Climate Change and Potential Impacts to Wildlife in Tennessee

An Update to Tennessee's State Wildlife Action Plan

2009

Tennessee Wildlife Resources Agency

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Executive Summary

The focus of this document centered on identifying the potential impacts, both positive and negative, to wildlife and their habitats that a changing climate will cause. This was accomplished by conducting a literature review of pertinent climatological and biological research papers and reports; then where possible relating those findings to the habitats and faunal groups of Tennessee.

In order to depict possible future conditions, various results of several models were described. The climate models discussed and the results shown are for example and discussion only. This document does not state or imply the validity of one model over another or one future condition over another.

Modeling climate change is a very complicated process. Climate models used today simulate the interactions of the atmosphere, oceans, land, and sea ice. Various models handle these components and their interactions differently, thus producing different results. The International Panel on Climate Change (IPCC) was created by the World Meteorological Organization and the United Nations Environmental Program to provide policymakers with an objective source of information on climate change impacts and adaptation and/or mitigation strategies. This latest IPCC report, issued in 2007, states "warming of the climate system is unequivocal". The report also sites observational data of natural systems that are already being affected by regional climate changes, especially temperature increases.

The potential impacts discussed below are based on assumptions that Tennessee's climate will warm over the remainder of the 21st century and precipitation may increase or decrease.

Potential Effects of Climate Change on Tennessee Forests

Mississippi Alluvial Valley –

- Current modeled forest -72% elm-ash-cottonwood forest type, 28% consisting of the oak-hickory
- Projected change under high carbon conditions - the elm-ash-cottonwood decreases to 46% and oak-hickory increases to 54%
- Projected change under low carbon conditions - the elm-ash-cottonwood decreases to 52% and oak-hickory increases to 48%
- Initially significant declines in forest biomass, followed by increases in forest biomass

Upper Gulf Coastal Plain

- Current modeled forest -80% of the UGCP consisting of oak-hickory type, 15% elm-ash-cottonwood forest type, 2% of oak-pine type, with remaining 3% without available data
- Projected change under high carbon conditions - the oak-hickory increases to 86%, elm-ash-cottonwood decreases to 6%, while oak-pine increases to 5% and loblolly-shortleaf pine disappears
- Projected change under low carbon conditions - the oak-hickory increases to 84%, elm-ash-cottonwood decreases to 7%, while oak-pine increases to 5% and loblolly-shortleaf pine disappears
- Slight to marked decline in forest biomass

Interior Low Plateau

- Current modeled forest -89% oak-hickory type, 4% elm-ash-cottonwood, 4% loblolly-shortleaf pine forest types, 2% oak/pine type, with remaining 1% without available data
- Projected change under high carbon conditions - the oak/hickory increases to 97% conditions, oak/pine remains at 2%, and elm/ash/cottonwood and loblolly/shortleaf pine types disappear, with remaining 1% without available data
- Projected change under low carbon conditions - oak/hickory decreases to 83%, oak/pine increases to 16%, and elm/ash/cottonwood and loblolly/shortleaf pine types disappear, with remaining 1% without available data
- Declines in forest biomass, followed by increases in forest biomass, with die-off of less adaptable tree species in the forest canopy, especially for the loblolly/shortleaf pine and elm/ash/cottonwood forest types

Cumberland Plateau and Mountains

- Current modeled forest -97% consisting of oak-hickory type, 3% without available data
- Projected change under high carbon conditions - oak-hickory decreases to 90% and oak-pine increases from 0% to 7%, with remaining 3% without available data
- Projected change under low carbon conditions – oak-hickory decreases to 83%, and oak-pine increases from 0% to 14%, with remaining 3% without available data
- eastern hemlock to disappear completely due to the hemlock woolly adelgid epidemic

Ridge and Valley

- Current modeled forest -94% oak-hickory type, with the remaining 6% without available data
- Projected change under high carbon conditions oak-hickory decreases to 62% and oak-pine increases from 0% to 32%, with remaining 6% without available data
- Projected change under low carbon conditions- oak-hickory decreases to 36%, and oak-pine increases from 0% to 58%, with remaining 6% without available data
- widespread decline of the less adapted oaks and other tree species that currently comprise the overstory, resulting in an increase in canopy gaps of varying sizes

Southern Blue Ridge

- Current modeled forest -84% oak-hickory type, 14% consisting of maple-beech-birch type, with the remaining 2% without available data
- Projected change under high carbon conditions -oak-hickory decreases to 75%, oak-pine increases from 0% to 24%, and the maple-beech-birch type disappears, with remaining 2% without available data
- Projected change under low carbon conditions- oak-hickory decreases to 65%, oak-pine increases from 0% to 33%, and the maple-beech-birch type disappears, with remaining 2% without available data
- Increase in diversity of Appalachian Forest with a shift of dominant species. Chestnut oak increases initially and then declines in terms of its contribution to stand biomass, basswood increases in biomass, and hickory diversity and biomass also increase.

Diseases and Insects

- Climate change could intensify infestations of the native southern pine beetle and could result in 4 to 7.5 times the current annual mortality of pines
- Warmer temperatures may enhance the spread of hemlock woolly adelgid

- Changing precipitation and temperatures patterns will increase the likelihood of pests and mortality associated with loblolly pine. Use of the tree expected to increase due to meet market demands.

Fire

- Climate change may result in the increase of forest fire intensity, extent, and frequency.
- Under the warmer climate scenarios, catastrophic fire could be the major change agent for decline of southeastern forests.

Potential Effects of Climate Change on Tennessee Birds

- Bird populations will likely experience a variety of impacts of climate change, but on a per species or "suite" basis.

- Nongame birds found in wetlands and mature forests may suffer declines in Tennessee with habitat loss, northward range shifts, and reduced reproductive success related to mistimed spring arrival with peak insect emergence, reduced insect availability with drought conditions, poor physical condition upon arrival on breeding ground related to poor conditions on winter grounds.

- Nongame birds associated with early succession habitat, i.e. grasslands, scrub-shrub, and pine or oak savannas, may benefit with increased habitat availability.

- Resident nongame birds may not be impacted greatly by climate change; however some residents may increase with greater availability of early succession habitat.

- Short-distance migrant non-game birds may have earlier spring arrival dates, earlier nesting, and some species may soon be found spending the winter in Tennessee.

- Long-distance migrant non-game birds will likely suffer the greatest declines with the confounding factors of reduced winter habitat quality (i.e. more xeric) and direct loss of winter habitats in the tropics, thus birds may arrive to breed when in poor physical condition.

- Northern Bobwhite and Ruffed Grouse populations may increase with increased early succession habitats, if the habitats and populations are managed properly.

- Migratory waterfowl populations are generally expected to decrease with lower reproductive success on northern breeding grounds.

- Migratory waterfowl populations in winter in Tennessee are expected to decline as winter weather is warmer, retaining open water conditions to the north, thus many birds will stay further north. Migratory Canada Geese populations in Tennessee have declined dramatically over the last 30 years. Expanding this trend to other waterfowl will likely reduce hunting opportunities for other waterfowl in Tennessee.

- Resident waterfowl, i.e. wood ducks and Canada geese, may decline with drier conditions, reducing hunting opportunities.

Potential Effects of Climate Change on Tennessee Amphibians

- Wetland acreage may be reduced and aquatic and semi-aquatic species will suffer declines as habitat disappears. Because species distributions are a function of dispersal ability, amphibians may suffer more than other vertebrates.

- Species range expansions or contractions may be experienced. The bird-voiced treefrog (*Hyla avivoca*) is known from the Coastal Plain of West Tennessee and along the lower Cumberland River in Middle Tennessee to near Ashland City. It has been observed in Cheatham County since 1995. This species is expanding its range and abundance in Cheatham County.

- The Green Treefrog (*Hyla cinerea*) is expanding eastward in range. The west Tennessee species can now be found in Hamilton and Anderson Counties. Possible explanations may be climate change, anthropogenic interference or the release of pet Green Treefrogs.

Potential Effects of Climate Change on Tennessee Caves, Karst and Bats

- Indiana bats prefer cold air caves and will only hibernate in caves that have stable winter temperatures ranging from 37 - 43 degrees F. Caves that are currently at the upper end of this range could become unsuitable for Indiana bats.

- Cave crickets are a primary energy source for caves, especially dry caves. Cave Crickets exhibit extreme thermal sensitivity. Reduced or elimination of cave cricket populations could disrupt energy flow resulting in trophic level alterations or collapse in some caves.

- Karst aquifers are important to both to the surface and subsurface ecology of a region and to domestic water supplies. If drought cycles increase in regularity and intensity these ground water resources could become dry.

Potential Impacts of Climate Change on Tennessee Nonvolant Mammals

- Changes in forest composition from oak/hickory forests to savannah-like conditions could significantly impact forest mammals.

- Range contraction or expansion of small mammal species is likely, especially in high elevations.

- Species restricted to high elevation, cool, humid habitats may be lost in Tennessee.

Potential Impacts of Climate Change on Tennessee aquatic environments and aquatic life

- With warming temperatures, the Tennessee River Basin is expected to undergo greater water stress during the remainder of the 21st century than other regional basins.

- Droughts and increased water demand can affect hydrologic changes in microhabitats, reduced wetted area and degrade water quality. Droughts reduce invertebrate production, disrupt fish migrations, and expose all fauna to higher water temperatures, and lower dissolved oxygen resulting in stress and mortality

- Effects on fish and mussel populations are expected to be greatest in mountainous parts of the Cumberland Plateau and east Tennessee where large numbers of endemic species exist.

- Increased water withdrawals may also be anticipated if demands for irrigation and other forms of human consumption respond to rising temperatures and longer growing seasons.

- The coldest headwaters and spring influenced habitats are at risk of being lost due to increased air temperature. Brook trout are likely to lose the most habitat. Brown and rainbows might be able to shift upstream in a warmer headwater habitat, while the brook trout will have no upstream alternative

- In large tributary reservoirs an increase in temperature will negatively affect cool to coldwater fish habitat and possibly benefit some warmwater species. With suggested temperature increases, warmwater reservoir habitat in tributary impoundments would still be within an acceptable range for most warmwater species, such as largemouth bass, crappie, catfish, and bluegill. Conversely smallmouth bass will likely lose habitat due to increased temperature and turbidity in streams and rivers, and sections of reservoirs.

- If winter temperatures become warmer, winter shad kills in reservoirs could be rare.

- Tributary impoundments will be required to release any runoff that accumulates during the spring flood season. During discharge warm runoff stays on the surface of the reservoir while deeper cold water is discharged via the turbines. As this cold water is discharged, it cannot be replaced until next winter, thus coldwater habitat is lost for that summer season. In this event these tailwater trout fisheries could loose several years of trout production including highly valued trophy-sized trout.

- Excessive sedimentation is the number one nonpoint pollutant in Tennessee. Increased precipitation will increase non-point runoff and sedimentation in areas of poor or inadequate riparian buffer. Increased sedimentation can cause smothering of fish eggs.

- If turbidity does increase on reservoirs we will expect to see a shift away from black crappie towards more white crappie in these waters.

- Warmer temperatures could improve TWRA’s management options for introducing Florida-strain largemouth bass.

- Both the striped bass and the Cherokee bass can be expected to loose habitat in a warming climate.

- Even a minor increase in temperature will reduce production at our cold water hatcheries, and an increase of 4 ^{o}C or more would require cost prohibitive measures (operating of cooling units) to maintain production year-round. The current supply of spring water is reduced at our hatcheries during dry periods in the summer and fall. Severe droughts would greatly reduce water supply and our production capacity. The loss of any of these hatcheries for one season of the year would greatly disrupt statewide production schedules and the size of trout available for stocking.

Adaptation Strategies to Address Potential Impacts of Climate Change on habitats and Wildlife

- Uncertainties on future climate change impacts and wildlife response, particularly in the southeastern United States, suggest that for at least the short term, wildlife agencies should focus their adaptation activities and efforts on reducing the known stresses to wildlife and ecosystems from sources other than climate change.
- In June 2008, the U.S. Climate Change Science Program issued a report entitled Adaptation Options for Climate-Sensitive Ecosystems and Resources (Julius et al. 2008). A key finding of this report is included in the following excerpt: *"Many existing best management practices for "traditional" stressors of concern have the added benefit of reducing climate change exacerbations of those stressors.*
- Seven "adaptation approaches" are offered by the CCSP report: 1) Protecting key ecosystem features; 2) Reducing anthropogenic stresses; 3) Representation; 4) Replication; 5) Restoration; 6)Refugia; 7) Relocation.
- Some examples of protecting key ecosystem features would include: 1) Maintain or establish riparian buffers along streams to lessen impacts of temperature increases; 2) Protect headwater streams of priority aquatic systems (e.g., Duck River, etc.); 3) Maintain or establish corridors to facilitate migration routes for species and/or populations, and to facilitate gene flow;
- Anthropogenic stresses are expected to increase in Tennessee and the southeastern region of the United States for the next several decades, with continued population growth, and the impacts of urbanization on the waters and landscapes of the region. Projections indicate that an additional 2 million people will make Tennessee their home by 2025, bringing our state's population to 8 million. Strategies to mitigate these stresses should be adopted as part of a climate change adaptation program.
- Representation – Ensuring that biological systems come in a variety of forms will provide some level of resilience. We should maintain a mixture of habitat types, protect Priority conservation areas identified in Tennessee's State Wildlife Action Plan, and maintain numerous viable populations (SWAP species goals and objectives).
- Replication - Maintain numerous viable populations (SWAP species goals and objectives), Protect strategically important lands and waters through fee acquisition or conservation easement (Priority conservation areas identified in Tennessee's State Wildlife Action Plan)
- An important adaptation strategy for TWRA will be the restoration of habitats and ecosystems, to support GCN species and other priority fish and wildlife. Of particular

relevance to climate change is terrestrial carbon sequestration, especially in bottomland hardwood systems.

- The potential for restoring ecosystem functions and sequestering carbon through re-foresting bottomland hardwoods has been demonstrated in the Lower Mississippi Valley Joint Venture, through work by the US Fish and Wildlife Service, Ducks Unlimited, The Nature Conservancy, and other conservation organizations active in this region.
- Refugia – refugia refers to areas or environments that are less affected by climate change than other areas. In many ways, strategies for creating refugia are included in the strategies above, such as representation or restoration. Acquisition and/or protection of subterranean systems may be good candidates for this strategy.
- Vulnerability Assessments – research should be conducted to determine and identify those species and ecosystems that are most vulnerable to climate change.
- Monitoring and Adaptive Management – long term monitoring systems that are strategically designed to evaluate climate change impacts and wildlife responses are a high priority for TWRA.

Introduction

On October 1, 2005 the U. S. Fish and Wildlife Service received Tennessee's Wildlife Action Plan (formerly known as Comprehensive Wildlife Conservation Strategy). This plan was the effort of a broad array of partners including other government agencies, conservation groups, private landowners, and the public.

Tennessee's Wildlife Action Plan identified 686 species of greatest conservation need (GCN) and mapped priority conservation areas based on GCN species occurrence and habitat preferences. To address potential problems facing GCN species, 5 major stress categories were identified (Table 1.) with 37 individual sources of stress. During plan development, information on impacts of climate change was beginning to emerge in the literature. Climate change was identified as an issue of concern yet the availability of regional data and our understanding of the implications, was not sufficient for including climate change as a potential source of stress.

In the plan, a total of 97 conservation actions were identified to address, singularly or in combination, the 37 identified sources of stress. Many of the conservation actions put forth will facilitate wildlife acclimation and adaptation to climate change, yet, since the issue was not addressed, actions were not thoroughly discussed or directly linked.

This addendum to Tennessee's Wildlife Action Plan will summarize pertinent literature, identify implications to habitats and faunal groups and propose conservation actions to address climate change in Tennessee.

Global Climate Change

In 1988 the World Meteorological Organization and the United Nations Environmental Program established the Intergovernmental Panel on Climate Change (IPCC). The IPCC was created to provide policymakers with an objective source of information on climate change and its impacts, as well as, adaptation and mitigation strategies. To that end, three working groups were established. Working Group 1 focuses on the physical basis of climate change, Working Group 2 centers on impacts, adaptation and vulnerabilities, and Working Group 3 concentrates on mitigation of climate change. Since its inception, the IPCC has issued a series of climate reports with the fourth and latest report being *Climate Change, 2007.*

This latest IPCC report states “warming of the climate system is unequivocal” (IPCC 2007). Observational data indicates natural systems are already being affected by regional climate changes, especially temperature increases. Changes in snow, ice and frozen ground has resulted in increased number and size of glacial lakes, ground instability (melting permafrost), increased run-off and earlier spring peak discharge. Earlier timing of spring events (bird nesting) and northern shifts and altitudinal shifts in some plants and animal distributional ranges are consistent with a warming climate.

North America Impacts

Warming is not spatially consistent. The global spatial distribution of warming indicates strongest warming in the interiors of Asia, northwestern North America and mid-latitude areas of the Southern Hemisphere (Trenberth et al. 2007) (Figure 1). Likewise spatial patterns of precipitation have shown an increase in the average annual precipitation over most of North America, especially the high latitudes of Canada. An exception, a decrease in precipitation has occurred in the southwest U.S. and parts of South America (Trenberth 2007) Figure 2).

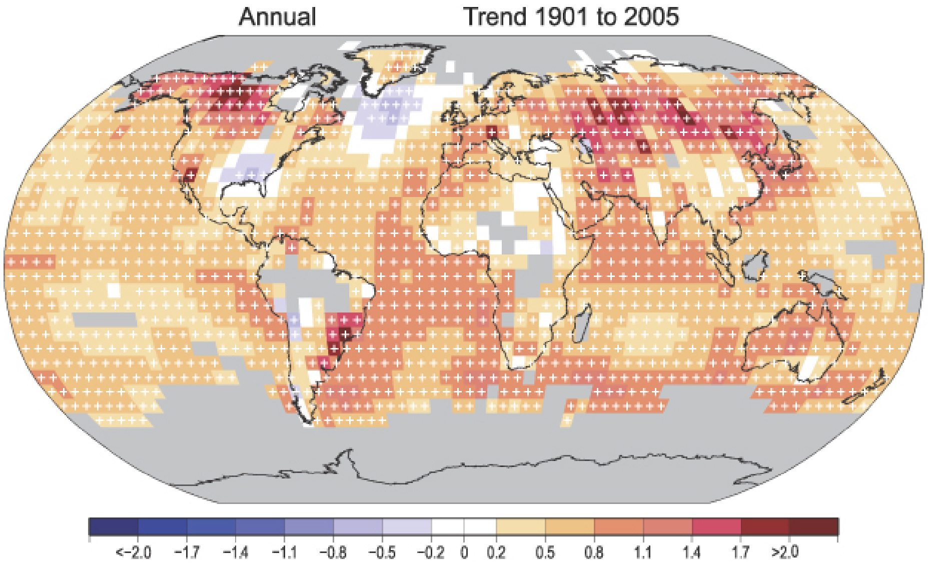


Figure 1. Geographical distribution of global temperature trends, 1901 to 2005. Taken from Trenberth 2007.

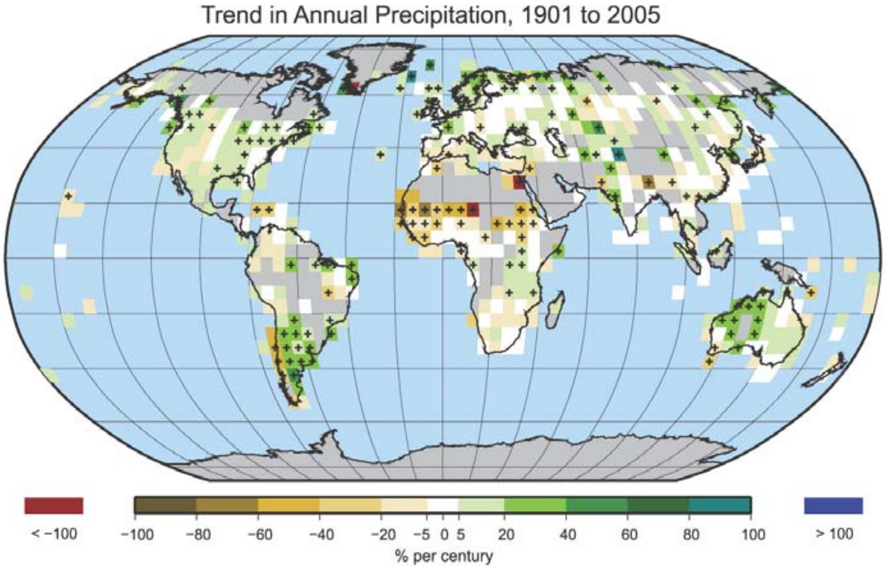


Figure 2. Geographical distribution of global precipitation trends,

1901 to 2005. Taken from Trenberth 2007.

Impacts to ecosystems in North America may be negative or positive depending on location. A northern shift in vegetation and forest types could potentially occur resulting in habitat changes (Watson et al. 1997) and animal distributions. Forest density may decline in some areas and increase in others. Increased frequency and size of wildfires, drying of the prairie pothole region and changes in cool/cold water species distributions could be expected.

Climate Trends in the Southeastern U.S

Climate models predict varied outcomes for the southeastern U.S. The Hadley Climate Model and the Canadian Climate Model predict increased warming with the Canadian model suggesting a higher degree of warming and subsequent drying, while the Hadley model predicts less warming and increased precipitation.

The Hadley model predicts the southeastern U.S. may be the least effected region of the country in terms of increased temperature (NAST 2001). The model predicts a 1.8 F increase in temperature by 2030 and a 2.3 F increase by 2100 (Fig. 3). Conversely, the Canadian model predicts the southeastern U.S. will experience the highest increase in temperatures when compared to the nation as a whole, 3.0 F increase by 2030 and a 10.0 F by 2100 (NAST 2001). Additionally, summer temperatures in the southeast are predicted to increase 5 F by 2030 and 12 F by 2100.

Fig. 3. Observed conditions and predicted model scenarios for temperature in the southeast due to climate change.

There is not agreement between the two models in terms of precipitation across the southeastern U.S (Fig. 4.). The Hadley model suggests a slight decrease in precipitation through 2030 then an increase in precipitation, as much as 20% by 2090. The Canadian model suggests 10% less precipitation by 2090 with little change until 2030. Associated parameters such as soil moisture follow predictions. The Hadley model predicts increased soil moisture while the Canadian model simulates drying by 2090 (NAST 2008).

