbelly watersnake	0	0	100	0	0	0	0	100	0	0	0
Amphibians												
Hyla gratiosa	Barking treefrog	0	0	100	0	0	0	0	100	0	0	0
Gyrinophilus gulolineatus	Berry Cave salamander	0	0	0	100	0	0	0	50	50	0	0
Desmognathus welteri	Black Mountain dusky salamander	0	0	90	10	0	0	0	60	40	0	0
Lithobates areolatus	Crawfish frog	0	0	90	10	0	0	0	60	40	0	0
Desmagnatus abditus	Cumberland dusky salamander	0	0	90	10	0	0	0	60	40	0	0
Hemidactylium scutatum	Four-toed salamander	0	0	100	0	0	0	0	100	0	0	0
Hyla versicolor	Gray treefrog	0	0	100	0	0	0	0	100	0	0	0

Table 17. Direct CCVI exposure factors for selected Tennessee CGN species

		Exposure to Temperature Variables					Exposure to Moisture Variables					
Scientific Name	**Common Name**	**A >5.5F**	**A 5.1F**	**A 4.5F**	**A 3.9F**	**A <3.9F**	**< -0.119**	**-0.119**	**-0.096**	**-0.073**	**-0.05**	**>-0.028**
Aneides aeneus	Green salamander	0	0	100	0	0	0	100	0	0	0	0
Cryptobranchus alleganiensis	Hellbender	0	0	100	0	0	0	95	5	0	0	0
Desmognathus imitator	Imitator salamander	0	0	90	10	0	0	0	60	40	0	0
Plethodon jordani	Jordan's red-cheeked salamander	0	0	90	10	0	0	0	60	40	0	0
Psedacris brachyphona	Mountain chorus frog	0	0	90	10	0	0	0	60	40	0	0
Pseudtriton montanus	Mud salamander	0	0	100	0	0	0	0	100	0	0	0
Plethodon montanus	Northern gray-cheeked salamander	0	0	90	10	0	0	0	60	40	0	0
Desmognathus organi	Northern pygmy salamander	0	0	90	10	0	0	0	60	40	0	0
Plethodon shermani	Red-legged salamander	0	0	90	10	0	0	0	60	40	0	0
Desmognathus aeneus	Seepage salamander	0	0	90	10	0	0	0	60	40	0	0
Acris gryllus	Southern cricket frog	0	0	100	0	0	0	0	100	0	0	0
Desmognathus wrighti	Southern pygmy salamander	0	0	90	10	0	0	0	60	40	0	0
Plethodon richmondi	Southern ravine salamander	0	0	90	10	0	0	0	60	40	0	0
Ambystoma barbouri	Streamside salamander	0	0	90	10	0	0	0	60	40	0	0
Plethodon aureolus	Tellico salamander	0	0	90	10	0	0	0	60	40	0	0
Gyrinophilus palleucus	Tennessee cave salamander	0	0	0	100	0	0	0	50	50	0	0
Plethodon wehrlei	Wehrle's salamander	0	0	90	10	0	0	0	60	40	0	0
Plethodon welleri	Weller's salamander	0	0	90	10	0	0	0	60	40	0	0
Plethodon yonahlossee	Yonahlossee salamander	0	0	90	10	0	0	0	60	40	0	0
Fish												
Attractosteus spatula	Alligator gar	0	0	100	0	0	0	0	100	0	0	0
Etheostoma sagitta	Arrow darter	0	0	100	0	0	0	0	0	100	0	0
Cyprinella caerulea	Blue shiner	0	0	100	0	0	0	0	0	100	0	0
Cycleptis elongatus	Blue sucker	0	0	100	0	0	0	0	70	30	0	0
Salvelinus fontinalis	Brook trout	0	0	100	0	0	0	0	60	20	20	0
Etheostoma cervus	Chickasaw darter	0	0	100	0	0	0	0	100	0	0	0
Noturus crypticus	Chucky madtom	0	0	100	0	0	0	0	0	100	0	0
Etheostoma pyrrhogaster	Firebelly darter	0	0	100	0	0	0	0	100	0	0	0
Carpiodes velifer	Highfin carpsucker	0	0	100	0	0	0	0	50	50	0	0
Acipenser fulvescens	Lake sturgeon	0	0	100	0	0	0	0	50	50	0	0

Table 17. Direct CCVI exposure factors for selected Tennessee CGN species												
		Exposure to Temperature Variables					Exposure to Moisture Variables					
Scientific Name	Common Name	A >5.5F	A 5.1F	A 4.5F	A 3.9F	A <3.9F	< -0.119	-0.119	-0.096	-0.073	-0.05	>-0.028
Chrosomus saylori	Laurel dace	0	0	100	0	0	0	0	0	100	0	0
Etheostoma bellum	Orangefin darter	0	0	100	0	0	0	0	100	0	0	0
Polyodon spathula	Paddlefish	0	0	100	0	0	0	0	60	40	0	0
Noturus fasciatus	Saddled madtom	0	0	100	0	0	0	0	100	0	0	0
Etheostoma boschungi	Slackwater darter	0	0	100	0	0	0	0	100	0	0	0
Clinostomus funduloides	Smoky dace	0	0	100	0	0	0	0	60	20	20	0
Typhlichthys subterraneus	Southern cavefish	0	0	100	0	0	0	0	100	0	0	0
Percina aurantiaca	Tangerine darter	0	0	90	10	0	0	0	0	100	0	0
Noturus flavipinnis	Yellowfin madtom	0	0	100	0	0	0	0	0	95	5	0
Mussels and Crayfish												
Strophitis connasaugaensis	Alabama creekmussel	0	0	100	0	0	0	0	0	100	0	0
Villosa nebulosa	Alabama rainbow	0	0	100	0	0	0	0	0	100	0	0
Orconectes pagei	Big Sandy crayfish	0	0	100	0	0	0	0	100	0	0	0
Cambarus bouchardi	Big southfork crayfish	0	0	100	0	0	0	0	0	100	0	0
Ligumia recta	Black sandshell	0	0	100	0	0	0	0	25	75	0	0
Orconectes burri	Blood River crayfish	0	0	100	0	0	0	0	100	0	0	0
Barbicambarus cornutus	Bottlebrush crayfish	0	0	100	0	0	0	0	100	0	0	0
Strophitus undulatus	Creeper	0	0	100	0	0	0	0	50	50	0	0
Medionidus conradicus	Cumberland moccasinshell	0	0	100	0	0	0	0	40	60	0	0
Alasmidonta marginata	Elktoe	0	0	100	0	0	0	0	10	90	0	0
Pleurobema hanleyianum	Georgia pigtoe	0	0	100	0	0	0	0	0	100	0	0
Orconectes wrighti	Hardin County crayfish	0	0	100	0	0	0	0	100	0	0	0
Fallicambarus hortoni	Hatchie burrowing crayfish	0	0	100	0	0	0	0	100	0	0	0
Obovaria olivaria	Hickorynut	0	0	100	0	0	0	0	100	0	0	0
Villosa lienosa	Little spectaclecase	0	0	100	0	0	0	0	100	0	0	0
Fusconaia subrotunda	Longsolid	0	0	100	0	0	0	0	60	40	0	0
Villosa vanuxemensis	Mountain creekshell	0	0	100	0	0	0	0	60	40	0	0
Pleurobema cordatum	Ohio pigtoe	0	0	100	0	0	0	0	50	50	0	0
Villosa taeniata	Painted creekshell	0	0	100	0	0	0	0	60	40	0	0
Actinonaias pectorosa	Pheasantshell	0	0	100	0	0	0	0	70	30	0	0
Toxolasma lividus	Purple lilliput	0	0	100	0	0	0	0	70	30	0	0
Pleurobema rubrum	Pyramid pigtoe	0	0	100	0	0	0	0	40	60	0	0
Quadrula cylindrica	Rabbitsfoot	0	0	100	0	0	0	0	25	75	0	0
Obovaria subrotunda	Round hickorynut	0	0	100	0	0	0	0	60	40	0	0
Pleurobema sintoxia	Round pigtoe	0	0	100	0	0	0	0	50	50	0	0