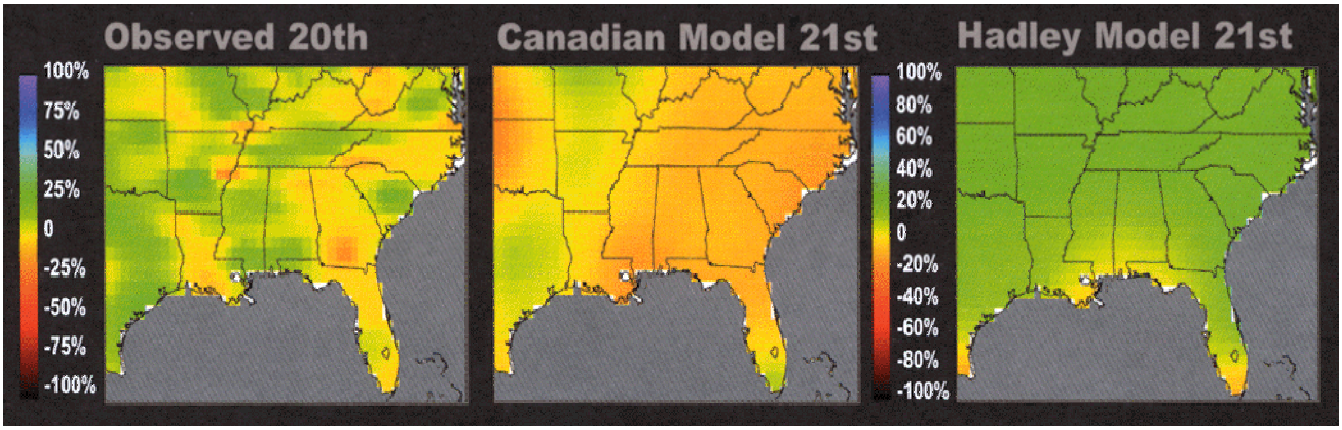


Fig. 4. Observed conditions and predicted model scenarios for precipitation in the southeast due to climate change.

Tennessee's Current Climate

Tennessee is a rectangular state that stretches west to east from longitude of approximately -90 to -81 and south to north, latitudes 35 to 36.5. Precipitation in the state is influenced by the Gulf of Mexico with a general decrease in amounts south to north (SRCC 2004). Primarily, much of the states precipitation occurs in winter and early spring with a secondary peak in mid-summer. Over the past 111 years, average annual precipitation ranged from a low of 35.6 to a high of 66.6inches per year with considerable variability. (Fig.5.). Local amounts can be extreme as exampled by mountain-affect rainfall with precipitation at Mt. LeConte, in the Great Smoky Mountains, reaching about 81 inches per year.

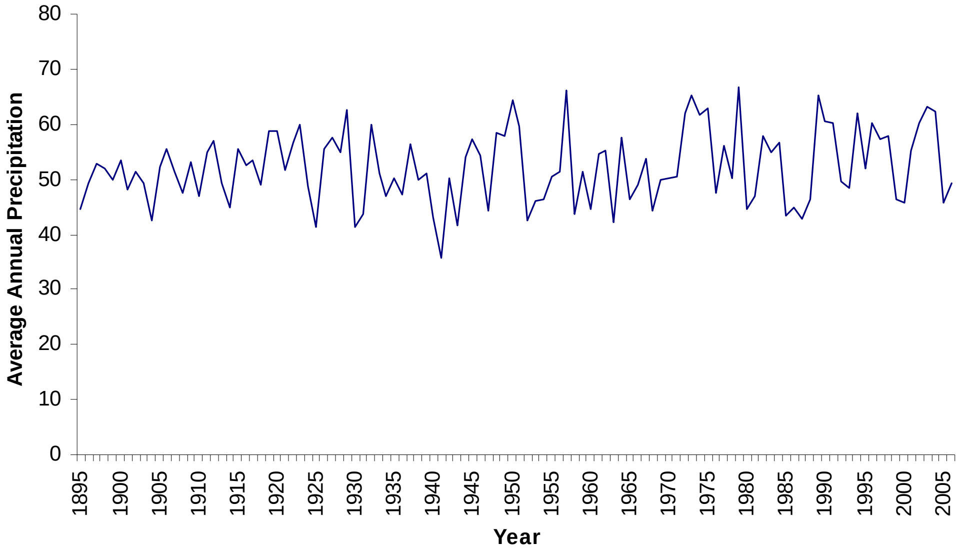


Fig. 5. Annual average precipitation, 1895 through 2006. Data from National Climate Data Center, 2008.

Average annual temperature has varied over the last 111 years (Fig.6.). Annual temperature has ranged from 55.5 F to 61 F with considerable variability. Again local topographic and environmental conditions can cause extreme affects with Mt. LeConte averaging 42 F annually.

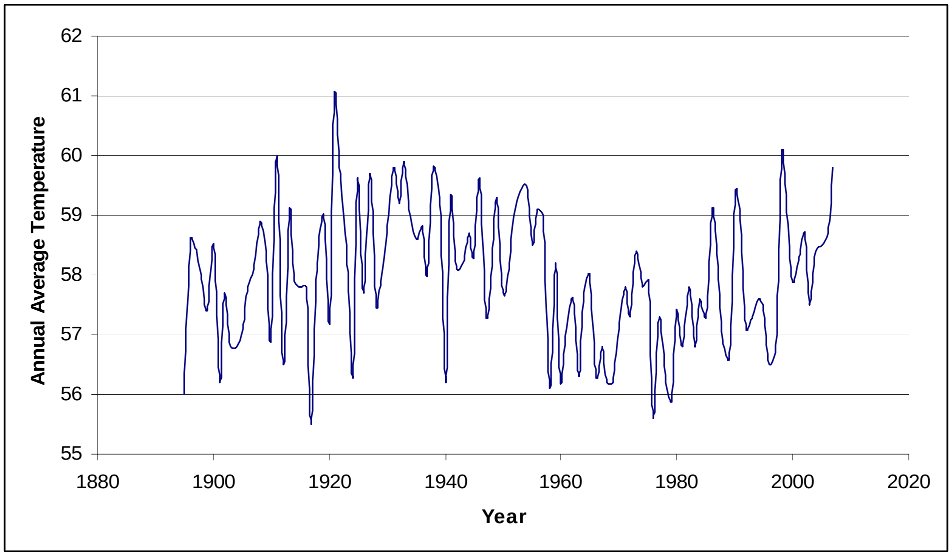


Fig. 6 . Annual average temperature, 1895 through 2006. Data from National Climate Data Center, 2008.

Potential Climate Change for Tennessee.

To demonstrate potential climate change in Tennessee, a web-based interactive software created by The Nature Conservancy, the University of Washington, and the University of Mississippi. was utilized. This software employs three general circulation models, CSIRO-MK3.0 developed in Australia, the MIROC3.2 (meters) developed in Japan, and IKMO-HadCM3 developed in the United Kingdom. The user can select a specific model or see the ensemble results of all models. The wizard also allows users to select one of three emission scenarios for the model results. These three scenarios are three of the six defined by the IPCC (2000) and represent possible future conditions. Each scenario assumes differing values for global population, economy, technology, energy, land use, and agriculture. For a more complete scenario description refer to the documentation for the climate wizard at http://www.climatewiz.org/CWLite.html or the IPCC Special Report on Emission Scenarios (IPCC 2000).

For use here, ensemble model results from emission scenario a1b are provided for Tennessee. These model and emission selections were chosen to depict middle-of-the-road model results. For precipitation and temperature, changes in Tennessee climate are shown in figures 7 and 8.

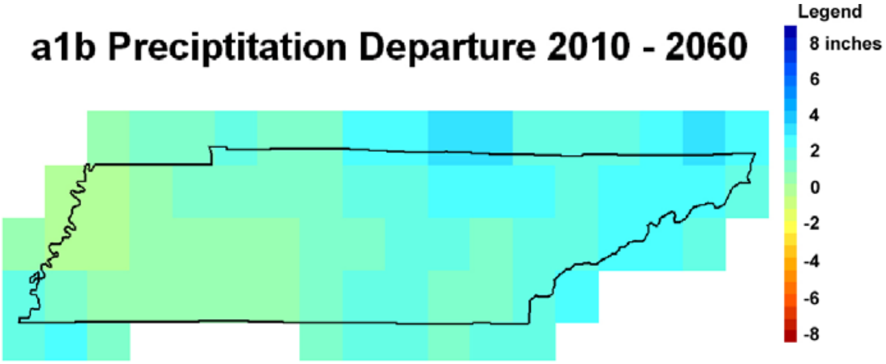
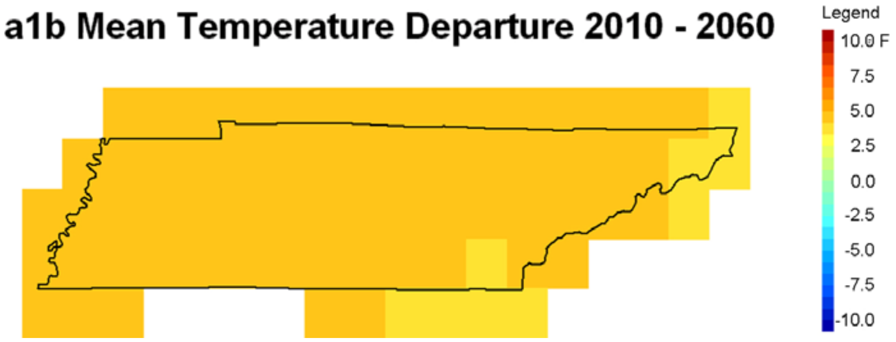


Figure 7. Change in precipitation across Tennessee during the period of 2010-2060.

Figure 8. Change in temperature across Tennessee during the period of 2010-2060.



Regardless of the models used, the climate of the southeastern U.S. and Tennessee is expected to change and impacts to habitats and wildlife may occur for decades to come. Furthermore, the cumulative impacts of a changing climate in concert with other sources of stress could produce significant impacts to Tennessee's incredible diversity of habitats and wildlife.

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Potential Effects of Climate Change on Tennessee Forests

Tennessee forests are ecologically characterized as part of two major Forest Regions of the Eastern Deciduous Forest: Mixed Mesophytic and Southeastern Evergreen (Braun 1950, Dyer 2006). The Southeastern Evergreen Forest Region is represented in Tennessee by bottomland and swamp forest communities associated with the Mississippi Alluvial Plain that is commonly referred to as bottomland hardwoods (Braun 1950).

Broadly speaking, the ecological and silvicultural classifications of forests correspond to the physiographic regions of Tennessee as follows. The Southeastern Evergreen Forests (bottomland hardwoods) correspond directly with the Mississippi Alluvial Plain. Mixed Mesophytic Forest corresponds with the Upper Gulf Coastal Plain and Interior Low Plateau. The Cumberland Plateau and Mountains, Ridge and Valley, and Southern Blue Ridge are in the Mixed Mesophytic Forest.

All of the forest associations of Tennessee have been influenced by logging, clearing for agriculture, pollution (Tkacz et al. 2007), and various levels of human development (Macie and Hermansen 2003). Introduced exotic and invasive plants compete with native forest vegetation (Baiser et al. 2008, Inderjit et al. 2008, Mason et al. 2008), herbivory of increased white-tailed deer (*Odocoileus virginianus*) populations have impacted some species (Baiser et al. 2008, Tripler et al. 2005), and introduced disease and insect pests have reduced or eliminated some species (Koch 2006). Most notable in the latter case is the dramatic loss of American chestnut in the early 20th Century (Ellison et al. 2005). The allelopathic qualities of the American chestnut allowed this species to have foundation status (Ellison et al. 2005, Vandermast et al. 2002). Lack of fire has significantly altered the composition of the forest communities of Tennessee (Nowacki and Abrams 2008) and the extinction of the passenger pigeon (*Ectopistes migratorius*) is thought to have changed species composition of forests (Ellsworth and McComb 2003). As such, composition and successional patterns have been altered by many and interacting factors. Climate change may be only one factor in the future.

However, despite the human related alterations, in order to fully understand how forests might change due to future human induced climate change, we must understand what the forests are like in terms of tree composition. Specific forest community types are well described in Braun (1950) and Eyre (1980). Favored species common and scientific names are from Kirkman et al. (2007).

<u>Mississippi Alluvial Plain bottomland forests</u>— Forests in this region consist primarily of swamp forests dominated by bald cypress (*Taxodium distichum*), and water tupelo (*Nyssa aquatica*), and

hardwood bottoms comprised of red maple (*Acer rubrum*), boxelder (*A. negundo*), swamp chestnut oak (*Quercus michauxii*), overcup oak (*Q. lyrata*), willow oak (*Q. phellos*), water oak (*Q. nigra*), Nuttall's oak (*Q.* texana), cherrybark oak (*Q. falcate var. pagodifolia*), green ash (*Fraxinus pennsylvanica*), pumpkin ash (*F. profunda*), and sweetgum (*Liquidambar styraciflua*) (Braun 1950).

Upper Gulf Coastal Plain Mesophytic Forest— The Mesophytic Forest in the UGCP is transition between the Mixed Mesophytic Forest to the east (Cumberland Plateau and Mountains) and the Oak-Hickory forest found to the north and west and is similar to the Mesophytic Forest found in the adjacent Interior Low Plateau. This forest was originally considered the Western Mesophytic Forest by Braun (1950) but has since been considered as the same forest by Dyer (2006). However, as a general rule slope forests have American beech (*Fagus grandifolia*), sugar maple (*A. saccharum*) , yellow-poplar (*Liriodendron tulipifera*), white oak (*Q. alba*), white ash (*F. Americana*), northern red oak (*Q. rubra*), black oak (*Q. velutina*), Shumard oak (*Q. shumardii*), blackgum (*N. sylvatica var. sylvatica*) , pignut hickory (*Carya glabra*), and other oaks and hickories. Dry sites on west or south facing slopes will be predominately chestnut oak (*Q. montana*), and other dry site oaks, and hickories. Mesophytic forest is not present in some areas due to lack of sufficient time since anthropogenic disturbance (Franklin and Kupfer 2004) or lack of disturbance (Eickmeier 1988) complicated by all of the forest alterations as noted above.

Interior Low Plateaus Mesophytic Forest— The Mesophytic Forest in the ILP is transition between the Mixed Mesophytic Forest to the east (Cumberland Plateau and Mountains) and the Oak-Hickory forest found to the north and west and is similar to the Mesophytic Forest of the adjacent UGCP. This forest was originally considered the Western Mesophytic Forest by Braun (1950) but has since been considered as the same forest by Dyer (2006). Slope forests have American beech, sugar maple, yellow-poplar, white oak, white ash, northern red oak, black oak, Shumard oak, blackgum, pignut hickory, and other oaks and hickories. Dry sites on west or south facing slopes are predominately chestnut oak, and other dry site oaks, and hickories. Mesophytic forest is not present in some areas due to lack of time since anthropogenic disturbance (Franklin and Kupfer 2004) or lack of disturbance (Eickmeier 1988) complicated by all of the forest alterations as noted above.

Cumberland Plateau and Mountains— This forest comprises the classical mixed mesophytic forest as originally outlined in Braun (1950). Historically the forest was dominated by American beech, yellow poplar, white basswood (*Tilia americana var. heterophyla*), sugar maple, yellow buckeye (*Aesculus flava*), chestnut oak, northern red oak, white oak, and eastern hemlock (*Tsuga canadensis*) on moist and well drained sites (Braun 1950). The optimum development of this forest is in the Cumberland Mountains portion of these two regions. This forest is comprised of a complex of many site-specific communities dominated in various ways by the above mentioned tree species. Hemlock is always confined to lower slopes such as along streams. Areas of shallow sandy soils should typically be dominated by Virginia pine (*Pinus virginiana*), shortleaf pine (*P. echinata*), or pitch pine (*P. rigida*).

Ridge and Valley/Southern Blue Ridge— This region contains the highest elevations in Tennessee. The original forest was oak-chestnut and is now greatly modified by loss of the American chestnut (Braun 1950). The primary forest communities are northern hardwoods, spruce-fir, mixed mesophytic, and dry slope/ridge forests. The northern hardwoods forests are dominated by sugar maple, yellow birch (*Betula alleghaniensis*), American beech, yellow buckeye, white ash, and cucumbertree (*Magnolia acuminata*). Spruce-fir occurs at high elevations and consists of Fraser's fir (*Abies fraseri*) and red spruce (*Picea rubens*). Mixed mesophytic communities, essentially identical to those of the mixed mesophytic forest, occur in coves and lower north facing mountain slopes. Dry slope and ridge forests consist of various oaks with eastern white pine (*P. strobus*) or table mountain pine (*P. pungens*), the latter of which occurs on ridges and south facing slopes.

Potential Climate Change Effects

To date, research on effects of climate change on forests have focused on changes in distribution of individual tree species, abundance, richness, and community types (Iverson and Prasad 1998, Iverson et al. 1999, Schwartz et al. 2001, Iverson and Prasad 2001, Iverson et al. 2004, Iverson et al. 2005, McKenney et al. 2007, Iverson et al. 2008). In addition to native forest tree species, some exotic species may also change in distribution and abundance (Simberloff 2000). Changes to existing forests are likely to be nonlinear (Burkett et al. 2005) and lead to reassembly of forest communities (Schaeffer et al. 2008).

The above cited studies and some as yet unpublished data are used to provide an indication of forest change with climate change.

Research and Models Used in TWRA Report

Iverson et al. (2008) compared current modeled forest cover and tree species data with several future modeled predictions under varying climate scenarios (Fig. 9-11). Dr. Iverson and other personnel with the USDA Forest Service Northern Research Station, Delaware, Ohio, assisted us by manipulating this data for the Eastern United States to allow us to display it specifically for each of the six terrestrial ecosystems in Tennessee (see acknowledgements). For the TWRA report, we have chosen to compare their projections from current modeled scenario based primarily on Forest Inventory and Analysis (FIA) data in conjunction with 38 environmental variables used to predict the current distribution, the future Gcm3Hi scenario (the average of three climate change General Circulation Models combined with high carbon emissions, i.e., little conservation efforts to mitigate CO2 emissions), and the Gcm3Lo scenario (low carbon emissions due to significant conservation effort). These latter two models are projected through the year 2100. The models' forest cover type projections include all land in each ecoregion as potential forest habitat, including land currently in agricultural, urban, and other non-forest use; therefore, these models should be used more as general trends in forest cover type changes rather than predictors of actual area covered by each forest type.

We also present projections from Hodges et al. (forthcoming), who reports results of an assessment of potential changes in forest cover, recreational use, and the economic impacts for Tennessee for two future periods, 2030 and 2080, using three Global Climate Models (GCMs) resulting in what are described as dry, middle, and wet scenarios. Theirs is part of a larger report by Dale et al. (in review) that includes additional information on the climate projections and forest simulations for Tennessee. Hodges et al. (forthcoming) presents total forest biomass projections through these periods for each of the three scenarios, ending in the year 2300, and also describes some projected forest composition changes.

The five Bailey's Ecoregions used in Hodges' report vary from the six terrestrial ecoregions used by Tennessee SWAP (see Figs. 12-13 for comparison), the latter six ecoregions being used in conjunction with Iverson and Prasad's forest cover and tree species change projections (Figs. 9-11, Figs. 14-19, and Tables 2-7). These differences will be described below, under each of the 6 ecoregion descriptions. To briefly summarize forest composition changes in Hodges et al. (forthcoming), forest species composition shifted in all 5 ecoregions, with the hickories and hackberry became more dominant, basswood attaining more biomass in some scenarios and less in others, and both chestnut oak and black oak decreasing their biomass contribution to the forest. Compared to the 1989 equilibrium, the contribution of tree species to total biomass changed for all forest provinces in all climate change scenarios.

While the conclusions in Hodges et al. (forthcoming) exhibit some similarities to those of Iverson et al. (2008), there are also some conflicting results regarding some of the tree species that each predicts to increase or decrease in future abundance. We were not able to gain access to Dale et al. (in review) on which Hodges' conclusions were based (except for a related but separate report for the Northern Cumberlands by Dale et al. 2008 in press) and which contained more specifics regarding the predictions; therefore, we will base our species conclusions more heavily on Iverson et al. (2008), while using the conclusions of Hodges et al. (forthcoming) more for its predicted changes in forest biomass over time. However, we will cite Dale et al. (2008 in press) to describe changes in the Cumberland Plateau and Mountains ecoregion.

It is important to note that the predictions of Dale et al. (2008 in press) and Hodges et al. (forthcoming), which show rather large initial declines in forest biomass for some scenarios in all five ecoregions, do not consider the effect of increasing CO2 on forest stand structure. However, in another study, Hanson et al. (2005) simulated increased temperatures and wetter winters in a model that predicts an 11% increase in stand biomass over 100 years attributable to increased CO2, with little change in tree species composition of an east Tennessee forest dominated by tulip poplar, white oak, chestnut oak and red maple. This report states that although its conclusions are specific to the composition and characteristics of the upland-oak forest type in the study location on the Cumberland Plateau in Oak Ridge, Tennessee, they should be applicable to similar oak forests with deep soils located in the eastern United States. Iversen and Norby (2008) concluded after a five-year study on the effects of elevated CO2 in an east Tennessee closed canopy sweetgum stand that increased biomass occurred mostly due to fine-root production and not to increased wood production, as a result of limited nitrogen availability. Therefore, it is possible that increased CO2 will somewhat mitigate biomass losses predicted by Dale et al. (2008 in press) and Hodges et al. (forthcoming), but perhaps not result in the biomass gains predicted in Hanson et al. (2005).

<u>Mississippi Alluvial Plain (MAP) bottomland forests</u>—
The current modeled forest type data shows approximately 72% of the MAP consisting of elm-ash-cottonwood forest type, and 28% consisting of the oak-hickory forest type (Iverson et al. 2008). However, under the Gcm3Hi scenario, the elm-ash-cottonwood potential habitat decreases to 46% and oak-hickory increases to 54%. Potential habitat value is projected to

increase for a number of individual hardwood species including bur oak, water oak, willow oak, southern red oak, post oak, pecan, boxelder, silver maple, sugarberry, eastern cottonwood, winged elm, and black willow under this model, as well as for baldcypress and loblolly and shortleaf pines. Potential losers include sugar maple, black walnut, black cherry, and white oak.

Under the Gcm3Lo scenario, the elm-ash-cottonwood decreases to 52% and oak-hickory increases to 48% compared to the current modeled forest (Table 1, and Figs. 9-11). Potential habitat value is projected to increase for a number of individual tree species including water oak, willow oak, post oak, Shumard oak, pecan, boxelder, silver maple, sugarberry, eastern cottonwood, winged elm, and black willow under this model, as well as for loblolly pine. Potential losers include sugar maple, black walnut, black cherry, and Nuttall oak. For a more complete list of species' potential habitat values under the current and future modeled scenarios refer to Table 2 and Fig. 14.

Hodges et al. (forthcoming) presents forest changes under 3 climate scenarios for Bailey's Mississippi Riverine Forest, which roughly corresponds to SWAP Mississippi Alluvial Plain. The "dry" scenario predicts a marked decline in total forest biomass from 2030 to 2080, slowly increasing back to the 1989 level by 2300 (Fig. 20). The "wet" scenario predicts a less pronounced decline in total forest biomass before 2100, with an increase back to 1989 levels by 2300 (Fig. 20). The "middle" scenario predicts a slight decline in total forest biomass until 2100, and then an increase back to 1989 levels by 2300 (Fig. 20).

Projected biomass for the MS Riverine Forest declined in chestnut oak, black oak, basswood, and shumard oak. For the "dry" scenario, red maple, hickory, southern red oak, loblolly pine, and beech assumed dominance. For the "middle" and "wet" scenarios, hickory species represent about 40% of the stand biomass and hackberry about 30%.

Implications for Wildlife Habitat:
The changes in forest types described above are likely to be accompanied by significant declines in forest biomass, followed by increases in forest biomass, with die-off of less adaptable tree species in the forest canopy, especially for the elm/ash/cottonwood forest type, but also for components of the oak/hickory type. Hodges' model for the dry and wet scenarios shows large drops in biomass to almost the year 2100, then slow increases until leveling off occurs before 2200 (middle scenario shows a much smaller decline and increase). It is difficult to predict how this will impact wildlife habitat; however several general conclusions can be drawn. With widespread decline of the less adapted tree species that currently comprise the overstory, there will be an increase in canopy gaps of varying sizes. This will result in more understory vegetation and more early-successional wildlife habitat, especially where overstory decline is greatest (i.e., current elm/ash/cottonwood forest), until better-adapted tree species establish their place in the overstory.

This decline will be less dramatic in the current oak/hickory forest type, although there are still likely to be gaps created in the overstory as certain species decline, with the resulting increase in understory vegetation. Wherever the overstory declines, invasive exotic vegetation (ground vegetation, vines shrubs, and trees), especially those species which have benefited from increasing temperatures and carbon dioxide levels, may gain a foothold through increased light penetration to the forest floor, delaying and even preventing native tree species from regenerating or form attaining dominance in the canopy (Simberloff, 2000).

The large-scale expansion of the oak-hickory forest type will benefit wildlife species that depend highly on hard mast for food. Likewise, dramatic reduction of the elm/ash/cottonwood forest type will affect a number of wildlife species dependent on this forest type. Where tree mortality is greatest, the disappearance of areas of later-successional forest, most pronounced in the elm/ash/cottonwood type, will negatively affect interior forest wildlife species. The increase of early-successional forest, again, predominantly in the elm/ash/cottonwood type, will benefit early-successional wildlife species.

Forest land comprises approximately 24 % of the total land area of the five counties comprising the MAP (Schweitzer 1999). This is low compared to the Tennessee state average of 52% (Oswalt 2007), due to extensive conversion of 80% of the original MAP forests to agricultural in the 1960s and 1970s (Creasman et al. 1992), with agriculture remaining a predominant land use in the MAP today. Therefore, predicted large-scale declines in biomass and changes in forest succession and forest types could have profound effects on wildlife that depend on the relatively small amount of forest in the MAP (e.g., migrating waterfowl, neotropical migratory songbirds, amphibians). Rapid changes in forest structure could make it difficult for certain species to adapt to changes, especially species that do not have mobility to move to new habitat.

Upper Gulf Coastal Plain (UGCP)—Mesophytic Forest

The current modeled forest type data shows approximately 80% of the UGCP consisting of oak-hickory type, 15% consisting of elm-ash-cottonwood forest type, 2% of oak-pine type, a trace of loblolly-shortleaf pine type, with remaining 3% without available data (Iverson et al. 2008). However, under the Gcm3Hi scenario, the oak-hickory increases to 86%, and elm-ash-cottonwood decreases to 6%, while oak-pine increases to 5% and loblolly-shortleaf pine type disappears. Potential habitat value is projected to increase for a number of individual tree species under this model including blackjack oak, water oak, Shumard oak, post oak, bitternut hickory, black hickory, sugarberry, common persimmon, sweetgum, eastern cottonwood, black willow, winged elm, and shortleaf and loblolly pines. Potential losers include red maple, sugar maple, black walnut, yellow poplar, white oak, black oak, and black locust.

Under the Gcm3Lo scenario, the oak-hickory increases to 84%, and elm-ash-cottonwood decreases to 7%, while oak-pine increases to 5%, and loblolly-shortleaf pine type disappears (Table 1 and Figs. 9-11). Potential habitat value is projected to increase for a number of individual tree species under this model including blackjack oak, water oak, willow oak, Shumard oak, post oak, bitternut hickory, black hickory, silver maple, sugarberry, common persimmon, sweetgum, eastern cottonwood, black willow, winged elm, and shortleaf and loblolly. Potential losers include red maple, sugar maple, eastern redbud, black walnut, yellow poplar, white oak, black oak, and black locust. For a more complete list of species' potential habitat values under the current and future modeled scenarios refer to Table 3 and Fig. 15.

In Hodges et al. (forthcoming), Bailey's Central Tennessee Broadleaf Forest and Southern Mixed Forest combined roughly correspond to SWAP's Interior Low Plateau and Upper Gulf Coastal

Plain combined. The “dry” scenario for the Central and Southern Mixed Forests predicts a marked decline in total forest biomass from 2030 to 2080, with the Central Forest increasing to somewhat below the 1989 level by 2300, and the Southern Forest only remaining well below 1989 level by 2300 (Fig. 20). The “wet” scenario predicts a much less pronounced decline in total forest biomass before 2100, but greater for the Southern than for the Central Forest, with an increase to just below 1989 levels by 2300 (Fig. 20). The “middle” scenario predicts an early, slight decline in total forest biomass for the Central Forest, which increases slowly to 1989 levels by 2300, whereas the Southern Forest shows a slightly greater until 2100, with only a slight rebound through 2100 (Fig. 20).

The Southern Mixed Forest experienced the greatest alteration in forest composition among the provinces considered. Under the “dry” scenario, the Southern Mixed Forest becomes dominated by four species [loblolly pine (*Pinus taeda*) and three oaks]. The “middle” and “wet” scenarios both resulted in a greater dominance of hackberry and less biomass of basswood.

For the “middle” and “wet” scenarios, the Central TN Broadleaf Forest stands were dominated by six hickory species, hackberry, and basswood. For the “dry” case, the forest stands consisted mostly of four hickory species, white oak, southern red oak, and American beech.

Implications for Wildlife Habitat:

The changes in forest types described above are likely to be accompanied by significant declines in forest biomass, followed by increases in forest biomass, with die-off of less adaptable tree species in the forest canopy, especially for the elm/ash/cottonwood forest type, but also for the areas currently in oak/hickory type that change to oak-pine . The model used by Hodges et al. (forthcoming) for the dry scenario of the Southern Mixed Forest (southern part of the UGCP) predicts a dramatic decline in biomass to almost the year 2100, then only a slight increase before 2200, followed by a leveling-off through 2300. The wet and middle scenarios predict much smaller biomass declines. The Central Tennessee Broadleaf Forest’s biomass scenarios are similar to the Southern Mixed Forest’s except that for the dry scenario, biomass decrease is not quite as large, and it recovers eventually to a level somewhat below the current. It is difficult to predict how this will impact wildlife habitat; however several general conclusions can be drawn. If the dry scenario occurs, it is by far the most dramatic decline in biomass predicted for any of Tennessee’s forest areas presented in Hodges et al. (forthcoming), and could indicate major die-off of the forest canopy within a 50-year period, and large-scale conversion to primarily early-successional habitat, until better-adapted tree species establish their place in the overstory. The fact that the dry scenario maintains a low level of forest biomass after the initial decline could indicate that a more woodland or scrub forest condition will develop in this southern part of the UGCP, with a major change in wildlife habitat from the previous forest.

If the middle or wet scenarios occur in the UGCP, the biomass decline will be less dramatic than that described above, but will nevertheless occur to some extent, especially in areas where the current elm/ash/cottonwood forest type are replaced by the oak/hickory type, and where the current oak/hickory forest type are replaced by the oak/pine type. With widespread decline of the less adapted tree species that currently comprise the overstory, there will be an increase in canopy gaps of varying sizes. This will result in more understory vegetation and more early-successional wildlife habitat, especially where overstory decline is greatest, until better-adapted tree species establish their place in the overstory.

This decline will be less dramatic in the current oak/hickory forest type, although there are still likely to be gaps created in the overstory as certain species decline, with the resulting increase in understory vegetation. Wherever the overstory declines, invasive exotic vegetation (ground vegetation, vines shrubs, and trees), especially those species which have benefited from increasing temperatures and carbon dioxide levels, may gain a foothold through increased light penetration to the forest floor, delaying and even preventing native tree species from regenerating or form attaining dominance in the canopy (Simberloff, 2000).

Predicted declines in biomass and changes in forest succession and forest types will have positive effects on some species and negative effects on others. The predicted modest expansion of the oak-hickory forest type will benefit wildlife species that depend highly on hard mast for food, as will the expansion of the oak-pine type, to a lesser extent. The added pine component will also benefit some wildlife species. Likewise, reduction of the elm/ash/cottonwood forest type will affect a number of wildlife species dependent on this forest type. Where tree mortality is greatest, the disappearance of areas of later-successional forest, most pronounced in the elm/ash/cottonwood type, will negatively affect interior forest wildlife species. The increase of early-successional forest, again, predominantly in the elm/ash/cottonwood type, will benefit early-successional wildlife species.

Interior Low Plateau (ILP) Mesophytic Forest —

The current modeled forest type data shows approximately 89% of the ILP consisting of oak-hickory type, 4% consisting of the elm-ash-cottonwood, 4% of the loblolly-shortleaf pine forest types, 2% of oak/pine type, with remaining 1% without available data (Iverson et al. 2008). However, under the Gcm3Hi scenario, the oak/hickory increases to 97%, oak/pine remains at 2%, and elm/ash/cottonwood and loblolly/shortleaf pine types disappear. Potential habitat value is projected to increase for a number of individual tree species under this model including blackjack oak, water oak, post oak, bitternut hickory, black hickory, common persimmon, sweetgum, winged elm, American elm, and shortleaf and loblolly pines. Potential losers include sugar maple, pignut hickory, flowering dogwood, white ash, black walnut, and yellow poplar, and white oak, scarlet oak and eastern redcedar.

Under the Gcm3Lo scenario, the oak/hickory decreases to 83%, oak/pine increases to 16%, and elm/ash/cottonwood and loblolly/shortleaf pine types disappear (Table 1 and Figs. 9-11). Potential habitat value is projected to increase for a number of individual tree species under this model including blackjack oak, water oak, post oak, bitternut hickory, black hickory, sweetgum, winged elm, and shortleaf and loblolly pines. Potential losers include sugar maple, pignut hickory, shagbark hickory, flowering dogwood, American beech, white ash, black walnut, yellow poplar, white oak, scarlet oak, sassafras, and eastern redcedar. For a more complete list of species' potential habitat values under the current and future modeled scenarios refer to Table 4 and Fig. 16.

In Hodges et al. (forthcoming), Bailey's Central TN Broadleaf Forest (plus the Southern Mixed Forest) roughly corresponds to SWAP's Interior Low Plateau and Upper Gulf Coastal Plain combined. The "dry" scenario for the Central Forest predicts a marked decline in total forest biomass from 2030 to 2080, with an increase to somewhat below the 1989 level by 2300 (Fig. 20). The "wet" scenario predicts a much less pronounced decline in total forest biomass before 2100, with an increase to just below 1989 levels by 2300 (Fig. 20). The "middle" scenario predicts an early, slight decline in total forest biomass for the Central Forest, which increases slowly to 1989 levels by 2300 (Fig. 20).

For the "middle" and "wet" scenarios, the Central TN Broadleaf Forest stands were dominated by six hickory species, hackberry, and basswood. For the "dry" case, the forest stands consisted mostly of four hickory species, white oak, southern red oak, and American beech.

Implications for Wildlife Habitat:

The changes in forest types described above are likely to be accompanied by significant declines in forest biomass, followed by increases in forest biomass, with die-off of less adaptable tree species in the forest canopy, especially for the loblolly/shortleaf pine and elm/ash/cottonwood forest types. The model used by Hodges et al. (forthcoming) for the dry scenario of the Central Tennessee Broadleaf Forest predicts a large decline in biomass followed by a gradual recovery to a level somewhat below the current by 2200, followed by a slight downturn through 2300. The wet and middle scenarios predict much smaller biomass declines. It is difficult to predict how this will impact wildlife habitat; however several general conclusions can be drawn. With widespread decline of the less adapted tree species that currently comprise the overstory, there will be an increase in canopy gaps of varying sizes. This will result in more understory vegetation and more early-successional wildlife habitat, especially where overstory decline is greatest (i.e., current loblolly/shortleaf pine and elm/ash/cottonwood forest types), until better-adapted tree species establish their place in the overstory.

If the middle or wet scenarios occur in the UGCP, the biomass decline will be less dramatic than that described above, but will nevertheless occur to some extent, especially in areas where the current loblolly/shortleaf pine and elm/ash/cottonwood forest types are replaced by the oak/hickory and oak/pine types. With widespread decline of the less adapted tree species that currently comprise the overstory, there will be an increase in canopy gaps of varying sizes. This will result in more understory vegetation and more early-successional wildlife habitat, especially where overstory decline is greatest, until better-adapted tree species establish their place in the overstory.

This decline will be less dramatic in most of the current oak/hickory forest type, although there are still likely to be gaps created in the overstory as certain species decline, with the resulting increase in understory vegetation. Wherever the overstory declines, invasive exotic vegetation (ground vegetation, vines shrubs, and trees), especially those species which have benefited from increasing temperatures and carbon dioxide levels, may gain a foothold through increased light penetration to the forest floor, delaying and even preventing native tree species from regenerating or form attaining dominance in the canopy (Simberloff, 2000).

Predicted declines in biomass and changes in forest succession and forest types will have positive effects on some species and negative effects on others. The predicted modest expansion of the oak-hickory forest type will benefit wildlife species that depend highly on hard mast for food, as will the expansion of the oak-pine type where formally loblolly/shortleaf pine or elm/ash/cottonwood , to a lesser extent. Likewise, reduction of the elm/ash/cottonwood forest type will affect a number of wildlife species dependent on this forest type. Where tree mortality is greatest, the disappearance of areas of later-successional forest, most pronounced in the elm/ash/cottonwood type, will negatively affect interior forest wildlife species. The increase of early-successional forest in the declining forest types will benefit early-successional wildlife species.

Cumberland Plateau and Mountains (CPM) —
The current modeled forest type data shows approximately 97% of the CPM consisting of oak-hickory type, with the remaining 3% without available data (Iverson et al. 2008). However, under the Gcm3Hi scenario, the oak-hickory decreases to 90% and oak-pine increases from 0% to 7%, with remaining 3% without available data (Iverson et al. 2008). Potential habitat value is projected to increase for a number of individual tree species under this model including southern red oak, blackjack oak, water oak, post oak, black oak, bitternut hickory, hackberry, common persimmon, sweetgum, winged elm, American elm, shortleaf pine and eastern redcedar. Potential losers include white oak, scarlet oak, chestnut oak, red maple, sugar maple, flowering dogwood, yellow poplar, sourwood, pitch pine, and Virginia pine.

Under the Gcm3Lo scenario, the oak-hickory decreases to 83%, and oak-pine increases to 14% (Table 1 and Figs. 9-11). Potential habitat value is projected to increase for a number of individual tree species under this model including southern red oak, blackjack oak, water oak, northern red oak, post oak, common persimmon, sweetgum, winged elm, shortleaf pine, and loblolly pine. Potential losers include scarlet oak, chestnut oak, red maple, sugar maple, yellow poplar, sourwood, pitch pine, eastern white pine, and Virginia pine. For a more complete list of species' potential habitat values under the current and future modeled scenarios refer to Table 5 and Fig. 17.

Dale et al. (2008 in press) projects a decline in stand biomass for wet, middle, and dry scenarios for the Northern CPM, which are described for both the Plateau and Mountains sub-regions (Fig. 21). For the purposes of this TWRA report, the results presented by Dale et al. (2008 in press) for the Northern CPM will be applied to the entire CPM, these being more applicable than predictions presented in Hodges et al. (forthcoming) for the entire East Tennessee Broadleaf Forest. Dale et al. (2008 in press) predicts that climate changes will reduce growth and bring about demise of some trees. Both the middle and wet scenarios for the Plateau and Mountains reestablish biomass close to their original levels by 2150 and 2100, respectively (Fig. 21). In both areas, the dry scenarios are slower to reestablish stand biomass to original levels (Fig. 21).

For all scenarios for the Cumberland Plateau, American basswood and shagbark hickory become greater contributors of biomass, with chestnut oak, black oak, and yellow buckeye contributing less. Red maple, pignut hickory, black hickory, mockernut hickory, and hackberry exhibit a slight increase in biomass, especially in the dry scenario.

Projections for the Cumberland Mountains paint a different picture, with American basswood and shagbark hickory increasing in all scenarios, but with chestnut oak with a major change only in the dry scenario, where it increases and then declines. All scenarios have black oak remaining stable, but sugar maple declining. Yellow buckeye biomass becomes greater in the middle scenario, but increases and then declines in the dry and wet ones.

Implications for Wildlife Habitat:
The changes in forest types described above are likely to be accompanied by significant declines in forest biomass, followed by increases in forest biomass, with die-off of less adaptable tree species in the forest canopy, especially where the oak/hickory forest type is changing to oak/pine.

The projection by Dale et al. (2008 in press) for the dry scenario in the Cumberland Plateau subregion of the Northern CPM predicts a larger biomass decline and slower recovery than for the dry scenario in the Cumberland Mountains (Fig. 21). For the Cumberland Mountains, all three scenarios decline by about the same amount, but the dry scenario takes longer to recover lost forest biomass. It is difficult to predict how this will impact wildlife habitat; however several general conclusions can be drawn. With widespread decline of the less adapted tree species that currently comprise the overstory, there will be an increase in canopy gaps of varying sizes. This will result in more understory vegetation and more early-successional wildlife habitat, especially where overstory decline is greatest (i.e., current oak/hickory type), until better-adapted tree species establish their place in the overstory. Although predictions by Iverson et al. (2008) and Dale et al. (2008 in press) in some cases differ for which species will increase and decline, predicted declines for some of the major oak species, as well as for other important species including sugar maple, red maple, and yellow poplar would result in significant change in forest ecosystem dynamics and wildlife food sources.

Where the current oak/hickory forest type is replaced by oak/pine, there will be widespread decline of the less adapted oaks and other tree species that currently comprise the overstory, resulting in an increase in canopy gaps of varying sizes. This will result in more understory vegetation and more early-successional wildlife habitat, especially where overstory decline is greatest, until better-adapted tree species establish their place in the overstory. The replacement of some oaks and hickories by pines in the transition from the oak/hickory to the oak/pine type will have a negative impact on wildlife species that depend on hard mast.

This decline will be less dramatic in most of the current oak/hickory forest type that does not change to oak/pine, although there are still likely to be gaps created in the overstory as certain species decline, with the resulting increase in understory vegetation. Wherever the overstory declines, invasive exotic vegetation (ground vegetation, vines shrubs, and trees), especially those species which have benefited from increasing temperatures and carbon dioxide levels, may gain a foothold through increased light penetration to the forest floor, delaying and even preventing native tree species from regenerating or form attaining dominance in the canopy (Simberloff, 2000).

Predicted declines in biomass and changes in forest succession and forest types will have positive effects on some species and negative effects on others. In some areas where tree mortality is greatest, which will likely be most pronounced in the drier scenarios for the oak/hickory type, loss of tree canopy could negatively affect some interior forest wildlife species that require more of a closed canopy. The increase of early-successional forest in the declining forest types will benefit some early-successional wildlife species.

Dale et al. (2008 in press) predicts the eastern hemlock to disappear completely from the CPM due to the spreading hemlock woolly adelgid epidemic, the spread and severity of which may be enhanced by warmer temperatures brought on by climate change. Eastern hemlock is an important species in the mesic mixed and mesic evergreen forest types of the CPM, and its loss from the mesic mixed and mesic evergreen cove forest types is likely to have effects on the entire system (Dale et al. 2008 in press). Small et al. (2005) found that as the hemlock basal area declined with death from the hemlock woolly adelgid, canopy dominance shifted to oak and mixed hardwoods, with an increase in understory vegetation, including several invasive shrubs and woody vines. Hemlocks not only provide unique habitats for many species of wildlife that depend on the tree's dense canopy for food, shelter and breeding sites, but also are commonly associated with riparian areas, where they play an important role in maintaining cool stream water temperatures for aquatic organisms, preventing erosion on steep banks, and providing shelter to a variety of wildlife by moderating temperatures in cold winter months and during hot summer days (State of Tennessee Hemlock Woolly Adelgid Task Force 2005). Unfortunately, without increased funding to state and federal agencies to eradicate the hemlock woolly adelgid, the eastern hemlock is likely to virtually disappear from the CPM as predicted by Dale et al. (2008 in press).

Ridge and Valley (R&V)

The current modeled forest type data shows approximately 94% of the R&V consisting of oak-hickory type, with the remaining 6% without available data (Iverson et al. 2008). However, under the Gcm3Hi scenario, the oak-hickory decreases to 62% and oak-pine increases from 0% to 32, with remaining 6% without available data (Iverson et al. 2008). Potential habitat value is projected to increase for a number of individual tree species under this model including southern red oak, blackjack oak, water oak, post oak, bitternut hickory, black hickory, common persimmon, sweetgum, winged elm, American elm, shortleaf pine and loblolly pine. Potential losers include chestnut oak, red maple, sugar maple, pignut hickory, flowering dogwood, American beech, black walnut, yellow poplar, sourwood, eastern redcedar, eastern white pine, and Virginia pine.