Table 17. Direct CCVI exposure factors for selected Tennessee CGN species													
		Exposure to Temperature Variables					Exposure to Moisture Variables						
Scientific Name	**Common Name**	**A >5.5F**	**A 5.1F**	**A 4.5F**	**A 3.9F**	**A <3.9F**	**< -0.119**	**-0.119**	**-0.096**	**-0.073**	**-0.05**	**>-0.028**
Pleuronaia dolabelloides	Slabside pearlymussel	0	0	100	0	0	0	0	25	75	0	0
Alasmidonta viridis	Slippershell mussel	0	0	100	0	0	0	0	40	60	0	0
Villosa vibex	Southern rainbow	0	0	100	0	0	0	0	95	5	0	0
Cumberlandia monodonta	Spectaclecase	0	0	100	0	0	0	0	100	0	0	0
Orconectes alabamensis	Stateline crayfish	0	0	100	0	0	0	0	100	0	0	0
Orconectes incomptus	Tennessee cave crayfish	0	0	100	0	0	0	0	100	0	0	0
Pleurobema oviforme	Tennessee clubshell	0	0	100	0	0	0	0	50	50	0	0
Lasmigona holstonia	Tennessee heelsplitter	0	0	100	0	0	0	0	0	100	0	0
Pleuronaia barnesiana	Tennessee pigtoe	0	0	100	0	0	0	0	40	60	0	0
Lasmigona complanata	White heelsplitter	0	0	100	0	0	0	0	50	50	0	0
Plants												
Hottonia inflata	American featherfoil	0	0	100	0	0	0	0	0	100	0	0
Asplenium scolopendrium var. americanum (syn. *Phyllitis scolopendrium var. americana*)	American hart's-tongue	0	0	100	0	0	0	0	0	0	100	0
Solidago spithamaea	Blue Ridge goldenrod	0	0	100	0	0	0	0	71	29	0	0
Boechera perstellata (syn. *Arabis perstellata*)	Braun's rockcress	0	0	100	0	0	0	0	100	0	0	0
Conradina verticillata	Cumberland rosemary	0	0	100	0	0	0	0	7	86	7	0
Minuartia cumberlandensis (syn. *Arenaria cumberlandensis*)	Cumberland sandwort/ Cumberland stitchwort	0	0	100	0	0	0	0	86	14	0	0
Helianthus eggertii	Eggert's sunflower	0	0	100	0	0	0	0	0	100	0	0
Panax quinquefolius	Ginseng	0	0	100	0	0	0	0	25	75	0	0
Scutellaria montana	Large-flowered skullcap	0	0	100	0	0	0	0	88	12	0	0
Dalea foliosa	Leafy prairie-clover	0	0	100	0	0	0	0	100	0	0	0
Clematis morefieldii	Morefield's leatherflower	0	0	100	0	0	0	0	0	0	100	0
Buckleya distichophylla	Pirate bush	0	0	100	0	0	0	0	0	100	0	0
Apios priceana	Price's potato bean	0	0	100	0	0	0	0	100	0	0	0
Astragalus bibullatus	Pyne's ground-plum	0	0	100	0	0	0	0	0	0	100	0
Hedyotis purpurea var. montana (syn. *Houstonia montana*)	Roan Mountain bluet/Venus' pride	0	0	100	0	0	0	0	100	0	0	0
Gymnoderma lineare	Rock gnome lichen	0	0	100	0	0	0	0	0	0	100	0
Pityopsis ruthii	Ruth's golden aster	0	0	100	0	0	0	0	100	0	0	0
Physaria globosa (syn. *Lesquerella globosa*)	Short's bladderpod	0	0	100	0	0	0	0	86	14	0	0

Table 17. Direct CCVI exposure factors for selected Tennessee CGN species													
		Exposure to Temperature Variables					Exposure to Moisture Variables						
Scientific Name	Common Name	A >5.5F	A 5.1F	A 4.5F	A 3.9F	A <3.9F	< -0.119	-0.119	-0.096	-0.073	-0.05	>-0.028
Isotria medeoloides	Small whorled pogonia/little five leaves	0	0	100	0	0	0	0	46	48	6	0
Geum radiatum	Spreading avens/ Appalachian avens	0	0	100	0	0	0	0	100	0	0	0
Paysonia perforata (syn. *Lesquerella perforata*)	Spring Creek bladderpod	0	0	100	0	0	0	0	100	0	0	0
Echinacea tennesseensis	Tennessee purple coneflower	0	0	100	0	0	0	0	0	100	0	0
Xyris tennesseensis	Tennessee yellow-eyed grass	0	0	100	0	0	0	0	100	0	0	0
Spiraea virginiana	Virginia spiraea/ Virginia meadowsweet	0	0	100	0	0	0	0	13	87	0	0
Platanthera integrilabia	White fringeless orchid/monkey-face orchid	0	0	100	0	0	0	0	29	71	0	0
Helianthus verticillatus	Whorled sunflower	0	0	100	0	0	0	0	100	0	0	0