Under the Gcm3Lo scenario, the oak-hickory decreases to 36%, and oak-pine increases to 58%, with remaining 6% without available data (Table 1 and Figs. 9-11). Potential habitat value is projected to increase for a number of individual tree species under this model including blackjack oak, water oak, post oak, black hickory, sweetgum, winged elm, shortleaf pine and loblolly pine. Potential losers include scarlet oak, chestnut oak, American basswood, red maple, sugar maple, pignut hickory, flowering dogwood, American beech, white ash, black walnut, yellow poplar, sourwood, eastern white pine, and Virginia pine. For a more complete list of species' potential habitat values under the current and future modeled scenarios refer to Table 6 and Fig. 18.

In Hodges et al. (forthcoming), Bailey's East TN Broadleaf Forest roughly corresponds to the combined R&V and CPM used by SWAP. The East TN Broadleaf Forest maintained high diversity under all cases, but with significant shifts in species composition. The "dry" scenario resulted in dramatic loss of biomass from 2030 through 2080, then an increase to current levels by 2160, with a slow increase and leveling off above current biomass levels through 2300 (Fig. 20). The wet and middle scenarios resulted in less biomass loss through 2030 and 2080, respectively, with recovery to current levels by 2130, with a slow increase and leveling off above current biomass levels through 2300 (Fig. 20). Under both the "middle" and the "wet" scenario, biomass increased for basswood and decreased for chestnut oak, black oak, and yellow buckeye.

Implications for Wildlife Habitat:
The changes in forest types described above are likely to be accompanied by significant declines in forest biomass, followed by increases in forest biomass, with die-off of less adaptable tree species in the forest canopy, especially in the dry scenario and where the oak/hickory forest type is changing to oak/pine.

It is difficult to predict how this will impact wildlife habitat; however several general conclusions can be drawn. With widespread decline of the less adapted tree species that currently comprise the overstory, there will be an increase in canopy gaps of varying sizes. This will result in more understory vegetation and more early-successional wildlife habitat, especially where overstory decline is greatest (i.e., current oak/hickory type), until better-adapted tree species establish their place in the overstory.

Although predictions by Iverson et al. (2008) and Hodges et al. (forthcoming) in some cases differ for which species will increase and decline, predicted increases and declines for some of the major tree species would result in significant change in forest ecosystem dynamics and wildlife food sources.

Where the current oak/hickory forest type is replaced by oak/pine, there will be widespread decline of the less adapted oaks and other tree species that currently comprise the overstory, resulting in an increase in canopy gaps of varying sizes. This will result in more understory vegetation and more early-successional wildlife habitat, especially where overstory decline is greatest, until better-adapted tree species establish their place in the overstory. The replacement of some oaks and hickories by pines in the transition from the oak/hickory to the oak/pine type will have a negative impact on wildlife species that depend on hard mast.

This decline will be less dramatic in most of the current oak/hickory forest type that does not change to oak/pine, although there are still likely to be gaps created in the overstory as certain species decline, with the resulting increase in understory vegetation. Wherever the overstory declines, invasive exotic vegetation (ground vegetation, vines shrubs, and trees), especially those species which have benefited from increasing temperatures and carbon dioxide levels, may gain a foothold through increased light penetration to the forest floor, delaying and even preventing native tree species from regenerating or form attaining dominance in the canopy (Simberloff, 2000).

Predicted declines in biomass and changes in forest succession and forest types will have positive effects on some species and negative effects on others. In some areas where tree mortality is greatest, which will likely be most pronounced in the drier scenarios for the oak/hickory type, loss of tree canopy could negatively affect some interior forest wildlife species that require more of a closed canopy. The increase of early-successional forest in the declining forest types will benefit some early-successional wildlife species.

Southern Blue Ridge (SBR)

The current modeled forest type data shows approximately 84% of the SBR consisting of oak-hickory type, 14% consisting of maple-beech-birch type, with the remaining 2% without available data (Iverson et al. 2008). However, under the Gcm3Hi scenario, oak-hickory decreases to 75%, oak-pine increases from 0% to 24%, and the maple-beech-birch type disappears, with remaining 2% without available data (Iverson et al. 2008). Potential habitat value is projected to increase for a number of individual tree species under this model including southern red oak, blackjack oak, water oak, post oak, black oak, bitternut hickory, black hickory, common persimmon, sweetgum, winged elm, American elm, eastern redcedar, shortleaf pine and loblolly pine. Potential losers include chestnut oak, northern red oak, black locust, red maple, sugar maple, flowering dogwood, yellow poplar, sourwood, and Virginia pine.

Under the Gcm3Lo scenario, the oak-hickory decreases to 65%, oak-pine increases from 0% to 33%, and the maple-beech-birch type disappears, with remaining 2% without available data (Table 1 and Figs. 9-11). Potential habitat value is projected to increase for a number of individual tree species under this model including blackjack oak, water oak, post oak, black hickory, sweetgum, winged elm, eastern redcedar, shortleaf pine and loblolly pine. Potential losers include chestnut oak, black locust, red maple, sugar maple, flowering dogwood, American beech, and yellow poplar. For a more complete list of species' potential habitat values under the current and future modeled scenarios refer to Table 7 and Fig. 19.

In Hodges et al. (forthcoming), Bailey's Appalachian Forest is similar to the Southern Blue Ridge used by SWAP, except SWAP includes more acreage in the southern part of TN and Bailey includes more acreage in the northern part of TN. The "dry" scenario for the Appalachian Forest predicts a marked decline in total forest biomass from 1989 to 2080, with an increase to somewhat above the 1989 level from 2180 to 2200, and then a decrease to just below 1989 levels by 2300 (Fig. 20). The "wet" scenario predicts a slightly greater decline than the dry scenario until 2030, at which time it increases to above 1989 levels by 2150, and then decreases below 1989 level in 2250 and beyond (Fig. 20). The "middle" scenario predicts a slightly smaller decrease than the "dry" scenario by 2050, then an increase to 1989 levels by 2100, peaking above 1989 levels by 2200, then falling slightly below 1989 levels by 2300 (Fig. 20). The dry scenario for the Appalachian Forest predicts less decrease in total biomass than for dry scenarios of the other four Bailey's Ecoregions (Fig. 20).

Hodges et al. (forthcoming) also predicts an increase in diversity of the Appalachian Forest with a shift of dominant species. Under all scenarios, chestnut oak increases initially and then declines in terms of its contribution to stand biomass, basswood increased in biomass, and hickory diversity and biomass also increase.

Implications for Wildlife Habitat:

The changes in forest types described above are likely to be accompanied by significant declines in forest biomass, followed by increases in forest biomass, with die-off of less adaptable tree species in the forest canopy, which will be more pronounced in the dry scenario and where the oak/hickory is changing to oak/pine and the maple/beech/birch forest type is changing to oak/pine or oak/hickory.

It is difficult to predict how this will impact wildlife habitat; however several general conclusions can be drawn. With widespread decline of the less adapted tree species that currently comprise the overstory, there will be an increase in canopy gaps of varying sizes. This will result in more understory vegetation and more early-successional wildlife habitat, especially where overstory decline is greatest (i.e., current oak/hickory and maple/beech/birch types), until better-adapted tree species establish their place in the overstory.

For this ecoregion, both Iverson et al. (2008) and Hodges et al. (forthcoming) predict a decrease in chestnut oak and increases in hickory. These changes, in addition to the various other species increases and declines summarized for Iverson above, would result in significant change in forest ecosystem dynamics and wildlife food sources.

Where the current oak/hickory forest type is replaced by oak/pine and where the maple/beech/birch is replaced by oak/pine or oak/hickory, there will be widespread decline of the less adapted tree species that currently comprise the overstory, resulting in an increase in canopy gaps of varying sizes. This will result in more understory vegetation and more early-successional wildlife habitat, especially where overstory decline is greatest, until better-adapted tree species establish their place in the overstory. The replacement of some oaks and hickories by pines in the transition from the oak/hickory to the oak/pine type will have a negative impact on wildlife species that depend on hard mast. The predicted disappearance of the maple/beech/birch forest type will negatively affect wildlife species adapted to this habitat type, which is found only in this ecoregion of our state. Decline and possible disappearance in Tennessee of the eastern hemlock due to the hemlock woolly adelgid epidemic will also have negative effects on the unique habitat provided by this tree species, as described for the CPM ecoregion.

Tree decline and canopy gap creation will be less dramatic in most of the current oak/hickory forest type that does not change to oak/pine, although there are still likely to be gaps created in the overstory as certain species decline, with the resulting increase in understory vegetation. Wherever the overstory declines, invasive exotic vegetation (ground vegetation, vines shrubs, and trees), especially those species which have benefited from increasing temperatures and carbon dioxide levels, may gain a foothold through increased light penetration to the forest floor, delaying and even preventing native tree species from regenerating or form attaining dominance in the canopy (Simberloff, 2000).

Predicted declines in biomass and changes in forest succession and forest types will have positive effects on some species and negative effects on others. In some areas where tree mortality is greatest, which will likely be most pronounced where the maple/birch/beech forest type disappears, and in some areas where oak/hickory transitions to oak/pine, loss of tree canopy could negatively affect some interior forest wildlife species that require more of a closed canopy. The increase of early-successional forest in the declining forest types will benefit some early-successional wildlife species.

In the SBR ecoregion, the high-elevation Appalachian spruce-fir forests are already threatened by air pollution (acid rain and ground-level ozone) as well as exotic pests (balsam wooly adelgid). Climate change could exacerbate these stresses as conditions suitable for the growth of red spruce and Fraser fir disappear under warmer and drier conditions (EPA: Climate Change and Tennessee, 1999). According to Iverson and Prasad (2001), all five GCM scenarios predict that the red spruce-Fraser fir forest type will not only be eliminated from the Southeast, but that its southern range will move beyond the U.S. border into Canada. Wildlife species that depend on this forest type for habitat in Tennessee will be adversely affected.

Other Forest Change Implications for Wildlife Habitat in Tennessee

Iverson et al. (2008) predict increased potential for loblolly pine throughout Tennessee, although their forest type scenarios include it mostly as part of an increased in the oak/pine forest type. On the other hand, Hodges et al. (2008) does not project an increase in natural occurrence of loblolly pine in Tennessee, but surmises that climate change could increase the potential for planting and managing stands of this species in the state, in response to a higher demand from timber companies needing to procure pine timber further north than they had previously. A significant increase of loblolly pine plantations replacing natural oak/hickory, oak/pine, or other forest types would have a negative impact on wildlife species in Tennessee that are largely dependent on hardwood forest types.

Insects and Diseases

Insect development is generally temperature-dependent, with at least some non-indigenous insect forest pests likely to have greatly increased populations due to faster development with rising temperatures due to climate change (Simberloff 2000). According to many researchers, increasing temperatures will result in more winter survival and greater numbers of insect generations per year, therefore greatly increasing pest pressures on forest vegetation (Mooney 1996, Simberloff 2000).

Global climate change could intensify infestations of the native southern pine beetle by a factor of 2.5 to 5, and could result in 4 to 7.5 times the current annual mortality of pines (Gan, 2004, Dale et al. 2008 in press).

Just as the northern spread of hemlock woolly adelgid may be slowed or prevented by cold temperature, warmer temperatures may enhance its spread (Skinner et al. 2003, Dale et al. 2008 in press).

A model developed for Pennsylvania predicted that increasing temperature alone would result in a great decrease in gypsy moth defoliation, while the same temperature increase combined with a precipitation increase would cause a major increase in defoliation (Williams and Liebhold 1995, Simberloff 2000). Therefore, it is possible that the rate of spread of gypsy moth to Tennessee could either be increased or decreased depending on whether precipitation increases or not, and once in Tennessee, the same factors could determine its severity.

With the potential for more planting and managing of loblolly pine in Tennessee due to predicted increased demand for this species, the changing precipitation and temperatures patterns will increase the likelihood of pests and mortality associated with this species (Hodges et al., forthcoming).

Invasive Plants

Invasive plants are plants that are able to reproduce and spread over a landscape because the niche constraints of the species have be reduced. Most, but not all, invasive plants are exotic species that were introduced into North America for crop, ornamental, erosion control, and wildlife habitat purposes (Swearingen et al. n. d.). Because ecological problems with invasive species have escalated in recent years, the U. S. Department of Agriculture has been moving toward removal of invasive species from their propagation facilities and from conservation practice specifications (Belt and Englert 2008).

Many plants that were tested and promoted for conservation purposes did not become invasive right away. It has taken decades for many plants to become invasive (Simberloff 2008). Notable examples are sericea lespedeza (*Lespedeza cuneata*), bicolor lespedeza (*L. bicolor*), and Thunberg lespedeza (*L. thunbergii*). Bradford or Callery pear (*Pyrus calleryana*) is an example of an ornamental plant that has become invasive in many areas in recent years (Swearingen et al. n. d.). Regardless, invasiveness is a costly process and often leads to the need for drastic measures in order to restore habitats for declining wildlife species.

Invasiveness is linked with nitrogen (N) and other nutrients as well as CO_2 (Reich et al. 2006). Many plants produce substances which inhibit germination and growth of other plants growing in the same soils in close proximity (Rice 1974). These allelopathic substances are important drivers of plant succession and can affect the way plant communities respond to disturbance.

Johnsongrass (*Sorghum helepense*) provides an example of how species invasiveness can alter the course of succession. This crop land weed efficiently uses N and produces allelopathic substances that reduce germination and development in many early successional plants Ball et al. 1996:36, Rice 1974:37-41). This ability allows Johnsongrass to dominate when former agricultural fields are being restored to native grasses, forbs, and trees. CO_2 further serves as "fertilizer" for grass growth.

As atmospheric CO_2 levels increase, there is a risk that plants currently not invasive will become so. TWRA will need to carefully assess all programs to assure that invasive plants are addresses and appropriate action taken to avoid introduction and spread of exotic species that may become invasive or are already known to be invasive.

Fire

Climate change may result in the increase of forest fire intensity, extent, and frequency (Flannigan et al. 2000, Dale et al. 2001). Fire can affect forests by killing trees, altering nutrient cycling and volatilizing soil nutrients, changing direction of succession, destroying soil seed banks, inducing seed germination, increasing landscape heterogeneity, and changing surface-soil organic layers and underground plant root and reproductive tissues (Dale et al. 2008 in press).

Fire can reduce density of fire-sensitive species such as red maple on the Cumberland Plateau (Gilbert et al. 2003. Dale et al. in press 2008).

Under the warmer, drier climate scenarios, catastrophic fire could be the major change agent for decline of southeastern forests (Gucinski et al. 2004).

Drought effects due to climate change will continue to result in greater probability of longer and bigger fire seasons, in more regions in the nation, with the Southeast (along with the Southwest) especially vulnerable to fire risk (International Association of Fire Chiefs, 2009 *Quadrennial Fire Review Draft Report*). Increased fuel accumulations along with continued problems with exotic invasives and insect kill, as well as faster drying of vegetation will make fuels more flammable (International Association of Fire Chiefs, 2009 *Quadrennial Fire Review Draft Report*).

Information Gaps and Research Needs

Because existing climate models to data cannot adequately predict future change they need to be continually refined by use of species specific data on tree species responses to temperature, humidity, and precipitation regimes. In addition, the close interplay between atmospheric CO_2, nitrogen, and other nutrients from atmospheric and agricultural inputs poses difficulties with predicting changes. For example, ample ecological studies have addressed how high mineralized nitrogen in agricultural soils inhibits succession natural vegetation after agricultural abandonment. Often, invasive species such as Japanese honeysuckle (*Lonicera japonica*) are enhanced by residual fertility and out-compete the native vegetation trying to colonize the site. Our understanding of these complex processes need to be increased with field scale enclosure studies and incorporated into future modeling.

In addition, our ability to detect change to complex forest systems means that we need to continue and perhaps increase forest inventories to assure our ability to detect change. We need to be certain that existing inventory efforts have the statistical power to detect relatively small changes in forest composition. A coordinated network of Continuous Forest Inventory (CFI) plots collecting similar forest data at synchronized intervals would be a logical method to detect these changes. In addition to Forest Inventory Analysis plots coordinated by the U.S. Forest Service, a series of CFI plots on State Forests and WMAs would aid in this data collection (the Tennessee Division of Forestry has plans to establish CFI plots on some of its state forests, and TWRA hopes to initiate CFI plot establishment in the Mississippi Alluvial Plain as part of a plan with other members of the Lower Mississippi Valley Joint Venture. Plots on WMAs in the rest of the state would be desirable, if manpower and funding allow. Likewise, monitoring of forest insect populations and diseases need to be enhanced to provide the optimum power of detection and trend. To be most effective, both forest inventory and insect and disease monitoring should be done on a statewide level with coordination among other state agencies, as well as with universities and federal agencies.

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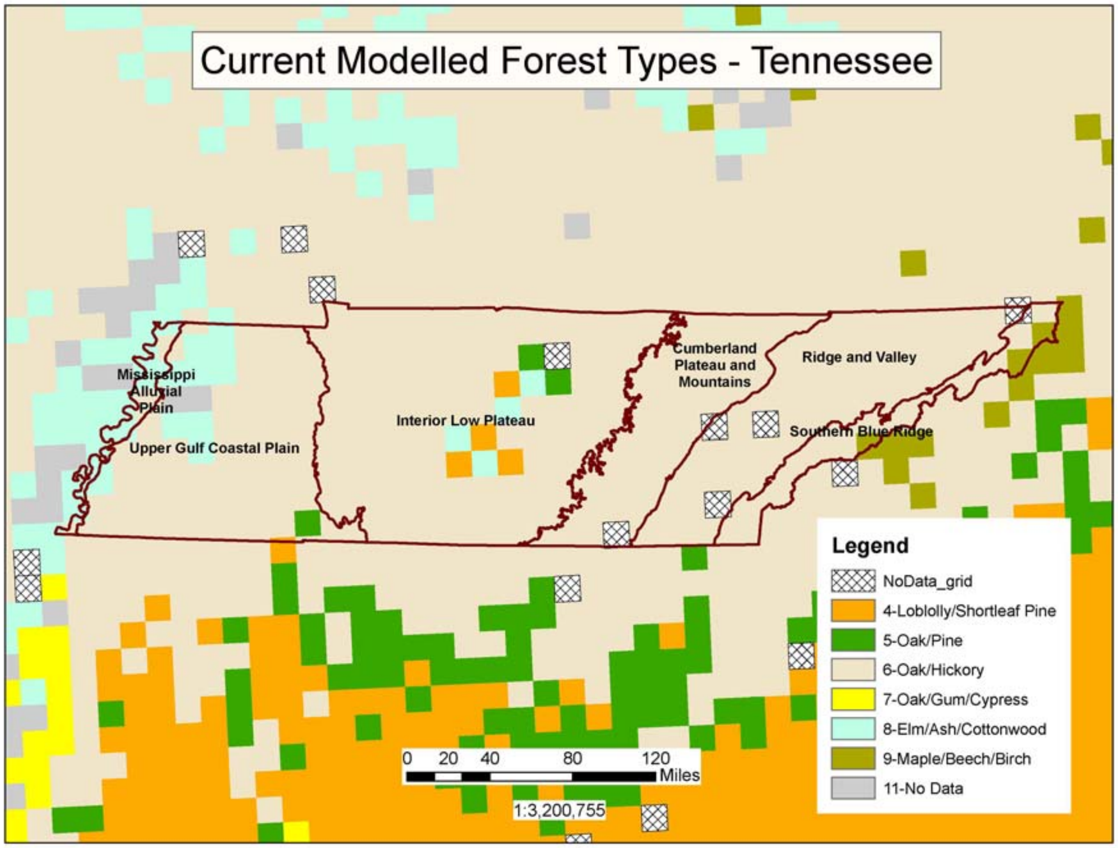


Fig. 9. Current TN forest types by ecoregion.

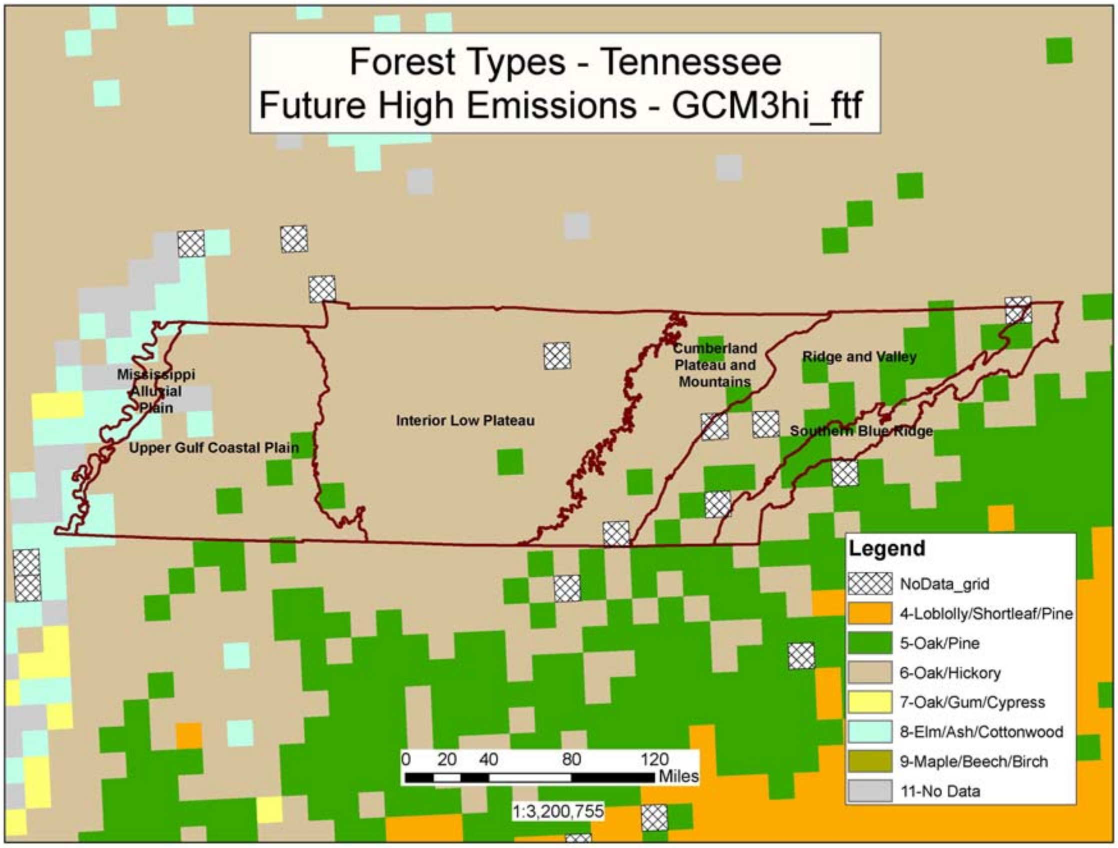


Fig. 10. Future TN forest types by ecoregion, gcm3hi.