APPENDIX C. INDIRECT EXPOSURE AND SENSITIVITY FACTORS FOR SELECTED TENNESSEE SPECIES

Tables 18-24 identify the findings for individual risk factors (i.e., indirect exposure and sensitivity) for the various Tennessee GCN species included in this assessment, as determined by the assessment team experts. None of the teams included Documented or Modeled Response to Climate Change in their analyses, so those categories are omitted here. The tables here are sorted by the species' common name to facilitate identification of findings for particular species of interest. The codes in these tables are defined as follows:

Individual Risk Factors

- GI = Greatly Increase Vulnerability
- Inc = Increase Vulnerability
- SI = Somewhat Increase Vulnerability
- N = Neutral
- SD = Somewhat Decrease Vulnerability
- Dec = Decrease Vulnerability
- U = Unknown
- NA = Not Applicable

CCVI Index Score

- EV = Extremely Vulnerable
- HV = Highly Vulnerable
- MV = Moderately Vulnerable
- PS = Presumed Stable
- IL = Increase Likely
- IE = Insufficient Evidence

Table 18. Indirect exposure and sensitivity factors for selected Tennessee mammals

Scientific Name	Common Name	Indirect Exposure Factors				Sensitivity Factors																
		Sea-level rise	Natural barriers	Anthropogenic barriers	Human response to climate	Dispersal and movements	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydro niche	Dependence on disturbance	Dependence on ice, snow	Restricted habitat features	Depend on spp for habitat	Dietary versatility (animals)	Pollinator versatility (plants)	Propagule dispersal	Other interspecific	Measured genetic variation	Evolutionary Bottlenecks	Phenological response	Index Score
Neotoma magister	Allegheny woodrat	N	N	N	U	SD	N	N	N	N	N	N	SI	N	N	NA	N	N	U	U	U	PS
Sorex palustris	American water shrew	N	SI	N	U	N	SI	SI	N	SI	N	N	N	N	N	NA	N	N	U	U	U	MV
Glaucomys sabrinus coloratus	Carolina northern flying squirrel	N	GI	SI	U	SD	SI	GI	N	N	SI	N	SD	N	SD	NA	N	SI	U	U	U	HV
Myotis leibii	Eastern small-footed bat	N	N	N	U	SD	N	N	N	N	N	N	SI	N	N	NA	N	N	U	U	U	PS
Myotis grisescens	Gray bat	N	N	N	U	SD	N	N	N	N	N	N	Inc	N	N	NA	N	N	U	U	U	PS
Parascalops breweri	Hairy-tailed mole	N	SI	N	U	N	N	N	N	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Myotis sodalis	Indiana bat	N	N	N	U	Dec	N	N	N	N	N	N	Inc	N	N	NA	N	N	U	U	U	PS
Mustela nivalis	Least weasel	N	N	N	U	N	N	N	N	N	SD	N	U	N	N	NA	N	N	U	U	U	PS
Myotis septentrionalis	Northern myotis	N	N	N	U	Dec	N	N	N	N	N	N	SI	N	N	NA	N	N	U	U	U	PS
Corynorhinus rafinesquii	Rafinesque's big-eared bat	N	N	N	U	SD	N	N	N	N	SI	N	N	N	N	NA	N	N	U	U	U	PS
Tamiasciurus hudsonicus	Red squirrel	N	N	U	U	N	SI	SI	N	N	N	N	SD	N	N	NA	N	N	U	U	U	PS
Sorex fumeus	Smoky shrew	N	SI	N	U	SI	N	N	N	SI	N	N	N	N	N	NA	N	N	U	U	U	PS
Microtus chrotorrhinus carolinensis	Southern rock vole	N	Inc	N	U	N	SI	GI	N	N	SD	N	SI	N	N	NA	N	N	U	U	U	MV
Condylura cristata	Star-nosed mole	N	SI	N	U	N	N	N	N	N	N	N	SI	N	N	NA	N	N	U	U	U	PS
Napaeozapus insignis	Woodland jumping mouse	N	N	N	U	N	N	SI	N	SI	N	N	N	N	N	NA	N	N	U	U	U	PS

Table 19. Indirect exposure and sensitivity factors for selected Tennessee birds

Scientific Name	Common Name	Indirect Exposure Factors				Sensitivity Factors																
		Sea-level rise	Natural barriers	Anthropogenic barriers	Human response to climate	Dispersal and movements	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydro niche	Dependence on disturbance	Dependence on ice, snow	Restricted habitat features	Depend on spp for habitat	Dietary versatility (animals)	Pollinator versatility (plants)	Propagule dispersal	Other interspecific	Measured genetic variation	Evolutionary Bottlenecks	Phenological response	Index Score
Botaurus lentiginosus	American bittern	N	N	N	N	SD	N	N	N	N	N	N	SI	N	N	NA	N	N	U	U	U	PS
Pluvialis dominica	American golden plover	N	N	N	N	SD	N	N	N	N	N	Inc	SI	N	SI	NA	N	N	U	U	U	PS
Scolopax minor	American woodcock	N	N	N	SI-N	SI	N	N	N	N	Inc	N	SI	N	SI	NA	N	U	U	U	U	MV
Anhinga anhinga	Anhinga	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SI	NA	N	U	U	U	SI	PS
Aimophila aestivalis	Bachman's sparrow	N	N	N	N	SI	N	N	N	N	Inc	N	Inc-SI	N	N	NA	N	U	U	U	U	MV
Riparia riparia	Bank swallow	N	N	N	N	SI	N	N	N	N	N	N	SI	N	SI	NA	N	U	U	U	U	PS
Tyto alba	Barn owl	SD	N	N	N	Dec	N	N	N	N	N	N	N	N	N	NA	U	U	U	U	N	IL
Vireo bellii	Bell's vireo	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SI	NA	U	U	U	U	SI	PS
Thryomanes bewickii	Bewick's wren	N	N	N	N	Dec	N	N	N	N	N	N	N	N	Inc	NA	U	U	U	U	SI	PS
Vermiforma pinus	Blue-winged warbler	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SI	NA	U	U	U	U	SI	PS
Sitta pusilla	Brown-headed nuthatch	N	N	N	SI-N	Dec	N	N	N	N	Inc	N	SI	N	N	NA	U	U	U	U	SI	PS
Tryngites subruficollis	Buff-breasted sandpiper	N	N	N	N	SD	N	N	N	N	N	SI	SI	N	SI	NA	U	U	U	U	SI	PS
Setophaga cerulea	Cerulean warbler	N	N	N	N	Dec	N	N	N	N	N	N	Inc	N	SI	NA	U	U	U	U	Inc	PS
Caprimulgus carolinensis	Chuck-will's-widow	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SI	NA	U	U	U	U	SI	PS
Spiza americana	Dickcissel	N	N	N	N	Dec	N	N	N	N	N	N	N	N	SD	NA	U	U	U	U	SI	IL

Table 19. Indirect exposure and sensitivity factors for selected Tennessee birds																						
Scientific Name	**Common Name**	**Indirect Exposure Factors**				**Sensitivity Factors**																
		Sea-level rise	**Natural barriers**	**Anthropogenic barriers**	**Human response to climate**	**Dispersal and movements**	**Historical thermal niche**	**Physiological thermal niche**	**Historical hydrological niche**	**Physiological hydro niche**	**Dependence on disturbance**	**Dependence on ice, snow**	**Restricted habitat features**	**Depend on spp for habitat**	**Dietary versatility (animals)**	**Pollinator versatility (plants)**	**Propagule dispersal**	**Other interspecific**	**Measured genetic variation**	**Evolutionary Bottlenecks**	**Phenological response**	**Index Score**
Ammodramus savannarum	Grasshopper sparrow	N	N	N	N	Dec	N	N	N	N	SI-N	N	SI	N	N	NA	U	U	U	U	SI	PS
Ardea alba	Great egret	N	N	N	N	Dec	N	N	N	N	N	N	N	N	SD	NA	U	U	U	U	SI	IL
Wilsonia citrina	Hooded warbler	N	N	N	N	Dec	N	N	N	N	N	N	N	N	N	NA	U	U	U	U	SI	PS
Limosa haemastica	Hudsonian godwit	N	N	N	N	Dec	N	N	N	N	N	N	N	N	SD	NA	U	U	U	U	SI	IL
Oporornis formosus	Kentucky warbler	N	N	N	N	Dec	N	N	N	N	N	N	N	N	SI	NA	U	U	U	U	SI	PS
Rallus elegans	King rail	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	N	NA	U	U	U	U	SI	PS
Chondestes grammacus	Lark sparrow	N	N	N	N	Dec	N	N	N	N	SI	N	SI	N	N	NA	U	U	U	U	SI	PS
Ixobrychus exilis	Least bittern	N	N	N	N	Dec	N	N	N	N	N	N	Inc	N	SD	NA	U	U	U	U	SI	PS
Egretta caerulea	Little blue heron	SI	N	N	N	Dec	N	N	N	N	N	N	SI	N	SD	NA	U	U	U	U	SI	PS
Lanius ludovicianus	Loggerhead shrike	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	N	NA	U	U	U	U	SI	PS
Seiurus motacilla	Louisiana waterthrush	N	N	N	N	Dec	N	N	N	N	N	N	N	N	SD	NA	U	U	U	U	SI	IL
Limosa fedoa	Marbled godwit	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	N	NA	U	U	U	U	SI	PS
Ictinia mississippiensis	Mississippi kite	N	N	N	SD	Dec	N	N	N	N	N	N	N	N	SD	NA	U	U	U	U	SI	IL
Parula americana	Northern parula	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SI	NA	U	U	U	U	SI	PS
Icterus spurius	Orchard oriole	N	N	N	N	Dec	N	N	N	N	N	N	N	N	SD	NA	U	U	U	U	SI	IL
Passerina ciris	Painted bunting	N	N	N	N	Dec	N	N	N	N	N	N	N	N	SD	NA	U	U	U	U	SI	IL

Table 19. Indirect exposure and sensitivity factors for selected Tennessee birds

Scientific Name	Common Name	Indirect Exposure Factors: Sea-level rise	Natural barriers	Anthropogenic barriers	Human response to climate	Sensitivity Factors: Dispersal and movements	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydro niche	Dependence on disturbance	Dependence on ice, snow	Restricted habitat features	Depend on spp for habitat	Dietary versatility (animals)	Pollinator versatility (plants)	Propagule dispersal	Other interspecific	Measured genetic variation	Evolutionary Bottlenecks	Phenological response	Index Score
Dendroica discolor	Prairie warbler	N	N	N	N	Dec	N	N	N	N	SI	N	SI	N	SI	NA	U	U	U	U	SI	PS
Protonotaria citrea	Prothonotary warbler	N	N	N	N	Dec	N	N	N	N	N	N	SI	SI	SI	NA	U	U	U	U	SI	PS
Calidris canutus	Red knot	SI	N	N	N	Dec	N	N	N	N	N	N	SI	N	Inc	NA	U	U	U	U	SI	PS
Melanerpes erythrocephalus	Red-headed woodpecker	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	N	NA	U	U	U	U	SI	PS
Passerculus sandwichensis	Savannah sparrow	N	N	N	N	Dec	N	N	N	N	N	N	N	N	SD	NA	U	U	U	U	SI	IL
Tyrannus forficatus	Scissor-tailed flycatcher	N	N	N	N	Dec	N	N	N	N	N	N	N	N	SI	NA	U	U	U	U	SI	PS
Accipiter striatus	Sharp-shinned hawk	N	N	N	N	Dec	N	N	N	N	N	N	SI-N	N	N	NA	U	U	U	U	SI	PS
Calidris himantopus	Stilt sandpiper	N	N	N	N	Dec	N	N	N	N	N	SI	SI	N	N	NA	U	U	U	U	SI	PS
Limnothlypis swainsonii	Swainson's warbler	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SI	NA	U	U	U	U	SI	PS
Elanoides forficatus	Swallow-tailed kite	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	N	NA	U	U	U	U	SI	PS
Bartramia longicauda	Upland sandpiper	N	N	N	N	Dec	N	N	N	N	U	N	Inc	N	SI	NA	U	U	U	U	SI	PS
Pooecetes gramineus	Vesper sparrow	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SD	NA	U	U	U	U	SI	PS
Calidris mauri	Western sandpiper	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SI	NA	U	U	U	U	SI	PS
Numenius phaeopus	Whimbrel	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SD	NA	U	U	U	U	SI	PS
Caprimulgus vociferus	Whip-poor-will	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SI	NA	U	U	U	U	SI	PS
Vireo griseus	White-eyed vireo	N	N	N	N	Dec	N	N	N	N	SI	N	N	N	SD	NA	U	U	U	U	SI	PS