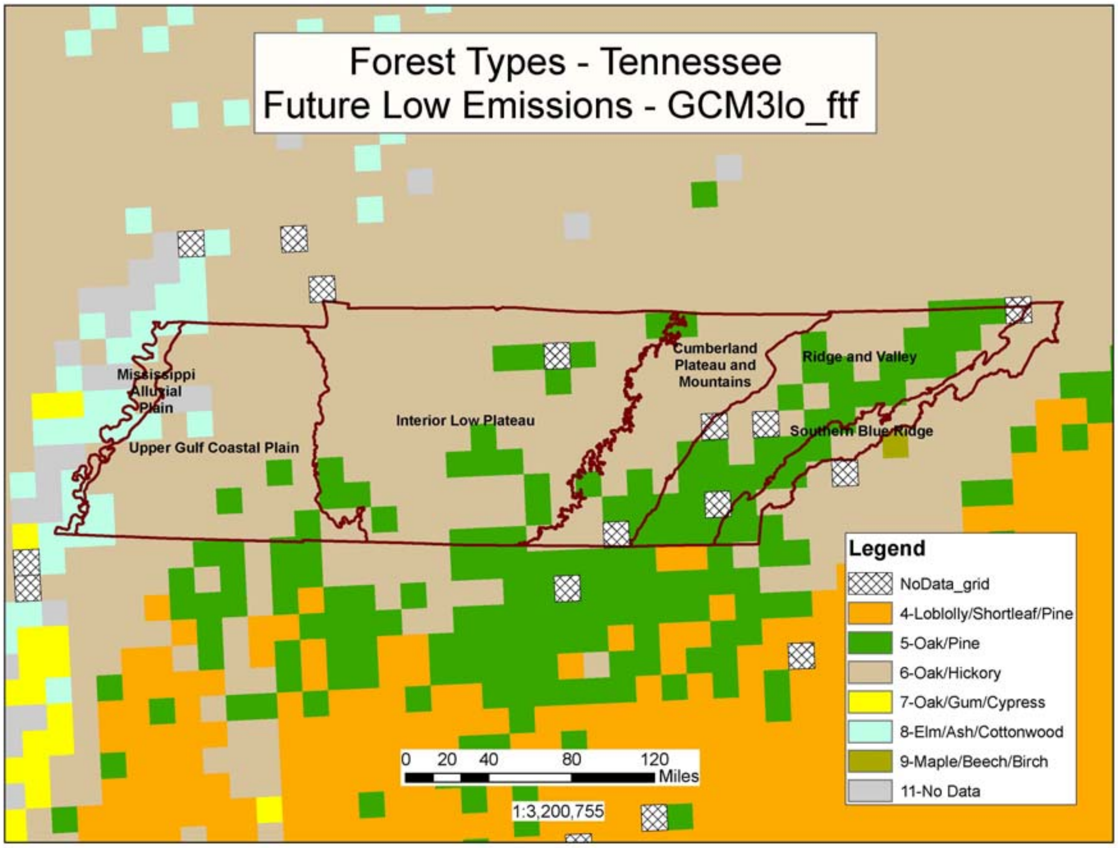
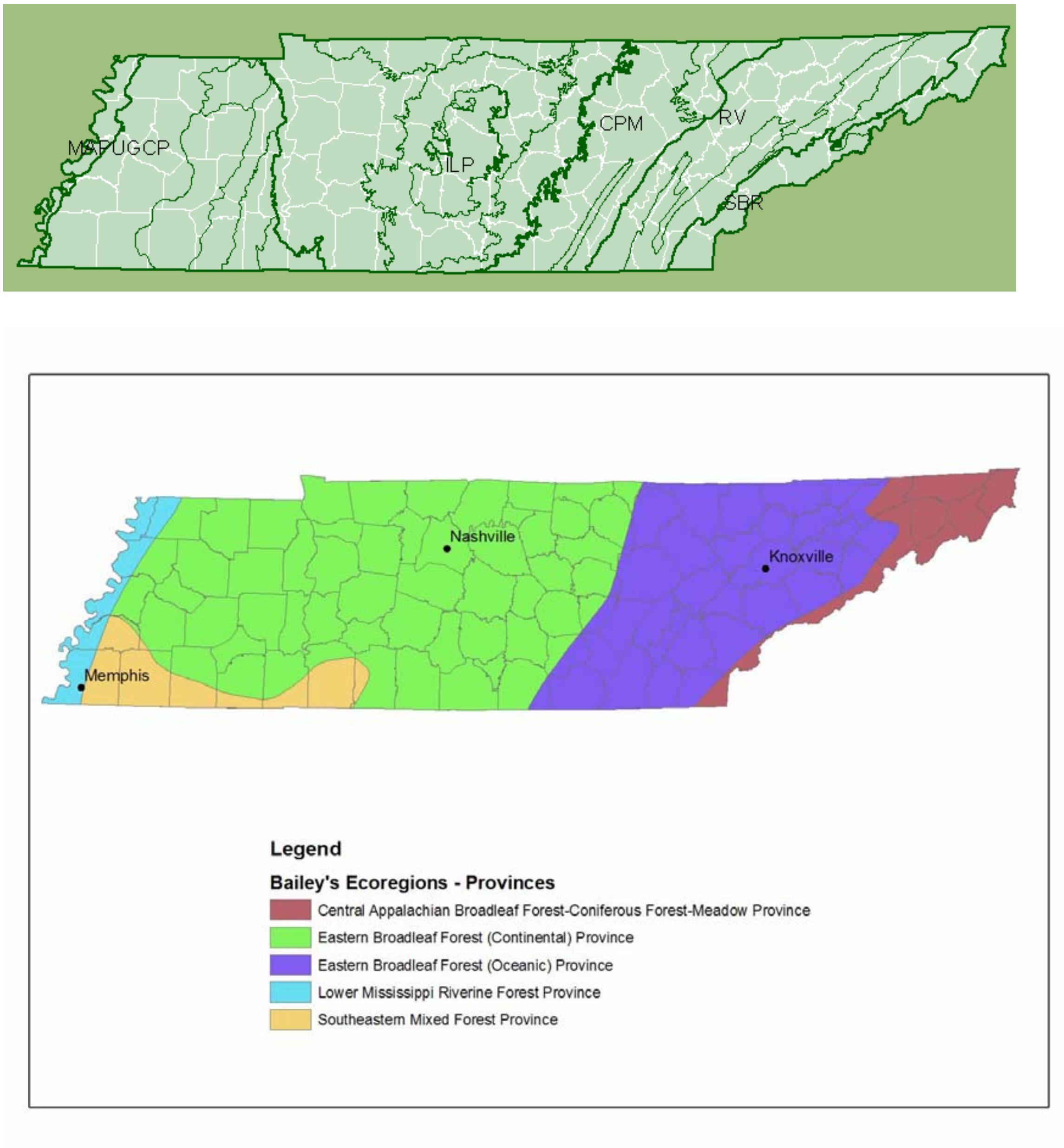


Fig. 11. Future TN forest types by ecoregion, gcm3lo.

Figs. 12-13. Comparing the Six Ecoregions Used in Tennessee's SWAP Plan with Five Bailey's Ecoregions Used in Hodges et al. (submitted for consideration for publication in 2008)



Note: the five Bailey's Ecoregions used in Hodges report vary from the 6 ecoregions used by Tennessee SWAP. Bailey's Appalachian Forest and SWAP's Southern Blue Ridge are similar, except SWAP includes more acreage in the southern part of TN and Bailey includes more acreage in the northern part of TN. Bailey's East TN Broadleaf Forest roughly corresponds to the SWAP Ridge and Valley and Cumberland Plateau and Mountains combined. Bailey's Central TN Broadleaf Forest and Southern Mixed Forest combined roughly correspond to SWAP's Interior Low Plateau and Upper Gulf Coastal Plain combined. Bailey's Mississippi Riverine Forest roughly corresponds to SWAP's Mississippi Alluvial Plain.

Table 1. Changes in area of TN forest types from current to future.

CHANGES IN AREA BETWEEN FOREST TYPES IN MODELED CURRENT AND TWO FUTURE CLIMATE SCENARIOS*

*** Km² are estimates only, derived using dot grids, as GIS could not calculate from Raster map data.**
Data is for all potential habitat including areas currently agricultural, urban, and other non-forest.

Forest Type by Ecoregion	Modeled Current Km²	%	Gcm3AvgHi Km²	%	Gcm3AvgLo Km²	%
Mississippi Alluvial Plain						
Loblolly/Shortleaf Pine						
Oak/Pine						
Oak/Hickory	615.2	28%	1,200.0	54%	1,065.0	48%
Oak/Gum/Cypress						
Elm/Ash/Cottonwood	1,600.0	72%	1,015.2	46%	1,150.2	52%
Maple/Beech/Birch						
No Data						
TOTAL	2,215.2	100%	2,215.2	100%	2,215.2	100%
Upper Gulf Coastal Plain						
Loblolly/Shortleaf Pine	100.0	0%				
Oak/Pine	400.0	2%	1,200.0	5%	1,300.0	5%
Oak/Hickory	20,125.3	80%	21,525.3	86%	21,225.3	84%
Oak/Gum/Cypress						
Elm/Ash/Cottonwood	3,700.0	15%	1,600.0	6%	1,800.0	7%
Maple/Beech/Birch						
No Data	800.0	3%	800.0	3%	800.0	3%
TOTAL	25,125.3	100%	25,125.3	100%	25,125.3	100%
Interior Low Plateau						
Loblolly/Shortleaf Pine	1,600.0	4%				
Oak/Pine	800.0	2%	800.0	2%	6,700.0	16%
Oak/Hickory	36,320.9	89%	39,520.9	97%	33,620.9	83%
Oak/Gum/Cypress						
Elm/Ash/Cottonwood	1,600.0	4%		0%		0%
Maple/Beech/Birch						
No Data	400.0	1%	400.0	1%	400.0	1%
TOTAL	40,720.9	100%	40,720.9	100%	40,720.9	100%
Cumberland Plateau & Mnts.						
Loblolly/Shortleaf Pine		0%		0%		0%
Oak/Pine		0%	1,050.0	7%	2,000.0	14%
Oak/Hickory	14,286.2	97%	13,236.2	90%	12,286.2	83%
Oak/Gum/Cypress						
Elm/Ash/Cottonwood		0%		0%		0%
Maple/Beech/Birch						
No Data	500.0	3%	500.0	3%		3%

					500.0	
TOTAL	14,786.2	100%	14,786.2	100%	14,786.2	100%
Ridge and Valley						
Loblolly/Shortleaf Pine		0%		0%		0%
Oak/Pine		0%	6,300.0	32%	11,462.1	58%
Oak/Hickory	18,724.1	94%	12,424.1	62%	7,262.0	36%
Oak/Gum/Cypress						
Elm/Ash/Cottonwood		0%		0%		0%
Maple/Beech/Birch						
No Data	1,200.0	6%	1,200.0	6%	1,200.0	6%
TOTAL	19,924.1	100%	19,924.1	100%	19,924.1	100%
Southern Blue Ridge						
Loblolly/Shortleaf Pine		0%		0%		0%
Oak/Pine		0%	1,500.0	24%	2,087.4	33%
Oak/Hickory	5,375.4	84%	4,775.4	75%	4,168.0	65%
Oak/Gum/Cypress						
Elm/Ash/Cottonwood		0%		0%		0%
Maple/Beech/Birch	900.0	14%			20.0	
No Data	100.0	2%	100.0	2%	100.0	2%
TOTAL	6,375.4	100%	6,375.4	100%	6,375.4	100%

Table 2. Mississippi Alluvial Plain tree species winners and losers.

TN ECOREGION - MISSISSIPPI ALLUVIAL PLAIN - TREE SPECIES "WINNERS AND LOSERS"

Tree Species	Modeled Current	Gcm3AvgHi	Gcm3AvgLo
sweetgum	7.446	9.224	8.335
winged elm	5.333	7.777	7.000
green ash	4.668	4.780	3.780
boxelder	3.999	7.777	4.887
American elm	3.668	4.112	3.668
red maple	3.334	3.222	2.780
sugarberry	2.999	4.888	3.665
white oak	2.890	1.891	2.113
black cherry	2.444	1.333	1.222
common persimmon	2.334	2.778	2.778
sycamore	2.332	2.553	2.332
Nuttall oak	2.110	1.332	0.999
loblolly pine	2.001	8.112	7.558
silver maple	2.001	5.891	4.111
sugar maple	2.001	0.335	0.447
pignut hickory	1.999	1.553	1.443
cherrybark oak	1.999	2.221	1.888
post oak	1.668	4.890	4.446
black willow	1.667	3.445	2.890
mockernut hickory	1.556	1.555	1.333
hackberry	1.554	1.332	0.664
overcup oak	1.446	2.114	1.779
baldcypress	1.444	2.666	2.334
southern red oak	1.444	2.554	2.000
eastern cottonwood	1.443	4.443	2.111
willow oak	1.334	2.668	2.333
honeylocust	1.333	3.001	1.000
red mulberry	1.222	4.333	1.222
blackgum	1.111	1.221	1.332
shagbark hickory	1.001	1.000	0.778
black walnut	1.000	0.000	0.000
bitternut hickory	0.778	1.334	1.889
pecan	0.778	3.001	2.890
river birch	0.777	0.777	0.111
shortleaf pine	0.554	1.997	1.333
water hickory	0.443	0.553	0.111
swamp chestnut oak	0.222	0.111	0.222
water oak	0.111	4.779	3.668
bur oak	0.000	3.222	0.111
Shumard oak	0.000	0.889	1.000

🟩	Increase in potential habitat value
🟧	Decrease in potential habitat value
🟨	No increase/decrease in potential habitat value

Fig. 14. Mississippi Alluvial Plain tree species winners and losers.

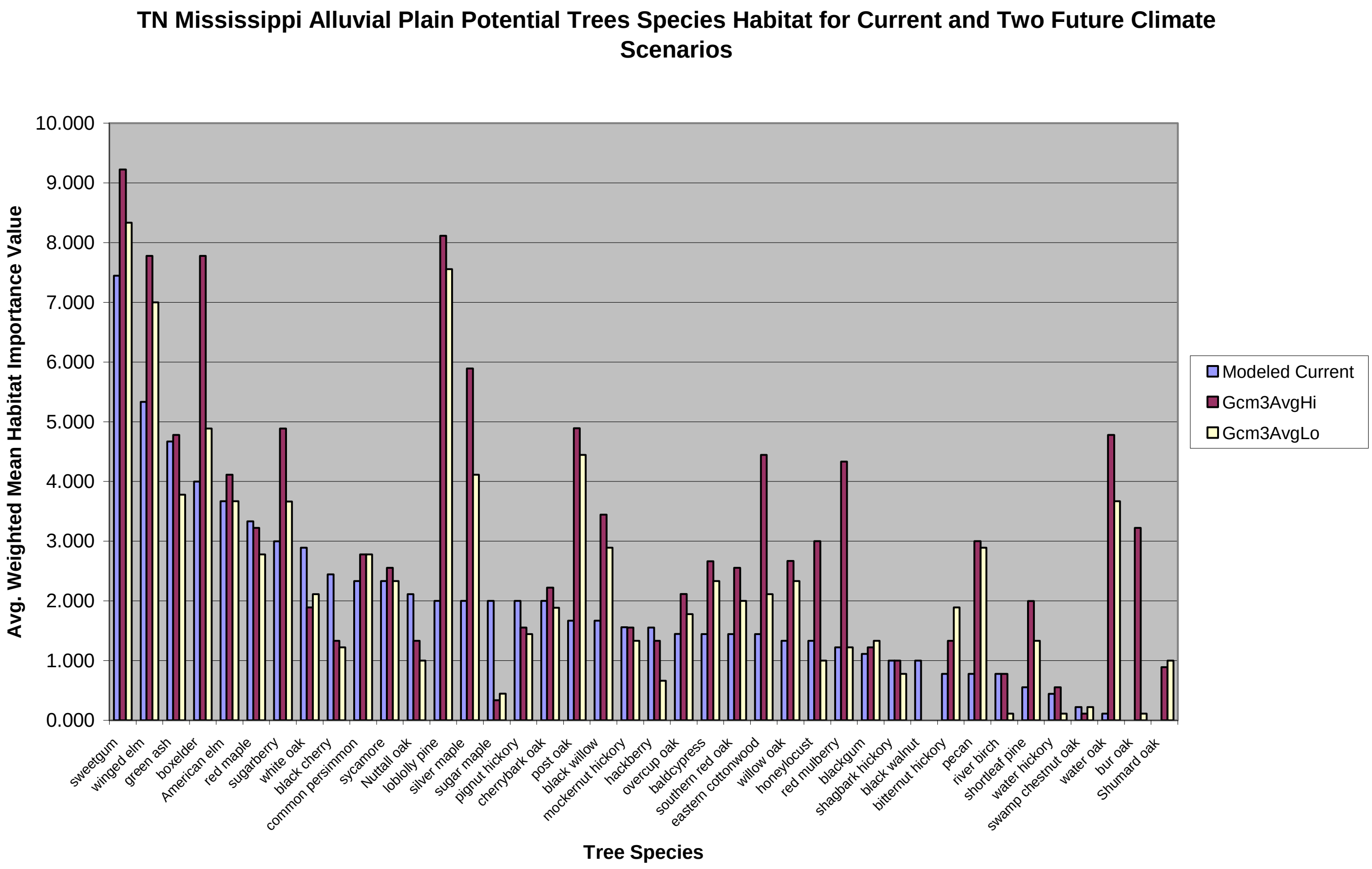


Table 3. Upper Gulf Coastal Plain tree species winners and losers.

TN ECOREGION - UPPER GULF COASTAL PLAIN - TREE SPECIES "WINNERS AND LOSERS"

Tree Species	Modeled Current	Gcm3AvgHi	Gcm3AvgLo
sweetgum	10.614	11.667	11.702
winged elm	6.264	8.159	7.983
loblolly pine	5.526	12.895	12.860
red maple	5.526	4.018	3.456
white oak	4.841	3.280	3.525
southern red oak	4.000	4.790	4.439
flowering dogwood	3.649	2.982	2.930
eastern redcedar	3.193	2.421	2.579
post oak	2.948	7.579	7.019
pignut hickory	2.930	2.000	1.965
yellow-poplar	2.895	1.140	1.088
blackgum	2.667	3.193	3.263
black oak	2.632	1.351	1.544
black cherry	2.316	1.983	1.579
mockernut hickory	2.229	2.036	1.948
shortleaf pine	2.211	4.685	4.247
boxelder	2.070	2.789	1.491
green ash	2.018	2.720	2.299
American elm	1.947	2.683	2.139
cherrybark oak	1.824	2.421	2.157
white ash	1.701	1.069	1.017
sugar maple	1.596	0.087	0.052
sycamore	1.456	1.543	1.368
common persimmon	1.386	2.561	2.158
shagbark hickory	1.245	0.982	0.701
American beech	1.157	0.965	0.894
northern red oak	0.825	0.316	0.316
sugarberry	0.684	2.175	1.386
water oak	0.579	4.404	3.580
black locust	0.544	0.000	0.000
chestnut oak	0.491	0.175	0.175
bitternut hickory	0.403	2.404	3.385
black walnut	0.351	0.000	0.000
eastern redbud	0.334	0.439	0.000
black willow	0.228	2.157	0.895
blackjack oak	0.210	1.613	1.245
silver maple	0.175	3.157	0.684
eastern cottonwood	0.070	2.315	0.351
black hickory	0.035	1.737	1.772
Shumard oak	0.018	1.141	1.159

🟩	Increase in potential habitat value
🟧	Decrease in potential habitat value
🟨	No increase/decrease in potential habitat value

Fig. 15. Upper Gulf Coastal Plain tree species winners and losers.

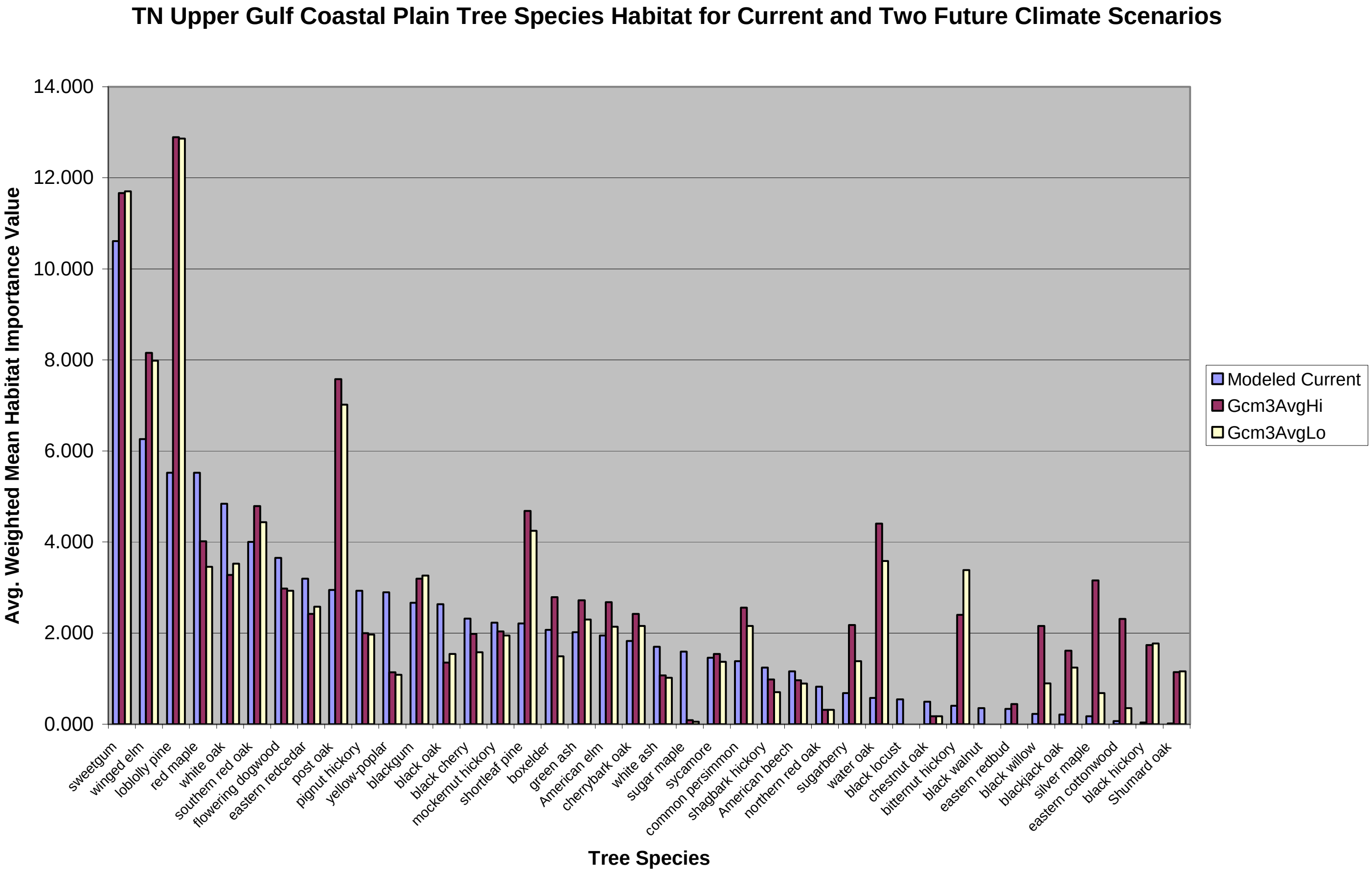


Table 4. Interior Low Plateau tree species winners and losers.