Table 19. Indirect exposure and sensitivity factors for selected Tennessee birds

Scientific Name	Common Name	Indirect Exposure Factors				Sensitivity Factors																
		Sea-level rise	Natural barriers	Anthropogenic barriers	Human response to climate	Dispersal and movements	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydro niche	Dependence on disturbance	Dependence on ice, snow	Restricted habitat features	Depend on spp for habitat	Dietary versatility (animals)	Pollinator versatility (plants)	Propagule dispersal	Other interspecific	Measured genetic variation	Evolutionary Bottlenecks	Phenological response	Index Score
Charadrius wilsonia	Wilson's plover	Inc	N	N	N	Dec	N	N	N	N	N	N	SI	N	SI	NA	U	U	U	U	SI	PS
Hylocichla mustelina	Wood thrush	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SD	NA	U	U	U	U	SI	PS
Helmitheros vermivorum	Worm-eating warbler	N	N	N	N	Dec	N	N	N	N	N	N	Inc	N	SI	NA	U	U	U	U	SI	PS
Coccyzus americanus	Yellow-billed cuckoo	N	N	N	N	Dec	N	N	N	N	N	N	SI	N	SI	NA	U	U	U	U	SI	PS

Table 20. Indirect exposure and sensitivity factors for selected Tennessee reptiles																						
Scientific Name	**Common Name**	**Indirect Exposure Factors**				**Sensitivity Factors**																
		Sea-level rise	**Natural barriers**	**Anthropogenic barriers**	**Human response to climate**	**Dispersal and movements**	**Historical thermal niche**	**Physiological thermal niche**	**Historical hydrological niche**	**Physiological hydro niche**	**Dependence on disturbance**	**Dependence on ice, snow**	**Restricted habitat features**	**Depend on spp for habitat**	**Dietary versatility (animals)**	**Pollinator versatility (plants)**	**Propagule dispersal**	**Other interspecific**	**Measured genetic variation**	**Evolutionary Bottlenecks**	**Phenological response**	**Index Score**
Macrochelys temminckii	Alligator snapping turtle	N	N	N	N	SD	N	N	SD	N	N	N	N	N	N	NA	N	N	U	U	U	IL
Glyptemys muhlenbergii	Bog turtle	U	SI	SI	N	N	N	N	N	N	N	U	Inc	SI	SD	NA	N	U	SI	U	U	MV
Masticophis flagellum	Coachwhip	U	N	N	N	N	N	SD	N	N	N	U	SD	N	N	NA	N	U	U	U	U	IL
Plestiodon anthracinus	Coal skink	N	N	N	N	Inc	N	N	SD	SI	N	N	N	N	N	NA	N	N	U	U	U	PS
Terrapene carolina	Eastern box turtle	N	N	Inc	N	SI	N	N	SD	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Herterodon platirhinos	Eastern hognose snake	N	N	Inc	N	Inc	N	N	SD	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Ophisaurus attenuatus longicaudus	Eastern slender glass lizard	N	N	SI	N	SI	N	N	SD	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Anolis carolinensis	Green anole	U	N	N	N	N	N	SD	N	N	N	U	SD	N	N	NA	N	U	U	U	U	IL
Clonophis kirtlandii	Kirtland's snake	U	N	N	N	SI	N	N	N	N	N	U	N	SI	SI	NA	N	U	U	U	U	PS
Nerodia cyclopion	Mississippi green watersnake	N	N	N	N	Inc	N	N	SD	Inc	N	N	N	N	N	NA	N	N	U	U	U	PS
Pituophis melanoleucus melanoleucus	Northern pine snake	N	N	SI	N	N	N	N	SD	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Virginia striatula	Rough earthsnake	N	N	N	N	N	N	N	SD	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Apalone mutica	Smooth softshell turtle	N	N	N	N	N	N	N	SD	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Crotalus horridus	Timber rattlesnake	N	N	SI	N	N	N	N	SD	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Sistrurus miliarius streckeri	Western pygmy rattlesnake	N	N	SI	N	N	N	N	SD	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Thamnophis proximus	Western ribbonsnake	U	N	N	N	N	N	N	N	N	N	U	N	N	N	NA	N	U	U	U	U	PS
Nerodia erythrogaser flavigaster	Yellowbelly watersnake	N	N	N	N	N	N	N	SD	N	N	N	N	N	N	NA	N	N	U	U	U	PS

Table 21. Indirect exposure and sensitivity factors for selected Tennessee amphibians

Scientific Name	Common Name	Indirect Exposure Factors				Sensitivity Factors																
		Sea-level rise	Natural barriers	Anthropogenic barriers	Human response to climate	Dispersal and movements	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydro niche	Dependence on disturbance	Dependence on ice, snow	Restricted habitat features	Depend on spp for habitat	Dietary versatility (animals)	Pollinator versatility (plants)	Propagule dispersal	Other interspecific	Measured genetic variation	Evolutionary Bottlenecks	Phenological response	Index Score
Hyla gratiosa	Barking treefrog	N	N	SI	N	N	N	N	SD	GI	N	N	SI	N	N	NA	N	N	U	U	U	MV
Gyrinophilus gulolineatus	Berry Cave salamander	N	SI	N	U	SI	SI	SI	SD	N	N	N	Inc	N	N	NA	N	N	U	U	U	MV
Desmognathus welteri	Black Mountain dusky salamander	N	Inc	N	N	SI	N	N	SD	SI	N	N	N	N	N	NA	N	U	U	U	U	PS
Lithobates areolatus	Crawfish frog	N	N	SI	U	SI	N	N	N	SI	N	N	N	SI	N	NA	N	N	U	U	U	MV
Desmognathus abditus	Cumberland dusky salamander	N	N	SI	N	SI	N	N	SD	SI	N	N	N	N	N	NA	N	N	U	U	U	PS
Hemidactylium scutatum	Four-toed salamander	N	N	SI	U	SI	N	N	SD	GI	N	N	SI	N	N	NA	U	N	U	U	U	MV
Hyla versicolor	Gray treefrog	N	N	N	U	SI	N	N	N	GI	N	N	N	N	N	NA	N	N	U	U	U	MV
Aneides aeneus	Green salamander	N	SI	SI	U	SI	N	SI	SD	N	N	N	SI	N	N	NA	U	U	U	U	U	MV
Cryptobranchus alleganensis	Hellbender	N	N	Inc	N	N	N	Inc	SD	SI	N	U	SI	N	SI	NA	N	N	U	U	U	HV
Desmognathus imitator	Imitator salamander	N	N	N	N	SI	SI	SI	SD	SI	N	N	N	N	N	NA	N	U	U	U	U	PS
Plethodon jordani	Jordan's red-cheeked salamander	N	N	N	N	SI	SI	SI	SD	N	N	N	N	N	N	NA	N	U	U	U	U	PS
Pseudacris brachyphona	Mountain chorus frog	N	N	SI	N	N	N	N	SD	GI	N	N	SI	N	N	NA	N	N	U	U	U	MV
Pseudotriton montanus	Mud salamander	N	N	SI	U	SI	N	N	SD	SI	N	N	SI	N	N	NA	N	N	U	U	U	PS
Plethodon montanus	Northern gray-cheeked salamander	N	N	N	N	SI	SI	SI	SD	N	N	N	N	N	N	NA	N	U	U	U	U	PS
Desmognathus organi	Northern pygmy salamander	N	N	N	N	SI	SI	SI	SD	N	N	N	N	N	N	NA	N	U	U	U	U	PS
Plethodon shermani	Red-legged salamander	N	N	N	N	SI	SI	SI	SD	N	N	N	N	N	N	NA	N	U	U	U	U	PS
Desmognathus aeneus	Seepage salamander	N	N	SI	N	SI	N	N	SD	GI	N	N	SI	N	N	NA	N	N	U	U	U	MV
Acris gryllus	Southern cricket frog	N	N	SI	U	SI	N	N	SD	GI	N	N	N	N	N	NA	N	N	U	U	U	MV
Desmognathus wrighti	Southern pygmy salamander	N	Inc	N	U	SI	SI	SI	SD	N	N	N	N	N	N	NA	N	U	U	U	U	PS
Plethodon richmondi	Southern ravine salamander	N	N	N	N	SI	SI	N	SD	N	N	N	SI	N	N	NA	N	N	U	U	U	PS
Ambystoma barbouri	Streamside salamander	N	N	SI	N	SI	N	N	SD	Inc	N	N	N	N	N	NA	N	U	U	U	U	PS

Table 21. Indirect exposure and sensitivity factors for selected Tennessee amphibians

Scientific Name	Common Name	Indirect Exposure Factors				Sensitivity Factors																
		Sea-level rise	Natural barriers	Anthropogenic barriers	Human response to climate	Dispersal and movements	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydro niche	Dependence on disturbance	Dependence on ice, snow	Restricted habitat features	Depend on spp for habitat	Dietary versatility (animals)	Pollinator versatility (plants)	Propagule dispersal	Other interspecific	Measured genetic variation	Evolutionary Bottlenecks	Phenological response	Index Score
Plethodon aureolus	Tellico salamander	N	N	N	N	SI	SI	N	SD	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Gyrinophilus palleucus	Tennessee cave salamander	N	SI	N	U	SI	SI	SI	SD	N	N	N	Inc	N	N	NA	N	N	U	U	U	MV
Plethodon wehrlei	Wehrle's salamander	N	N	N	N	SI	N	N	N	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Plethodon welleri	Weller's salamander	N	N	N	N	SI	SI	SI	SD	N	N	N	SI	N	N	NA	N	U	U	U	U	PS
Plethodon yonahlossee	Yonahlossee salamander	N	N	N	N	SI	SI	N	SD	N	N	N	SI	N	N	NA	N	N	U	U	U	PS

Table 22. Indirect exposure and sensitivity factors for selected Tennessee fish

Scientific Name	Common Name	Indirect Exposure Factors				Sensitivity Factors																
		Sea-level rise	Natural barriers	Anthropogenic barriers	Human response to climate	Dispersal and movements	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydro niche	Dependence on disturbance	Dependence on ice, snow	Restricted habitat features	Depend on spp for habitat	Dietary versatility (animals)	Pollinator versatility (plants)	Propagule dispersal	Other interspecific	Measured genetic variation	Evolutionary Bottlenecks	Phenological response	Index Score
Attractosteus spatula	Alligator gar	N	N	Inc	Inc	N	N	N	N	SI	SI	N	N	N	N	NA	N	N	U	U	SI	HV
Etheostoma sagitta	Arrow darter	N	N	Inc	Inc	SI	N	N	N	Inc-SI	N	N	N	N	N	NA	N	Inc	U	U	U	HV
Cyprinella caerulea	Blue shiner	N	N	N	N	N	N	N	N	Inc	N	N	N	N	N	NA	N	N	U	U	U	PS
Cycleptis elongatus	Blue sucker	N	N	Inc	SI	N	N	N	N	Inc-SI	N	N	N	N	N	NA	N	N	U	U	SI	MV
Salvelinus fontinalis	Brook trout	N	Inc	N	N	N	N	GI-Inc	N	Inc-SI	N	N	Inc-SI	N	N	NA	N	SI	U	SI	U	EV
Etheostoma cervus	Chickasaw darter	N	N	N	SI	N	N	N	N	SI	N	N	N	N	N	NA	N	N	U	U	U	PS
Noturus crypticus	Chucky madtom	SI	N	Inc	Inc	N	N	SI	N	SI	N	N	N	N	N	NA	N	N	U	U	U	HV
Etheostoma pyrrhogaster	Firebelly darter	N	N	N	Inc	N	N	N	N	SI	N	N	N	N	N	NA	N	N	U	U	N	PS
Carpiodes velifer	Highfin carpsucker	N	N	Inc	SI	N	N	N	N	Inc-SI	N	N	N	N	N	NA	N	N	U	U	SI	MV
Acipenser fulvescens	Lake sturgeon	N	N	GI-Inc	SI	N	N	Inc-SI	N	Inc	N	N	N	N	N	NA	N	N	N	NA	Inc	EV
Chrosomus saylori	Laurel dace	N	N	SI	U	N	N	SI	N	Inc-SI	N	N	SI-N	N	N	NA	N	N	U	U	U	MV