TN ECOREGION - INTERIOR LOW PLATEAU - TREE SPECIES "WINNERS AND LOSERS"

Tree Species	Modeled Current	Gcm3AvgHi	Gcm3AvgLo
eastern redcedar	7.062	3.604	4.062
white oak	6.041	4.176	4.395
sugar maple	5.990	0.188	0.104
yellow-poplar	4.698	1.583	1.355
flowering dogwood	4.396	3.229	3.021
red maple	3.667	2.990	2.615
blackgum	3.510	3.979	4.114
winged elm	3.375	6.864	6.677
white ash	3.156	1.427	1.458
pignut hickory	3.083	1.781	1.542
sweetgum	2.917	6.563	5.854
mockernut hickory	2.729	2.771	2.896
black oak	2.594	2.532	2.417
sassafras	2.448	1.593	1.406
hackberry	2.365	2.021	1.386
post oak	2.323	10.865	10.115
shagbark hickory	2.104	1.229	1.052
chestnut oak	2.021	1.396	1.375
loblolly pine	2.020	12.447	11.156
American beech	1.896	0.928	0.823
northern red oak	1.895	1.166	1.374
eastern hophornbeam	1.844	2.635	2.156
scarlet oak	1.750	0.344	0.052
sugarberry	1.698	2.562	2.135
southern red oak	1.656	2.572	2.427
black walnut	1.541	0.124	0.010
chinkapin oak	1.458	0.750	0.718
American elm	1.395	2.760	1.593
common persimmon	1.125	2.250	1.427
shortleaf pine	0.844	4.584	4.375
bitternut hickory	0.792	2.907	2.406
blackjack oak	0.260	3.218	2.697
black hickory	0.146	2.427	2.344
water oak	0.000	3.187	2.250
Shumard oak	0.000	0.990	0.958

🟩 Increase in potential habitat value
🟧 Decrease in potential habitat value
🟨 No increase/decrease in potential habitat value

Fig. 16. Interior Low Plateau tree species winners and losers.

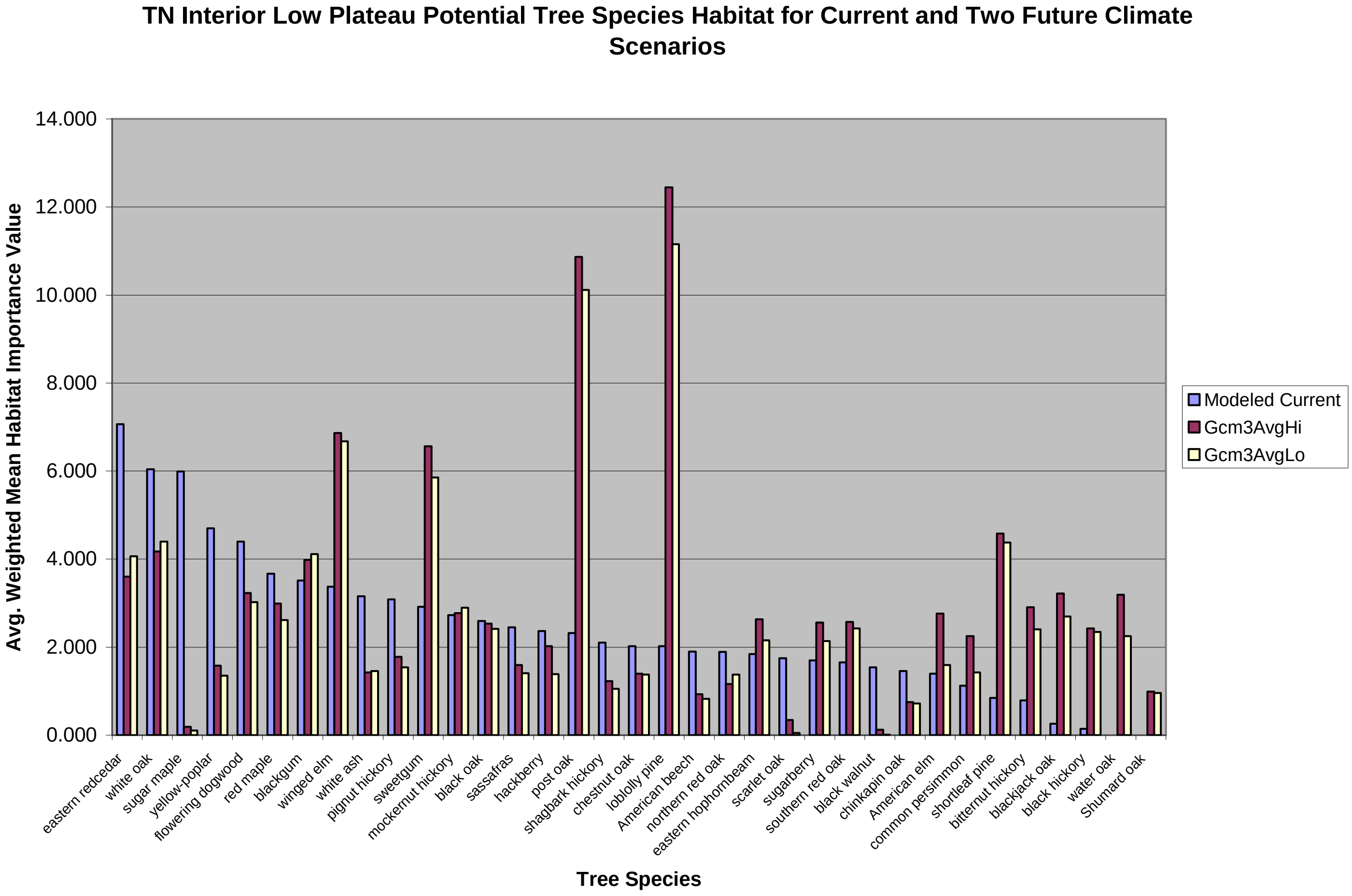


Table 5. Cumberland Plateau and Mountains tree species winners and losers.

TN ECOREGION - CUMBERLAND PLATEAU AND MOUNTAINS - TREE SPECIES "WINNERS AND LOSERS"

Tree Species	Modeled Current	Gcm3AvgHi	Gcm3AvgLo
red maple	10.888	🟧 4.805	🟧 5.472
white oak	7.861	🟧 5.472	🟧 7.722
yellow-poplar	6.972	🟧 2.166	🟧 2.360
Virginia pine	6.139	🟧 2.861	🟧 4.250
chestnut oak	5.499	🟧 3.500	🟧 3.637
flowering dogwood	4.945	🟧 3.806	🟧 4.167
sourwood	4.888	🟧 1.860	🟧 2.860
sugar maple	4.805	🟧 0.749	🟧 0.861
blackgum	4.473	🟩 5.140	🟩 4.917
scarlet oak	2.584	🟧 0.889	🟧 0.695
pignut hickory	2.556	🟧 1.945	🟧 1.750
black oak	2.528	🟩 3.834	🟩 3.250
loblolly pine	2.499	🟩 13.277	🟩 10.721
mockernut hickory	2.472	🟩 3.138	🟩 3.250
American beech	2.027	🟧 1.388	🟧 1.222
shortleaf pine	1.916	🟩 10.416	🟩 9.221
northern red oak	1.778	🟩 1.917	🟩 3.417
black cherry	1.695	🟩 2.334	🟧 1.640
sweetgum	1.694	🟩 5.584	🟩 4.917
white ash	1.639	🟧 1.028	🟧 1.055
eastern redcedar	1.528	🟩 3.556	🟩 2.416
post oak	1.472	🟩 12.833	🟩 8.972
eastern white pine	1.306	🟧 0.362	🟧 0.222
southern red oak	1.306	🟩 2.778	🟩 2.334
eastern hemlock	1.222	🟧 1.111	🟧 0.944
shagbark hickory	1.083	🟩 1.193	🟩 1.139
winged elm	0.666	🟩 6.555	🟩 4.416
bitternut hickory	0.500	🟩 2.806	🟩 0.583
American elm	0.472	🟩 2.916	🟩 0.972
common persimmon	0.361	🟩 2.860	🟩 1.417
hackberry	0.278	🟩 2.000	🟩 0.333
yellow buckeye	0.194	🟧 0.138	🟩 0.249
pitch pine	0.111	🟧 0.000	🟧 0.000
black hickory	0.000	🟩 4.195	🟩 2.916
blackjack oak	0.000	🟩 4.389	🟩 2.222
water oak	0.000	🟩 3.028	🟩 1.528

🟩	Increase in potential habitat value
🟧	Decrease in potential habitat value
🟨	No increase/decrease in potential habitat value

Fig. 17. Cumberland Plateau and Mountains tree species winners and losers.

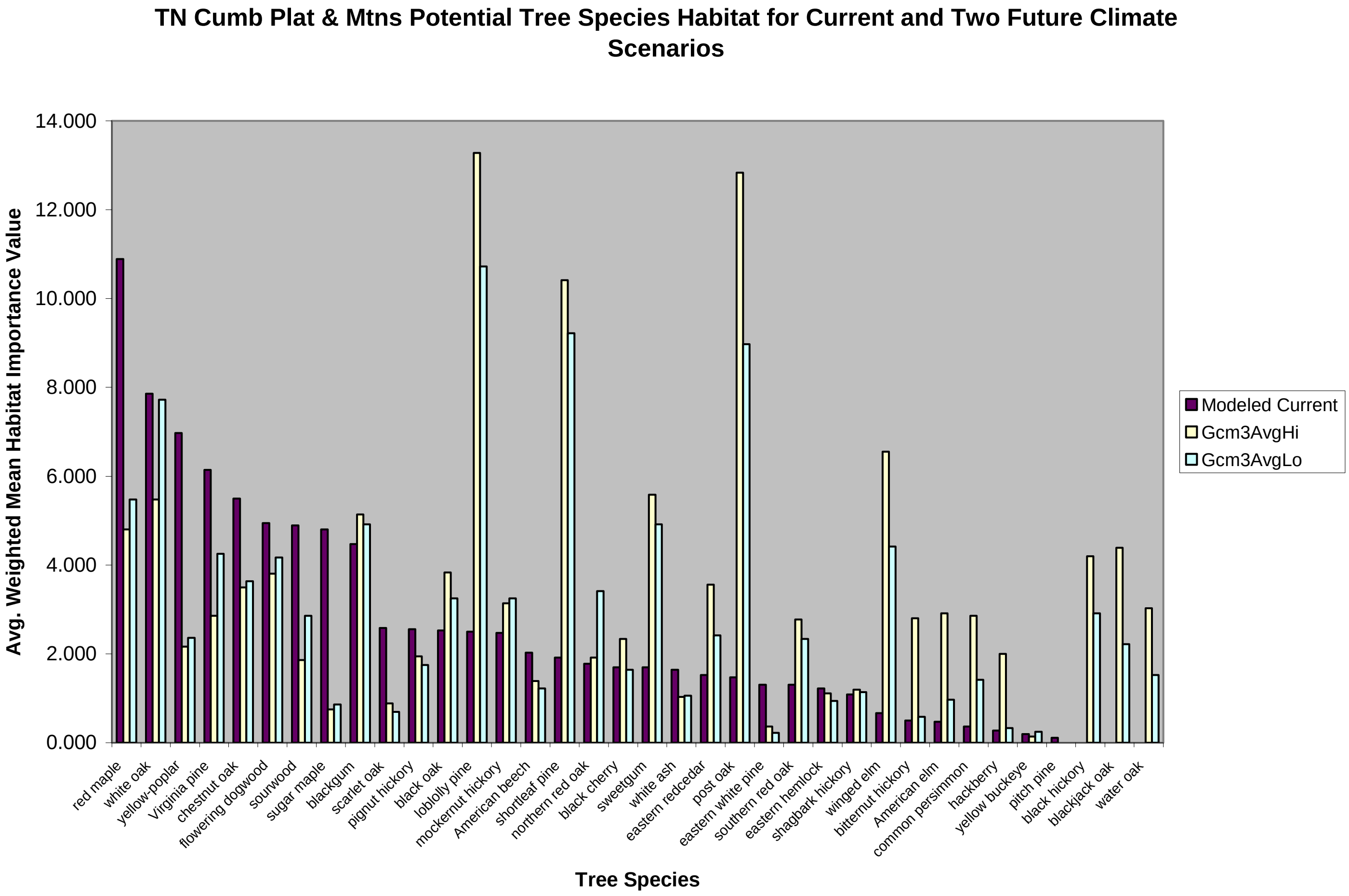


Table 6. Ridge and Valley tree species winners and losers.

TN ECOREGION - RIDGE AND VALLEY - TREE SPECIES "WINNERS AND LOSERS"

Tree Species	Modeled Current	Gcm3AvgHi	Gcm3AvgLo
yellow-poplar	6.957	1.659	1.914
red maple	6.469	3.533	3.660
white oak	5.170	4.488	4.787
flowering dogwood	5.064	3.191	3.533
Virginia pine	5.022	2.086	2.895
eastern redcedar	4.872	3.723	4.020
chestnut oak	4.468	2.298	2.361
sugar maple	3.894	0.298	0.405
blackgum	3.255	4.042	3.703
sourwood	3.021	1.341	1.745
pignut hickory	2.936	1.766	1.616
mockernut hickory	2.767	3.490	3.617
black oak	2.553	3.532	3.064
northern red oak	2.469	1.660	2.448
white ash	2.319	1.383	1.298
shortleaf pine	2.256	8.787	7.723
American beech	2.170	0.808	0.744
loblolly pine	2.149	11.893	10.000
sweetgum	1.787	4.681	4.086
scarlet oak	1.723	0.787	0.616
southern red oak	1.553	2.680	2.510
black walnut	1.405	0.276	0.362
shagbark hickory	1.362	1.085	1.043
American elm	1.298	2.383	1.298
winged elm	1.297	6.148	4.658
post oak	1.276	12.978	8.892
eastern white pine	0.936	0.085	0.064
common persimmon	0.746	2.066	1.192
bitternut hickory	0.703	2.554	0.682
blackjack oak	0.085	4.149	2.616
American basswood	0.064	0.021	0.000
black hickory	0.021	3.276	2.404
slash pine	0.000	0.978	0.000
longleaf pine	0.000	0.979	0.234
water oak	0.000	2.660	1.596

🟩 Increase in potential habitat value

🟧 Decrease in potential habitat value

🟨 No increase/decrease in potential habitat value

Fig. 18. Ridge and Valley tree species winners and losers.

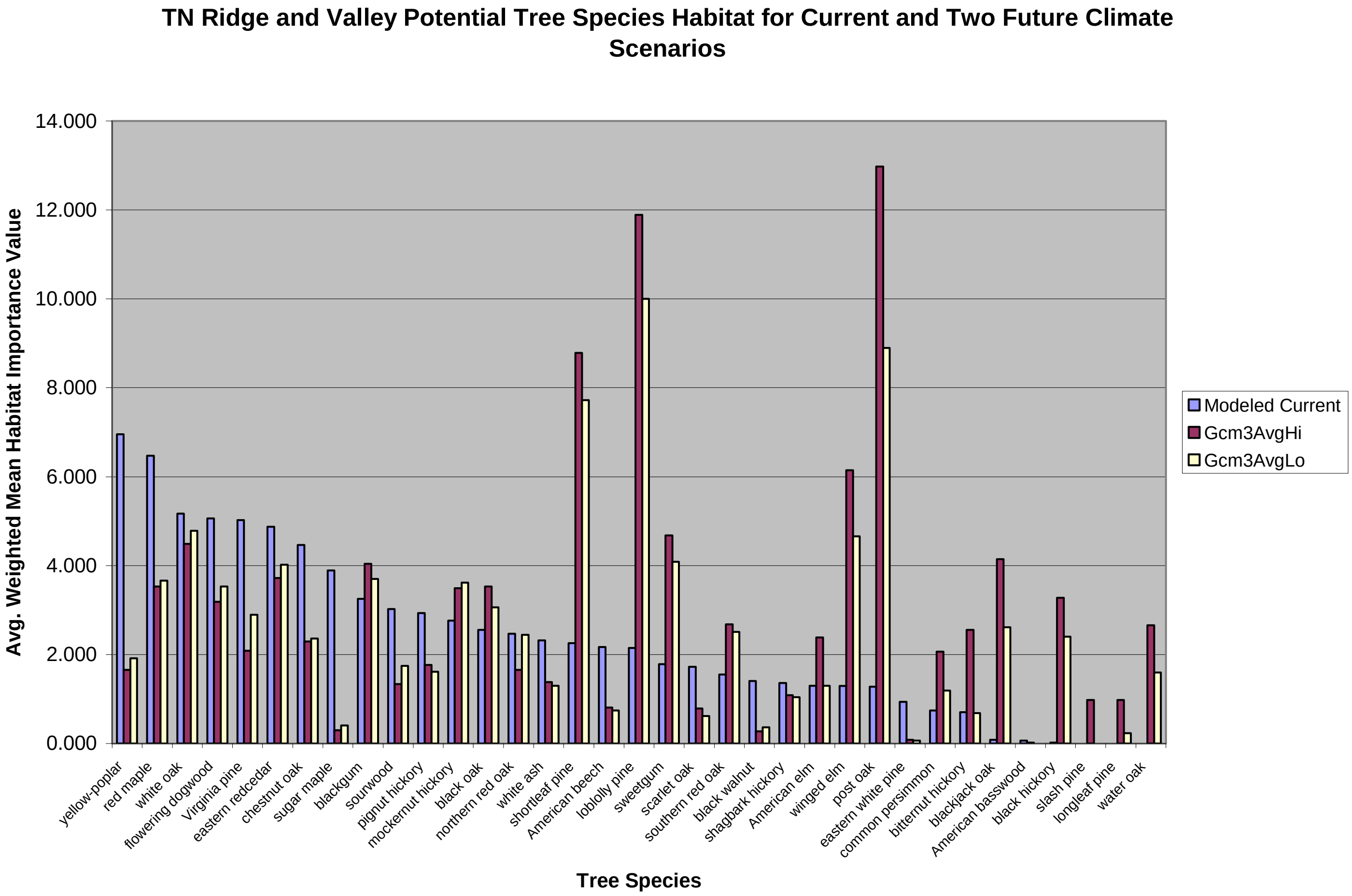


Table 7. Southern Blue Ridge tree species winners and losers.

TN ECOREGION - SOUTHERN BLUE RIDGE - TREE SPECIES "WINNERS AND LOSERS"

Tree Species	Modeled Current	Gcm3AvgHi	Gcm3AvgLo
red maple	10.375	4.750	7.583
yellow-poplar	7.042	2.417	3.875
chestnut oak	6.667	4.208	5.209
flowering dogwood	5.458	3.750	4.291
white oak	5.250	5.208	5.416
Virginia pine	5.166	2.916	4.499
blackgum	4.041	4.457	3.916
sourwood	3.959	2.084	3.501
sugar maple	3.542	0.708	1.417
northern red oak	3.416	2.375	3.041
eastern white pine	3.250	2.750	3.167
eastern redcedar	3.000	4.625	4.166
scarlet oak	2.792	0.834	1.834
black oak	2.667	3.708	2.875
pignut hickory	2.625	1.875	1.750
mockernut hickory	2.542	3.167	2.917
American beech	2.542	1.709	1.542
black locust	2.291	1.125	1.250
eastern hemlock	2.208	2.583	2.542
shortleaf pine	2.000	9.875	6.459
white ash	1.834	1.500	1.250
black cherry	1.667	1.792	1.458
loblolly pine	1.459	12.834	9.043
southern red oak	1.167	2.667	2.125
post oak	1.125	12.916	5.833
sweetgum	1.083	5.083	3.749
winged elm	0.917	6.500	2.958
shagbark hickory	0.667	1.625	1.208
yellow buckeye	0.625	0.708	0.791
common persimmon	0.583	2.167	1.291
yellow birch	0.542	0.500	0.542
American elm	0.500	1.542	0.709
cucumbertree	0.333	0.333	0.250
Table Mountain pine	0.125	0.458	0.417
bitternut hickory	0.125	2.208	0.334
red spruce	0.042	0.042	0.042
black hickory	0.000	4.083	1.667
blackjack oak	0.000	4.625	1.792
water oak	0.000	2.792	1.375

🟩	Increase in potential habitat value
🟧	Decrease in potential habitat value
🟨	No increase/decrease in potential habitat value

Fig. 19. Southern Blue Ridge tree species winners and losers.