Table 22. Indirect exposure and sensitivity factors for selected Tennessee fish																						
Scientific Name	**Common Name**	**Indirect Exposure Factors**				**Sensitivity Factors**																
		Sea-level rise	**Natural barriers**	**Anthropogenic barriers**	**Human response to climate**	**Dispersal and movements**	**Historical thermal niche**	**Physiological thermal niche**	**Historical hydrological niche**	**Physiological hydro niche**	**Dependence on disturbance**	**Dependence on ice, snow**	**Restricted habitat features**	**Depend on spp for habitat**	**Dietary versatility (animals)**	**Pollinator versatility (plants)**	**Propagule dispersal**	**Other interspecific**	**Measured genetic variation**	**Evolutionary Bottlenecks**	**Phenological response**	**Index Score**
Etheostoma bellum	Orangefin darter	N	N	SI	N	N	N	N	N	Inc	N	N	N	N	N	NA	N	N	U	U	SI	MV
Polyodon spathula	Paddlefish	N	N	GI-Inc	Inc-SI	N	N	N	N	SI	N	N	N	N	SI-N	NA	N	SI	U	U	U	HV
Noturus fasciatus	Saddled madtom	N	N	N	Inc	N	N	N	N	Inc	N	N	N	N	N	NA	N	N	U	U	U	MV
Etheostoma boschungi	Slackwater darter	N	N	Inc	Inc	N	N	N	N	Inc	N	N	N	N	N	NA	N	N	U	U	Inc	EV
Clinostomus funduloides	Smoky dace	N	SI	SI	N	N	N	SI	N	SI-N	N	N	SI	N	N	NA	N	N	U	U	N	MV
Typhlichthys subterraneus	Southern cavefish	N	SI-N	N	Inc	N	N	N	N	SI	N	N	SI	N	N	NA	N	N	U	U	U	PS
Percina aurantiaca	Tangerine darter	N	N	Inc	Inc	N	N	N	N	SI	N	N	N	N	N	NA	N	N	U	U	U	MV
Noturus flavipinnis	Yellowfin madtom	N	N	N	Inc	N	N	SI	N	N	N	N	N	N	N	NA	N	N	U	U	U	PS

Table 23. Indirect exposure and sensitivity factors for selected Tennessee mussels and crayfish

Scientific Name	Common Name	Indirect Exposure Factors				Sensitivity Factors																
		Sea-level rise	Natural barriers	Anthropogenic barriers	Human response to climate	Dispersal and movements	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydro niche	Dependence on disturbance	Dependence on ice, snow	Restricted habitat features	Depend on spp for habitat	Dietary versatility (animals)	Pollinator versatility (plants)	Propagule dispersal	Other interspecific	Measured genetic variation	Evolutionary Bottlenecks	Phenological response	Index Score
Strophitis connasaugaensis	Alabama creekmussel	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	MV
Villosa nebulosa	Alabama rainbow	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	MV
Orconectes pagei	Big Sandy crayfish	U	N	N	N	N	N	N	N	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Cambarus bouchardi	Big southfork crayfish	N	N	N	Inc	N	N	N	N	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Ligumia recta	Black sandshell	N	N	Inc	SI	N	N	N	N	N	N	N	N	N	N	NA	N	U	U	U	U	PS
Orconectes burri	Blood River crayfish	N	N	Inc	SI	N	N	N	N	N	N	N	N	N	N	NA	N	N	U	U	U	PS
Barbicambarus cornutus	Bottlebrush crayfish	N	N	SI	SI	N	N	N	N	N	N	N	SI	N	N	NA	N	N	U	U	U	PS
Strophitus undulates	Creeper	N	N	SI	U	N	N	N	N	N	N	N	N	N	N	NA	N	U	U	U	U	PS
Medionidus conradicus	Cumberland moccasinshell	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	MV
Alasmidonta marginata	Elktoe	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	MV
Pleurobema hanleyianum	Georgia pigtoe	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	MV
Orconectes wright	Hardin County crayfish	N	N	N	U	N	N	SI	SD	SI	N	N	N	N	N	NA	N	N	U	U	U	PS
Fallicambarus hortoni	Hatchie burrowing crayfish	N	N	N	SI	N	N	SD	N	SI	N	N	N	N	N	NA	N	U	U	U	U	PS
Obovaria olivaria	Hickorynut	N	N	N	Inc	N	N	N	N	N	N	N	N	N	N	NA	Inc	N	U	U	U	MV
Villosa lienosa	Little spectaclecase	N	N	SI	U	U	N	N	N	Inc	N	N	N	N	N	NA	SI	N	U	U	U	MV
Fusconaia subrotunda	Longsolid	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	HV
Villosa vanuxemensis	Mountain creekshell	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	HV
Pleurobema cordatum	Ohio pigtoe	N	N	Inc	U	SI	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	U	MV

Table 23. Indirect exposure and sensitivity factors for selected Tennessee mussels and crayfish																						
Scientific Name	**Common Name**	**Indirect Exposure Factors**				**Sensitivity Factors**																
		Sea-level rise	**Natural barriers**	**Anthropogenic barriers**	**Human response to climate**	**Dispersal and movements**	**Historical thermal niche**	**Physiological thermal niche**	**Historical hydrological niche**	**Physiological hydro niche**	**Dependence on disturbance**	**Dependence on ice, snow**	**Restricted habitat features**	**Depend on spp for habitat**	**Dietary versatility (animals)**	**Pollinator versatility (plants)**	**Propagule dispersal**	**Other interspecific**	**Measured genetic variation**	**Evolutionary Bottlenecks**	**Phenological response**	**Index Score**
Villosa taeniata	Painted creekshell	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	HV
Actinonaias pectorosa	Pheasantshell	N	N	SI	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	N	U	U	N	MV
Toxolasma lividus	Purple lilliput	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	HV
Pleurobema rubrum	Pyramid pigtoe	N	N	Inc	N	SI	N	N	N	N	N	N	N	N	N	NA	Inc	N	U	U	U	MV
Quadrula cylindrical	Rabbitsfoot	N	N	Inc	SI	SI	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	U	MV
Obovaria subrotunda	Round hickorynut	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	HV
Pleurobema sintoxia	Round pigtoe	N	N	Inc	N	N	N	N	N	N	N	N	N	N	N	NA	N	U	U	U	U	PS
Pleuronaia dolabelloides	Slabside pearlymussel	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	N	U	U	U	U	MV
Alasmidonta viridis	Slippershell mussel	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	MV
Villosa vibex	Southern rainbow	N	N	N	Inc	N	N	N	N	SI	N	N	N	N	N	NA	N	N	U	U	U	PS
Cumberlandia monodonta	Spectaclecase	N	N	SI	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	U	MV
Orconectes alabamensis	Stateline crayfish	N	N	N	U	N	N	N	N	SI	N	N	N	N	N	NA	N	U	U	U	U	ps
Pleurobema oviforme	Tennessee clubshell	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	HV
Lasmigona holstonia	Tennessee heelsplitter	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	MV
Pleuronaia barnesiana	Tennessee pigtoe	N	N	Inc	SI	Inc	N	N	N	N	N	N	N	N	N	NA	SI	U	U	U	N	MV
Lasmigona complanata	White heelsplitter	N	N	SI	U	N	N	N	N	N	N	N	N	N	N	NA	N	U	U	U	U	PS

Table 24. Indirect exposure and sensitivity factors for selected Tennessee plants																						
Scientific Name	**Common Name**	**Indirect Exposure Factors**				**Sensitivity Factors**																
		Sea-level rise	**Natural barriers**	**Anthropogenic barriers**	**Human response to climate**	**Dispersal and movements**	**Historical thermal niche**	**Physiological thermal niche**	**Historical hydrological niche**	**Physiological hydro niche**	**Dependence on disturbance**	**Dependence on ice, snow**	**Restricted habitat features**	**Depend on spp for habitat**	**Dietary versatility (animals)**	**Pollinator versatility (plants)**	**Propagule dispersal**	**Other interspecific**	**Measured genetic variation**	**Evolutionary Bottlenecks**	**Phenological response**	**Index Score**
Hottonia inflata	American featherfoil	N	N	N	U	Dec	SD	N	Inc	N	N	N	N	N	NA	N	N	N	U	U	U	PS
Asplenium scolopendrium var. americanum (syn. *Phyllitis scolopendrium var. americana*)	American hart's-tongue	N	GI	N	U	SI	N	GI	GI	N	N	N	Inc	N	NA	U	N	N	U	Inc	U	EV
Solidago spithamaea	Blue Ridge goldenrod	N	GI	N	U	N	SI	GI	GI	N	N	N	N	N	NA	N	N	U	U	U	U	HV
Boechera perstellata (syn. *Arabis perstellata*)	Braun's rockcress	N	SI	SI	N	Inc	N	N	Inc	N	N	N	N	N	NA	N	N	N	SI	NA	U	HV
Conradina verticillata	Cumberland Rosemary	N	GI	N	U	SI	N	N	Inc	N	N	N	N	N	NA	N	N	N	SD	NA	U	MV
Minuartia cumberlandensis (syn. *Arenaria cumberlandensis*)	Cumberland sandwort/ Cumberland stitchwort	N	Inc	N	U	SI	N	Inc	GI	Inc	N	N	SI	N	NA	N	N	U	SD	NA	U	PS
Helianthus eggertii	Eggert's sunflower	N	N	N	U	SI	N	SD	SI	SD	SD	N	SD	N	NA	N	N	N	SD	NA	U	IL
Panax quinquefolius	Ginseng	N	N	N	U	N	SD	N	N	N	N	N	SD	N	NA	N	U	U	SD	NA	U	IL
Scutellaria montana	Large-flowered skullcap	N	N	SI	U	SI	N	N	SI	N	N	N	SD	N	NA	N	N	N	SD	NA	U	PS
Dalea foliosa	Leafy prairie-clover	N	N	SI	U	SI-N	N	N	Inc	GI	SD	N	N	N	NA	N	N	N	SI	NA	U	MV
Clematis morefieldii	Morefield's leatherflower	N	N	N	U	SI	N	N	Inc	N	N	N	N	U	NA	N	N	N	U	N	U	PS
Buckleya distichophylla	Pirate bush	N	N	N	U	Inc	SD	N	Inc	N	N	N	N	N	NA	N	U	N	U	U	U	PS
Apios priceana	Price's potato bean	N	N	SI	U	SI	N	N	SI	N	N	N	SD	N	NA	N	N	N	U	N	U	PS
Astragalus bibullatus	Pyne's ground-plum	N	Inc	GI	U	Inc	N	N-SD	Inc	N	N-SD	N	Inc	N	NA	N	N	U	Inc	NA	U	EV
Hedyotis purpurea var. montana (syn. *Houstonia montana*)	Roan Mountain bluet/Venus' pride	N	SI	N	U	Inc	GI	GI	GI	N	N	N	N	N	NA	N	N	U	U	U	U	EV
Gymnoderma lineare	Rock gnome lichen	N	Inc	Inc-	N	Inc	SI	Inc	GI	Inc	N	N	N	N	NA	N	N	N	U	U	U	EV

Table 24. Indirect exposure and sensitivity factors for selected Tennessee plants																						
Scientific Name	**Common Name**	**Indirect Exposure Factors**				**Sensitivity Factors**																
		Sea-level rise	**Natural barriers**	**Anthropogenic barriers**	**Human response to climate**	**Dispersal and movements**	**Historical thermal niche**	**Physiological thermal niche**	**Historical hydrological niche**	**Physiological hydro niche**	**Dependence on disturbance**	**Dependence on ice, snow**	**Restricted habitat features**	**Depend on spp for habitat**	**Dietary versatility (animals)**	**Pollinator versatility (plants)**	**Propagule dispersal**	**Other interspecific**	**Measured genetic variation**	**Evolutionary Bottlenecks**	**Phenological response**	**Index Score**
				SI																		
Pityopsis ruthii	Ruth's golden aster	N	GI	N	U	SI	N	N	GI	N	N	N	SI	N	NA	N	N	N	Inc	NA	U	EV
Physaria globosa (syn. *Lesquerella globosa*)	Short's bladderpod	N	SI	Inc	U	SI	N	N-SD	Inc	N	SD	N	N	N	NA	N	N	U	U	SI	U	HV
Isotria medeoloides	Small whorled pogonia/little five leaves	N	N	N	U	N	N	N	Inc	N	N	N	Dec	N	NA	N	N	N	SI	NA	U	PS
Geum radiatum	Spreading avens/ Appalachian avens	N	GI-Inc	N	N	N	SI	Inc	SI	N	N-SD	N	N	N	NA	N	N	N	SI	NA	U	HV
Paysonia perforata (syn. *Lesquerella perforata*)	Spring Creek bladderpod	N	Inc	GI	Inc	SI	N	N	GI	SI	N	N	N	N	NA	N	N	N	N	NA	U	EV
Echinacea tennesseensis	Tennessee purple coneflower	N	N	Inc	U	SI	N	SD	GI	N	SD	N	N	N	NA	N	N	N	N	NA	U	MV
Xyris tennesseensis	Tennessee yellow-eyed grass	N	Inc	N	U	U	N	N	GI	GI	N	N	N	N	NA	N	U	U	Inc	NA	U	EV
Spiraea virginiana	Virginia spiraea/ Virginia meadowsweet	N	Inc	N	U	Inc	N	N	SI	Inc	N	N	N	N	NA	N	N	N	SI	NA	U	HV
Platanthera integrilabia	White fringeless orchid/ monkey-face orchid	N	SI	SI	U	N	N	N	Inc	GI	N	N	N	N	NA	SI	U	SI	U	U	U	HV
Helianthus verticillatus	Whorled sunflower	N	N	Inc	U	SI	N	N	GI	GI	N	N	SI	N	NA	N	N	N	SD	NA	U	EV