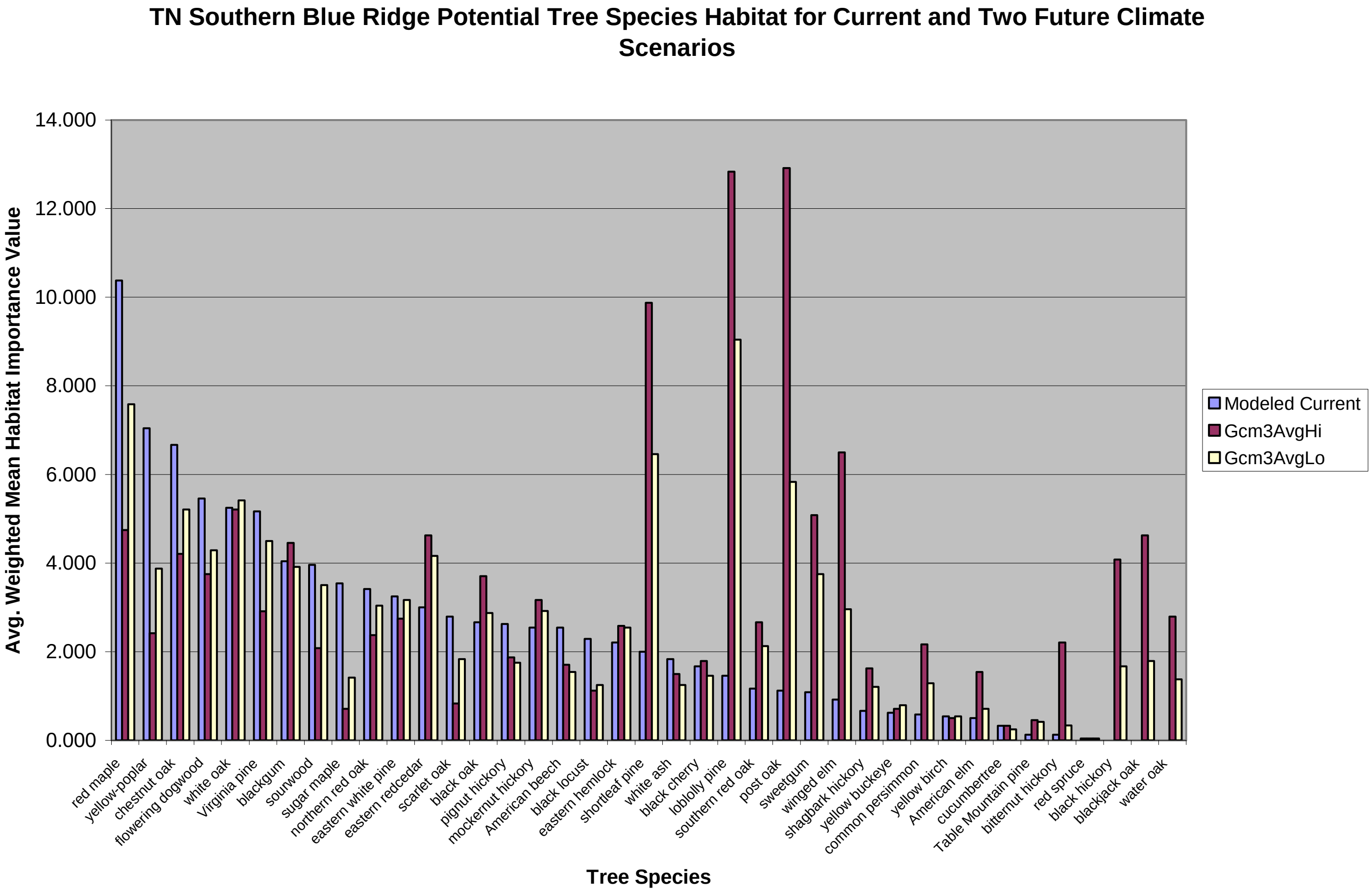
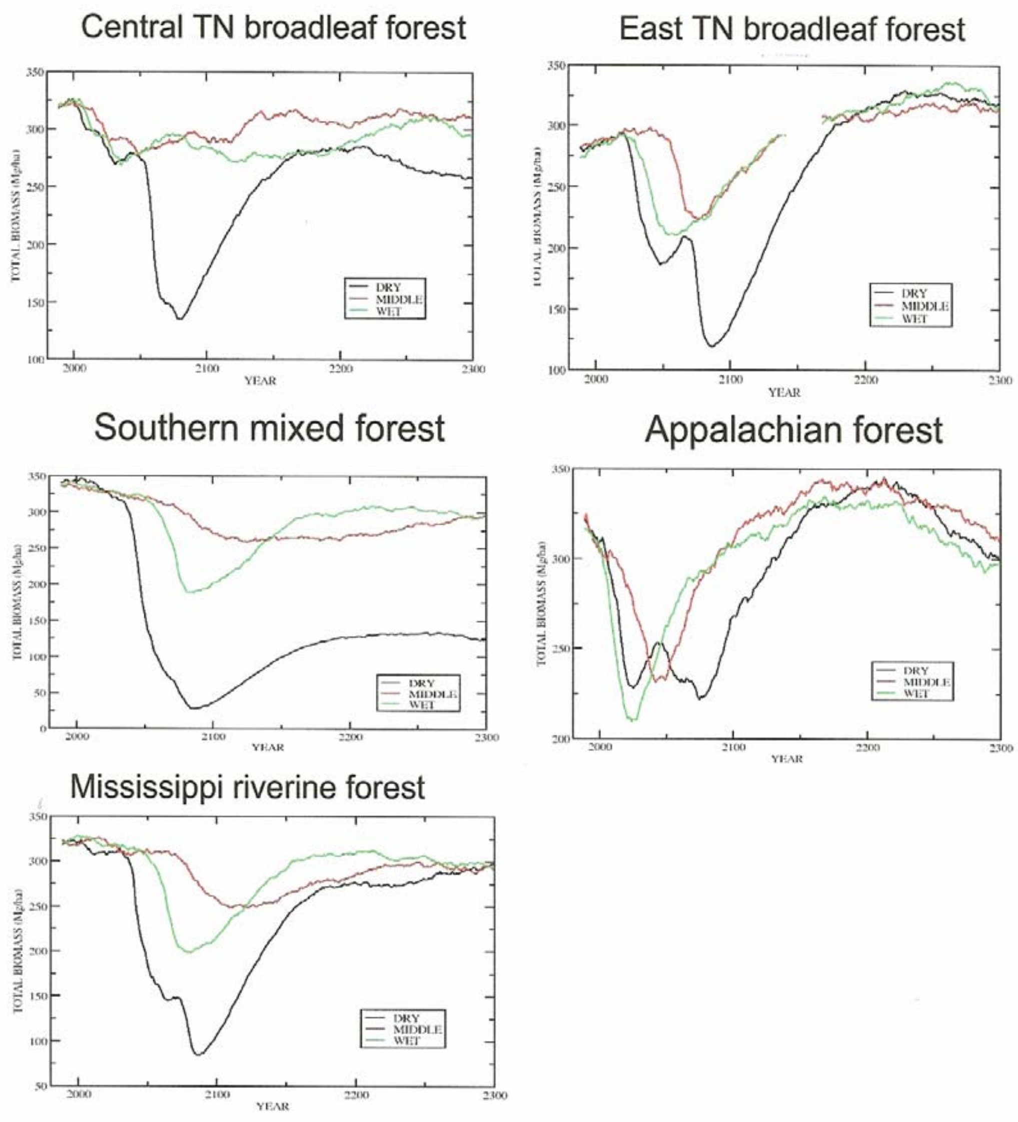


Fig. 20. Projected Biomass for Tennessee Forests (Hodges et al. submitted for consideration for publication in 2008).



Central TN broadleaf forest

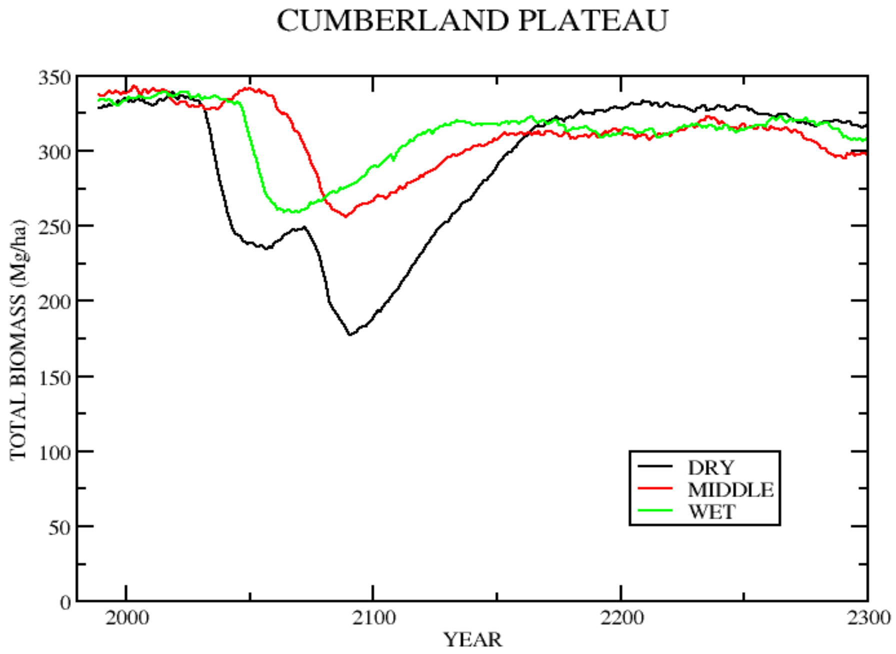
East TN broadleaf forest

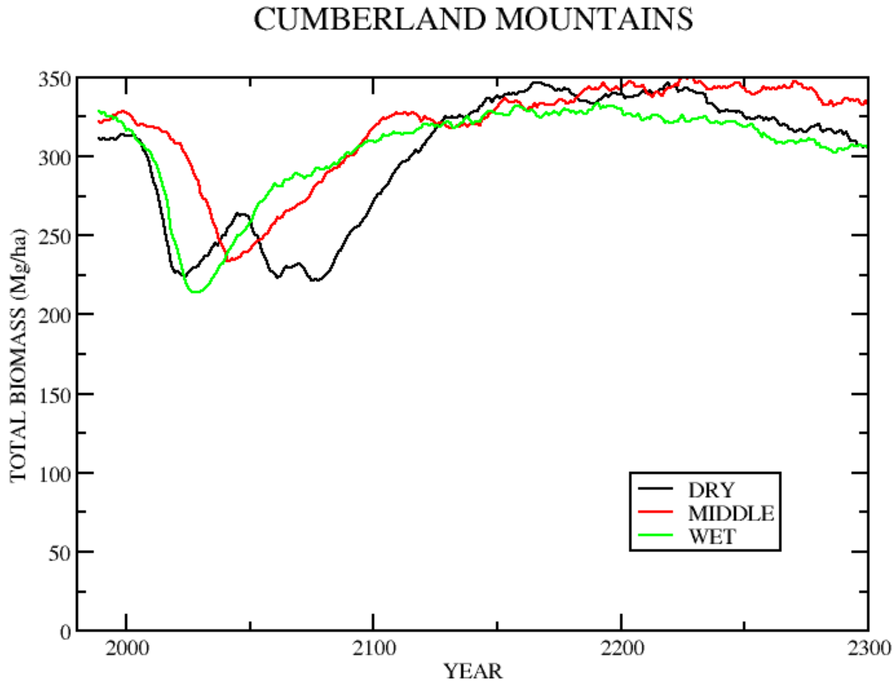
Southern mixed forest

Appalachian forest

Mississippi riverine forest

Fig. 21. Projected changes over time in total biomassfor the (A) Cumberland Plateau and (B) Mountains (Dale et al., in press 2008).





Potential Effects of Climate Change on Tennessee Birds

Background

There are three approaches to understanding possible effects of climate change on bird populations. The first is to document changes in phenology or distribution that are consistent with long-term changes in climatic condition (Seavy et al. 2008). Shifts in bird populations resulting from climate change are supported on several fronts including shifts in migration timing (Butler 2003, Murphy-Klassen et al. 2005, MacMynowski et al. 2007, Sparks and Tryjanowski 2007), initiation of breeding (Crick and Sparks 1999, Dunn and Kinkler 1999), elevational distribution (Pounds et al. 1999, Peh 2007), and latitudinal distribution (Thomas and Lennon 1999, Hitch and Leberg 2007, LaSorte and Thompson 2007). These shifts may be due to multiple factors in addition to climate change, such as land use changes and actual avian population size changes occurring over the same period of time (Tryjanowski and Sparks 2001).

A second approach is to use distribution modeling to predict how future climatic conditions may affect distributions of bird populations (Seavy et al. 2008). This approach utilizes historical distribution data to predict future distribution of birds as a function of climatic, land-use, or habitat variables under different climate scenarios (Peterson et al. 2002). Many of these models have shown there could be profound effects on bird populations, including large changes in bird community composition in the northeastern United States (Rodenhouse et al. 2008). These models rely on several simplifying assumptions, including the omission of the effects of species interactions on patterns of distribution while assuming future climate-distribution relationships will be the same as those found today (Ibanez et al. 2006, Seavy et al. 2008). In addition, these models describe species distributions on a relatively coarse scale and may be limiting in their value on a finer scale for making management decisions at a specific location (Seavy et al. 2008).

The third approach is to understand the underlying demographic mechanisms through which climate change affects population dynamics. Ornithologists have studied weather conditions on local scales (e.g. annual or seasonal rainfall or temperature) and large-scale indices (e.g. El Nino Southern Oscillation [ENSO]) and variation in demographic parameters such as fecundity (Sillett et al. 2000, Chase et al 2005, Lehikoinen et al. 2007), survival (Peach et al. 1991, Robinson et al. 2007), and breeding phenology (Frederiksen et al. 2004). We must evaluate how, when or whether these relationships will be important for understanding climate change and interpret these studies in the context of climate projections. This approach has been taken with two European bird species (Saether and Bakke 2000, Sanz 2003, Both et al. 2006, Seavy et al. 2008).

Nongame Birds

Increases in temperature and precipitation may have a variety of different effects on nongame birds in Tennessee. We are able to measure many of these changes by taking the first of the aforementioned three approaches to understanding the effects of climate change on nongame bird populations: document changes in phenology or distribution that are consistent with long-term changes in climatic conditions. There is a gathering collection of literature assessing various aspects of the lives of migratory birds and their responses to climate change, which may be applicable to changes we may observe in Tennessee.

In terms of impacts on non-game bird populations with respect to increased precipitation, we could expect an increase in insect abundance in spring, summer, and fall with increased precipitation. An increase in insect abundance during the breeding season may result in greater nestling weights and higher post-fledgling survival, which may in turn increase post-fledgling survival and produce higher numbers of juvenile birds surviving to reach their first migration (Sillett et al. 2000, Chase et al. 2005). However, increased numbers of fledged birds may not result in increasing bird populations if conditions along the migratory path or on the wintering grounds do not provide adequate resources (see below). These impacts could be positive for many declining Neotropical migratory songbirds breeding in Tennessee, i.e. Cerulean, Prairie, and Golden-winged Warbler, and Yellow-billed Cuckoo.

If spring precipitation increases in Louisiana, Mississippi, Alabama, and Georgia as predicted, we could expect earlier arrival of breeding birds in Tennessee. Increased food resources during migratory stopover, particularly in spring, could lead to increased refueling rates of migrating birds during stopover. Rapid fat replenishment rates could lead to more rapid northward movement of birds (Sparks and Tryjanowski 2007). In turn, this could facilitate earlier arrival dates of species in Tennessee and on breeding grounds to the north.

Although not exclusive from changes in precipitation, increased temperatures and earlier leaf-out and insect emergence may affect arrival dates of birds in Tennessee. Short-distance migrants wintering in Tennessee, i.e. White-throated Sparrows, Hermit Thrushes, many species of waterfowl, etc., are generally thought to be affected by warming temperatures and the passage of cold fronts (Butler 2003, Strode 2003), where as migratory patterns of long-distance migrants, i.e. Neotropical migratory songbirds and shorebirds breeding and migrating to and through Tennessee, are more influenced by photoperiod and endogenous controls (Berthold 1996, Butler 2003). However there are a growing number of studies that suggest spring arrival dates of long-distance migrants on the breeding grounds are more closely tied to interannual variation in winter climate, i.e. warmer conditions on the winter grounds (Cotton 2003, Saino et al. 2004, 2007, Marra et al 2005, Gordo 2007, Studds and Marra 2007, Wilson 2007). Regardless of photoperiod, birds are migrating north earlier with warmer conditions on the winter grounds and weather conditions conducive to a successful migration (strong northerly winds across the Gulf of Mexico) are occurring earlier (Jonzen et al. 2007).

In addition to arriving earlier, many species may begin nesting earlier as a result of warmer spring temperatures and advanced emergence of vegetation and food resources (Seavy et al. 2008). Crick and Sparks (1999) found that 37% of bird species in Europe had earlier nest initiation correlated with warmer spring temperatures. Tree Swallows were found to have advanced their nest initiation date by 9 days from 1959-1991 across North America (Dunn and Winkler 1999). Assuming birds are able to arrive earlier and time nest initiation dates with peak food resources for feeding nestlings, such shifts may not put birds at a disadvantage.

Nongame Birds and effects on tropical wintering grounds

Neotropical migratory songbirds breeding in Tennessee may be stressed on the winter grounds and return in poor breeding condition. Winter conditions in the Caribbean and Central American regions, which support dozens of species of Neotropical migratory birds, are predicted to get drier (Neelin et al. 2006, Studds, et al. 2008). Drier conditions, combined with loss of high quality habitat through physical habitat destruction and shifts in local microclimate (from mesic to more xeric), could result in moderate, but significant loss of suitable over-winter habitat for Neotropical migratory birds. Drier winter conditions may result in lower overwinter success for our Neotropical migrants wintering in the region. Studds and Marra (2007) noted that drier conditions result in lower body weights and body condition leading up to spring migration may lead to a later migration, possible mistimed arrival with peak food resources, arrival to find high quality territories being occupied resulting in nesting in poor habitat or longer migrations to find suitable habitat (Studds et al. 2007, Studds and Marra 2007, Studds et al. 2008). Arrival of birds on breeding grounds in poorer condition may result in reduced nesting success, possibly counteracting any positive effects from increased rainfall and increased insect abundance that could help nestling survival.

For those species that arrive on the breeding grounds earlier, they are more likely able to capitalize on the earlier emergence of ample food supplies; however some long-distance migrants may not be able to adjust their migration patterns to match up with peak food resources. Species that have not been able to arrive earlier to time nesting with peak food abundance have declined dramatically (Both and Visser 2001, Both et al. 2006). Murphy-Klaussen et al. (2005) noted that abilities to shift arrival dates are species specific for both short- and long-distance migrants. Lane and Pearman (2003) noted that Mountain Bluebirds arrived earlier to an area in Alberta, Canada, while the Tree Swallow, a direct competitor for nest cavities, did not arrive earlier with warmer spring temperatures. If Neotropical migratory songbirds do not arrive earlier on the breeding grounds to respond to earlier food resources, nesting success may decline and result in decreased populations.

Nongame Birds - Other Possible Effects

With possible expansion of early successional-scrub/shrub habitat in Tennessee, we may see species respond positively to increased amounts of habitat. Although Price (2002) predicted scrub-shrub species, i.e. Indigo Bunting, Field Sparrow, Chipping Sparrow, American Goldfinch, Willow Flycatcher, and Common Yellowthroat, to decline in summer with moderate to significant range contractions, we may expect population increases in some of these species with increases in available habitat. However, Willow Flycatcher and Indigo Bunting, both Neotropical migrants, may decline to aforementioned impacts of declining winter ground conditions. Range expansions and population increases may be observed for Painted Bunting, Dickcissel, Bachman’s Sparrow, Western Kingbird, Scissor-tailed Flycatcher, and Bell’s Vireo (Price 2002). We may also see increases in breeding grassland species, i.e. Grasshopper and Henslow’s Sparrow, if we observe increases in early successional habitat.

We may find that wetland systems, i.e. floodplains, marshes, etc., become drier as a result of climate change in Tennessee. Although precipitation is expected to increase, much of the increase is thought to come in large rain events (resulting in more frequent large floods) separated by extended periods of very dry conditions. The anticipated higher temperatures will likely increase evaporation rates resulting in drier wetlands. Wading birds nesting on islands in small wetlands and along small tributaries may be impacted with drought conditions. Rookeries along the Mississippi, Tennessee, and Cumberland Rivers may not be significantly affected. Without maintenance of flooded fields, migratory shorebirds will likely lose significant stopover habitats. Bottomland hardwood forest breeding birds, i.e. Swainson's, Kentucky, and Prothonotary Warbler, may be impacted by the excessive rotation between extreme floods and dry periods.

Bird ranges have also shifted northward as a result of climate change (Seavy et al. 2008). Hitch and Leberg (2007) analyzed Breeding Bird Survey (BBS) data and found many birds species with southern distributions shifted northward (i.e. Golden-winged, Blue-winged, Hooded, and Kentucky Warbler, Black-billed Cuckoo, etc.), while no species with northern distributions shifted southward in the United States from 1961-2002. A study found that breeding ranges for 83 bird species nesting in New York expanded north up to 64 km between surveys done in 1980-1985 and 2000-2005 and suspected climate change as a major cause of the shift (Livescience.com, 2008). They also noted that southern edges of the breeding ranges for these species advanced northward at a more rapid pace than northward expansion of their ranges.

LaSorte and Thompson (2007) assessed winter distributions, using Christmas Bird Counts (CBC) across North America from 1975-2004. They found a general shifting of northern boundaries, center of range, and center of abundance after taking into account range size and location of northern boundary. In general, species wintering at different latitudes respond differently to the influence of climate change suggesting that species closer to the tropics may have greater expansion north while species centered in more northern temperate areas experience more substantial changes in the center of abundance (LaSorte and Thompson 2007).

As forests change in floristic values and structure, mature forest bird species could lose suitable breeding habitat in Tennessee due to loss of specific habitats and northward range shifts. The American Bird Conservancy predicted the potential loss of several mature forest breeding birds in Tennessee (Price 2002), several of which are GCN species (SWAP plan 2005). Some Neotropical migratory species that may experience reduced populations include Blue-headed Vireo, Yellow-throated Vireo, Black-throated Green Warbler, Cerulean Warbler, Ovenbird, Scarlet Tanager, and Rose-breasted Grosbeak. Price (2002) also predicted a possible significant range contraction for Carolina Chickadee and White-breasted Nuthatch, which are common forest birds across the state. The forests these species use for nesting will also be negatively impacted by tree pests and exotic species, such as the hemlock wooly-adelgid, which are changing forest conditions on local and regional scales (Iverson et al. 2008).

In addition to northward shifts in breeding and wintering populations, ranges are shifting along the elevational gradient (Pounds et al. 1999, Matthews et al. 2004, Peh 2007). Habitats are rapidly shifting northward with increased temperatures at higher elevations in California (Kelly and Goulden, in press) and such processes are thought to be underway in the northeast United States (Rodenhouse et al. 2008). Warmer growing seasons may elevate mountain ecotones and confine high elevation plant and animal communities to progressively higher, smaller, and more isolated patches. An upward shift in spruce-fir in the mountains of the northeast United States may be underway (Hamburg and Cogbill 1988). Loss of spruce-fir forests to northern hardwood forests with mixed pines is expected to occur in Tennessee with increased temperatures. Birds nesting at high elevations may disappear from Tennessee over time as habitats shift (Rodenhouse et al. 2008). Indeed, high elevation areas are likely to be among the habitats most affected by climate change (Hodkinson 2005).

In Tennessee, several species that are restricted to high elevations may disappear from Tennessee as breeding birds. The habitats at greatest risk include grassy balds, alder thickets, and spruce-fir forests. Price (2002) predicted the loss of several species which are specialists in these habitats, i.e. Alder Flycatcher, Black-capped Chickadee, Red-breasted Nuthatch, Winter Wren, Blackburnian Warbler, Black-throated Blue Warbler, Canada Warbler, Savannah Sparrow, and Slate-colored Junco. Price (2002) left Magnolia Warbler off the list, but they would likely disappear with additional habitat shifts in their habitats that are found only above approximately 4000 ft elevation in the mountains of east Tennessee.

Nongame Birds - Impacts in Tennessee

Considering the aforementioned affects of climate change documented across North America and Europe, we can make additional predictions on possible changes in bird populations in Tennessee. Changes in bird populations need to be addressed from three directions. First, resident species, short-distance migrants, and long-distance migrants that spend part of their annual cycle in Tennessee may experience different environmental factors affecting their populations. Second, as habitats shift and vegetation structure and floristic values are altered with changes in temperature and precipitation, changes could occur to a suite of species using general habitat types, i.e. wetlands, bottomland hardwood forests, high elevation forests, etc. Third, individual species could experience additional impacts through possibly non-independent effects, i.e. inability to adapt to climate change fast enough.

Nongame Birds - Possible Impacts on resident, short- and long-distance migrants

Resident birds may benefit with increasing winter temperatures; however some species may decline, i.e. Ruffed Grouse (Newton 1998). Resident species may benefit from increased rainfall and the resulting additional food resources as long as the rainfall is prolonged and not concentrated in strong storms. Slight increases in temperature and rainfall in winter may increase over-winter survival. Partners in Flight species of concern, i.e. Brown Thrasher, Eastern Towhee, and Red-headed Woodpecker, may increase as mature forests begin convert towards more open scrub-shrub habitats.

Short-distance migrant species that over-winter further south and breed in Tennessee may show earlier arrival dates on the breeding grounds and range expansions in Tennessee. For example, Great Egrets have expanded their nesting range from west Tennessee (i.e. Mississippi Alluvial Valley) into a few places in middle Tennessee with a few birds nesting in east Tennessee in the last 10 years (M. Bierly, pers. comm.). We may expect earlier spring arrivals of other species such as Black-crowned Night-Heron, Blue-gray Gnatcatcher, Eastern Phoebe, Orange-crowned Warbler, and Blue-headed Vireo.

We may see short-distance migrants that breeding north of Tennessee and over-winter in the southeast begin to show earlier fall arrival and earlier spring departure dates, i.e. White-throated Sparrow, Purple Finch. In addition, we may begin to see some species that typically over-winter only as far north as central Mississippi, Alabama, and Georgia in winter in Tennessee, i.e. Blue-gray Gnatcatcher, Orange-crowned Warbler, and Blue-headed and White-eyed Vireo. Drier winter conditions in Florida may reduce over-winter quantity of habitat conditions and may facilitate winter ranges to possibly shift north with the general drying of the Caribbean basin.

Long-distance migrants may show different trends in populations in Tennessee. In general, Neotropical migratory songbirds, which are already showing population declines, may continue to decline as wintering grounds in Central America and the Caribbean basin become more xeric. As mesic habitats become drier, winter habitat quality is reduced, which in combination of rapid loss of winter habitat through physical destruction, and possibly mistimed arrival on breeding grounds could result in greater rates of population decline for some species regionally within Tennessee, across the state, or across the entire range of the species.

We may find increases in occurrences of rare species with increased temperatures across Tennessee. We may also see more occurrences of Wood Stork and Roseate Spoonbill in late summer as these birds move north from Louisiana, Texas, and Mexico along the Mississippi River. These birds typically reach as far north as west-central Mississippi and southeastern Arkansas, but are beginning to venture further north each year. Western Kingbirds were documented nesting in Shelby Co, Tennessee for the first time in 2005 and are found at 5-6 locations annually. We may see the expansion of this species across west Tennessee.

Climate change and Northern Bobwhite, American Woodcock, and Ruffed Grouse

The northern bobwhite, American woodcock and ruffed grouse are species that have been experiencing long term declines in Tennessee and the southeast. The northern bobwhite has been declining since the early 20th century although populations likely increased during periods of farm abandonment in the 1930's – early 1950's. In Tennessee, the ruffed grouse is at the extreme southern limit of the species continental range and thus subject to less complex dynamics (Williams et al. 2004). Although primarily a migrant and wintering species, American woodcock also nest in Tennessee perhaps in numbers higher than appreciated given their overall decline in more northern areas of their range.

Throughout the broad range of bobwhite, the habitat is largely the same; predominately herbaceous vegetation with scattered clumps of low woody vegetation. Tree cover has negative impacts on populations only where basal areas exceed 60 ft^2/acre (14 m^2/ha) and shade out herbaceous and shrubby vegetation. Vegetation communities suitable to bobwhites occur in non-monoculture grasslands, shrub-scrub, and savanna/woodland habitats. They also occur in conjunction with agricultural lands where these other communities are present to provide for breeding habitat, protective cover, and alternate food sources other than agricultural crops (Applegate, in preparation).

The predicted increase in early successional habitat through opening of the forest canopy and development of scrub-shrub habitat may provide additional habitat for bobwhite in Tennessee. We may be able to take advantage of slight habitat changes through additional management actions to stabilize or increase bobwhite populations in Tennessee; however loss of genetic diversity through release of pen-raised bobwhite may negatively affect survival in times of climate change (Evans et al., in press).

American woodcock utilize habitat very similar to that of bobwhite during the winter and nesting season. They require moist soils with abundant earthworm populations for feeding and brood rearing and open fields of grasses and shrubs for display areas during the breeding season. As with bobwhite, American Woodcock may have increased habitat due to opening of forest canopies and increased shrub-scrub habitat (Dessecker and McAuley 2001, Kelley and Williamson 2008).

The ruffed grouse is an early successional woodland bird found breeding in the higher elevations of eastern Tennessee. Populations of Ruffed Grouse are influenced annually by weather patterns and other stochastic influences. The greatest current and future threat to ruffed grouse is the lack of dense early successional forest lands in Tennessee (Dessecker et al. 2007).

The southern Appalachian Mountains of Tennessee are at the southern edge of the breeding range for Ruffed Grouse and the population may be negatively impacted through changes in habitat along the elevation gradient as habitats shift upwards. However; populations may increase with increases in early successional habitat in many locations through the opening of the forest canopy and greater understory cover.

Climatic changes that eliminate or reduce oak in the southern Appalachian forest will have a significant impact on grouse. However, if sufficient viable populations are not sustained through management in the short-term, the species may be gone before additional climate driven changes to habitat occur.

Tennessee Rails

The primary rail species that occur in Tennessee are the king rail (*Rallus elegans*), Virginia rail (*R. limicola*), and sora (*Porzana carolina*). Virginia Rail, King Rail, and Sora typically nest in emergent freshwater wetlands. During migration, rails will be found in wet fields of annual grasses and forbs (Eddleman et al. 1988). Winter habitat for these rails is poorly known. Extensive wetland losses have already eroded the core of habitats available to these three birds (Reid et al. 1994, Conway and Eddleman 1994, Melvin and Gibbs 1994). Population goals have been identified for King rails, but at present there are none for the Virginia Rail or Sora (Cooper 2008). Climate change leading to dryer conditions and elimination of shallow wetlands could lead to significant declines of these three species therefore, efforts to protect and maintain emergent wetlands and wet fields will be critical to the future of rails.

Waterfowl

The predicted changes under various climate models suggest that waterfowl face potential significant changes in the future (Melillo et al. 2000, Hadley Center for Climate Prediction and Research in Great Britain, and Canadian Climate Center models). Not only will migratory and resident waterfowl face changes on the breeding and wintering grounds, changes in migration patterns and timing will undoubtedly affect waterfowl hunting. Many believe that waterfowl have already begun to winter farther north and come south at later dates, for shorter periods. Waterfowl hunting will likely be most affected in southern states. This section will address possible impacts of global warming on migratory and resident waterfowl, and its effects on waterfowl hunting in Tennessee.

Waterfowl - Potential Breeding Ground Impacts to Migratory Waterfowl

The Prairie Pothole Region of Canada (PPR) is the most important breeding area for migratory waterfowl in North America (Batt et al. 1989) and is the greatest source for ducks and geese that winter in Tennessee (Unpublished band return data, TWRA 2008). Global climate models have been used to predict soil moisture levels and thus waterfowl abundance/reproduction in the prairie pothole region (Sorenson et al.1998). Some reports indicate that warmer temperatures will likely result in lower soil moisture, fewer wetlands, less flooding of seasonal wetlands, warmer water temperatures, decreases in invertebrate productivity and other potentially negative impacts (Clair et al. 2000). The species most likely affected by lower productivity in the prairies include: Mallard, Northern Pintail, Gadwall, Blue-winged Teal, Northern Shoveler, Lesser Scaup, Redhead and Canvasback. Waterfowl are adaptable and it is not known if they will be able to utilize more northern habitats. Even if they are able to expand their breeding ranges to more northerly latitudes, it is unlikely these areas will be as productive as the prairies.

Waterfowl utilizing the boreal forest for breeding comprise a significant portion of the migratory waterfowl that winter in Tennessee (Unpublished band return data, TWRA 2008). Not much is known about this vast area and its relationship with waterfowl that breed there. This may be one of the more vulnerable habitats and not much is known how climate change will impact it.

Migratory waterfowl will face significant changes as global warming progresses. Models predict fewer wetlands on the prairie pothole region and lower waterfowl production due to shorter nesting seasons, lower clutch sizes, lower nesting success and lower brood survival (Sorenson et al. 1998), resulting in lower recruitment rates and, potentially, declining population size. This changes will likely result in fewer waterfowl wintering in Tennessee in future decades.

Waterfowl - Potential Breeding Impacts to Resident Waterfowl

Although, as global warming continues, soil moisture levels will likely be most affected in more northern latitudes, southern wetlands will also face significant losses. The primary species affected in Tennessee will be wood ducks. Wood Duck depend on a variety of wetland types in Tennessee for brood rearing and winter habitat. All of these wetland types will likely be reduced in both quantity and quality. The wetlands that escape drought will likely have reduced productivity due to lower dissolved oxygen and will produce fewer wood ducks. Resident Canada Geese are more adaptable to habitat changes but could also see reduced reproduction due to lower wetland productivity in a warming climate.

Additional other effects to resident waterfowl may be seen with global warming. Species that traditionally breed in more southern latitudes may begin to significantly expand their breeding ranges northward. Black-bellied Whistling Ducks have been expanding their breeding range northward in recent years and were observed nesting in Shelby and Madison Counties, TN in April 2008 (TWRA unpublished observational data).

Waterfowl - Potential Effects to Migratory Waterfowl on the Wintering Grounds

The majority of migratory waterfowl wintering in Tennessee are found in the western half of the state. This broad area comprises two major ecological regions, the Mississippi Alluvial Valley and the East Gulf Costal Plain. The lower basin is the most important wintering area on the continent for Mallards, and in particular supports large numbers of other dabbling ducks and

Wood Ducks (Bellrose 1980). Wintering grounds will likely suffer similar effects as the breeding grounds in losing substantial wetland habitat.

Another significant effect of climate change on the wintering grounds will likely be reduced numbers of waterfowl for hunting. Hunters will likely have fewer waterfowl to hunt, which will result in shorter seasons, smaller bag limits and closed seasons on some species. Changes in migration patterns will likely occur as waterfowl adapt to these dynamic conditions. Migratory Canada geese have changed their winter patterns and now winter far north of the areas they utilized 30 years ago. A number of factors have contributed to this shift northward and warmer temperatures are thought to be a major factor. In Tennessee, more than 96% of our Canada Goose harvest comes from resident geese.

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Climate Change and Amphibians and Reptiles in Tennessee

Tennessee has 77 amphibians including 21 species of frogs and 56 species of salamanders making it the third most diverse state in amphibians following North Carolina with 90 amphibians and Virginia that has 78. Tennessee has listed six frogs and 24 salamanders as Species of Greatest Conservation Need (GCN) in their State Wildlife Action Plan (SWAP). According to the Atlas of Reptiles in Tennessee, this state is home to 58 reptiles. Those include 16 species of turtles, nine lizards and 33 snakes. Five turtles, three lizards and nine snakes have been listed as GCN species in Tennessee (Table 8).

Given their complex life cycle and other traits, amphibians are recognized as indicators of ecosystem health. Nearly 33% of the amphibian species of the world are categorized as vulnerable, endangered, or critically endangered according to The World Conservation Union (IUCN). Approximately 43% of amphibians are experiencing worldwide declines (Pounds, et al. 2005). Four percent of the world's reptiles are categorized as extinct, endangered or vulnerable by the IUCN (Gibbons et al. 2000).

Partners in Amphibian and Reptile Conservation has identified 6 major causes of amphibian declines (Gibbons, et al. 2000), they are:

1) Habitat loss and degradation
2) Introduced, invasive species
3) Environmental pollution
4) Disease and parasitism
5) Unsustainable use and
6) Global climate change.

These six categories of concern also contribute to the decline of reptiles (Gibbons 2000).

Many scientists consider loss of habitat to be the largest single factor contributing to declines of amphibians (Alford and Richards 1999). Less than 20% of the wetland acreage remains in some regions of the United States (Leja 1998). Semi-aquatic turtles require these same wetlands. The Bog Turtle specifically requires the Southern and Central Appalachian Bog and Fen wetlands. This habitat is threatened by drainage for residential construction. Global warming may further diminish wetland habitat in the United States. Future wetland acreage in the US may be greatly reduced under a variety of climate circulation models (Halpin 1997) and aquatic and semi-aquatic species will suffer declines as habitat disappears. Because species distributions are a function of dispersal ability, amphibians may suffer more than other vertebrates (Davis et al. 1998). Most amphibians rarely travel more than a few hundred meters over the course of their lives. Because of their limited dispersal abilities, reptiles and amphibians are especially vulnerable to rapid habitat changes and may suffer species extinctions as a result of a rapid rate of climate change (Schneider and Root 1998). Historically, organisms have responded to climate change by shifting their distribution. Today, landscape changes such as agriculture development, urbanization, deforestation, etc. constrain these mobile responses and greatly reduce the pool of replacement populations (Pounds, et al. 2005).

The Green salamander (*Aneides aeneus*) is found primarily in the Cumberland Mountains, Cumberland Plateau, and Eastern Highland Rim physiographic provinces of Tennessee. It has been identified in the Tennessee's State Wildlife Action Plan (SWAP) as a species of Greatest Conservation Need (GCN). The TWRA Region 3 Operational Plan identifies the gorge/ravine habitats occupied by Green salamanders as a particular conservation concern for the Cumberland Plateau and Mountains eco-region. Disjunct populations of the Green Salamander (Aneides aeneus) in the Southern Appalachians have apparently declined, but without similar declines in other portions of its range (Jeff Corser, USGS-BRD, Twin Creeks Resource Center, GSMNP, Gatlinburg, TN). Long-term monitoring of seven historical green salamander populations throughout the 1990's showed a 98% decline in relative abundance since 1970 (Corser, 2001). Habitat loss, overcollecting, epidemic disease and climate change could account for this region-wide decline (Corser, 2001). One leading hypothesis for the decline of the species is the extensive destruction and loss of suitable habitat. The Green salamander is understood to be a "crevice salamander," primarily inhabiting moist rock outcrops. Researchers have focused the examination of these rock outcrop habitats while overlooking the use of surrounding forest habitat. This may help to explain the observed decrease in population numbers as much of the forest habitat range of this species was logged extensively in the last century thereby reducing available forest/arboreal habitat and desiccating moist rock outcrops. This new information stresses the need to explore the relationship between Green Salamanders and their habitats. A collaborative project between TWRA and Tennessee Technological University (TTU) will conduct field surveys for the species and collect data to examine observed habitat relationships. A suite of habitat variables relevant to the Green salamander (to include Key Limiting Factors identified in the SWAP) will be developed and these variables will be recorded at all sites surveyed during the study. These habitat variables will be used to develop a predictive model for the presence/absence of Green salamanders and may involve habitat modeling using a GIS to predict the habitats most critical for recovery and survival of this species.

Introduced species have been cited as a problem for many amphibians (Stolzenburg 1999). The release of captive amphibians and reptiles is a concern due to the possible spread of disease and direct competition with native herptile populations.
The distribution and abundance of several western US frog species have been severely reduced by non-native fishes and bullfrogs (*Rana catesbeiana*), which were introduced into wetlands (Fisher and Shaffer 1996). Such species as Cuban Treefrogs *Osteopilus septentrionalis* have been documented in Tennessee but to this date have not been known to overwinter here. However, state herpetologists are aware of several populations of Mediterranean Geckos (*Hemidactylus turcicus)* that have become established. These lizards arrive in Tennessee on tropical plants and a recent case suggests boats from Florida. It is not known how these introduced species will affect our native herpetofauna. Increased winter tempertatures could increase the threat of exotic species to native amphibian and reptile populations by increasing the survival rate.of these invaders.

Environmental contaminants and pollutants have direct and indirect effects on both amphibians and reptiles (Hinton and Scott 1990, Hall and Henry 1992). Because many turtles and crocodilians heve environmental sex determination and large eggs that can incorporate high levels of pollutants they are especially vulnerable to endocrine disrupting chemicals such as PCBs (polychlorinated biphenyls) (Guillette and Crain 1996). Sex reversal and abnormal gonads have been found in turtles exposed to PCBs (Bergeron, et al. 1994, Guillete et al. 1995). Turtles and crocodilians also have temperature-dependent sex determination (Janzen 1994). Sex ratio of hatchlings is determined by nest temperatures during incubation. Rising temperatures could alter sex ratios that could affect population demographics and persistence (Gibbons et al. 2000). In general, except for soft-shell turtles, eggs incubated at warmer temperatures tend to produce females and those incubated at cooler temperatures produce males (Buhlman, et al. 2008). In an approximately three-year study of Reelfoot Lake turtles in Tennesseee, *Chrysemys picta* (Eastern Painted Turtle) and *Trachemys scripta* (Pond Slider) showed an overall sex ratio bias toward females although this bias was not strong (Cobb, 2008). In addition to studies that suggest climate change may unfavorably affect sex ratio in the many reptiles like *T. s. elegans* that have temperature-dependent sex determination (Mrosovsky and Provancha 1992; Janzen 1994), changes in climatic temperature during posthatching dormancy may directly and adversely affect the physiology, morphology, and survivorship of these turtles during early life stages. The post-hatching stage in turtles may also be greatly influenced by environmental conditions. Neonates often remain in the nests for many months after hatching, subsisting on yolk left over from embryogenesis (Gibbons and Nelson 1978; Ultsch 1989; Tucker et al. 1998*a*; Filoramo and Janzen 1999). Because turtles are ectotherms, the rate of expenditure of internalized energy stores by nest-bound hatchlings is presumably determined almost solely by thermal conditions. As nest thermal conditions are a function of local climate (Weisrock and Janzen 1999), variation in climatic temperatures necessarily impacts the morphology, physiology, and survival of such terrestrially over-wintering turtles (Nagle et al. 2000; Costanzo et al. 2004). In turn, the nutrients and energy available to surviving animals, as well as their body size, may shape their probability of surviving the critical period of transition from terrestrial to aquatic habitats that follows emergence from nests and ends when hatchlings reach their aquatic home (Janzen et al. 2000*a*, 2000*b*; Tucker 2000). Red-eared slider turtles are common and widely distributed in the central United States (Ernst et al. 1994), with other subspecies and related species distributed throughout the New World (Ernst and Barbour 1989). Embryos of *T. s. elegans* develop in the eggs for several months and the resulting offspring overwinter in terrestrial nests for many additional months in the highly variable northern temperate climate (Tucker 1997); similar behaviour is also exhibited by sliders and their relatives elsewhere (Gibbons and Nelson 1978; Morjan and Stuart 2001). According to the Tennessee Animal Biogeographic System website the incubation of Red-eared or Pond Slides is 2-2.5 months in Kansas, winters sometimes cause high mortality, dessication contributes to nest mortality and young may overwinter in nest. In a recent Reelfoot Lake turtle study, Vince Cobb noted high road mortality for hatchlings migrating from their nesting site to the water in April. Peak egg laying was reported to occur in June and July indicating that in Tennessee slider turtles spend several months in the nest including over the winter thus making them vulnerable to desiccation during extended periods of drought.

Parasites and disease have been documented as cause for declines in some amphibian species (Daszak et al. 1999). The *Batrachochytrium dendrobatidis* (Bd), the amphibian chytrid fungus, has been linked to catastrophic amphibian declines around the world (Skerratt et al 2007). Recently, a spreading of chytrid fungus is thought to be causing the decline of anurans in Central America and Australia (Berger et al. 1998, Lips 1999) and an iridovirus may be the primary cause of the periodic population crashes in Sonoran Tiger Salamander populations (Jancovich et al. 1997). Some amphibian biologists now believe disease may rival habitat destruction as the largest single cause of the decline of amphibians. Diseases have devastating impacts on wildlife when the population has decreased immunity caused by one or more primary environmental stressors, such as habitat degradation, invasive species, or pollution. Climate change may exasperate the threat of disease by increasing the proliferation and survival of zoospores, either through reduced exposure to sub-optimal ambient temperatures or by reducing "basking" microhabitats available to amphibians that would otherwise be able to clear Bd infections (Pounds et al. 2006). It should be stated that studies by Lips et al. (2008) showed that the spread of Bd is independent of climate change in Lower Central America and Andean South America. However, under temperate conditions Raffel et al. (2006) showed that amphibian immunity was decrease when exposed to increased temperatures when already cold-acclimated, i.e. a winter warm-up.

Another disease contributing to amphibian decline is Ranavirus. Recent research conducted by the University of Tennessee (Gray and Hoverman, 2008) suggests that warmer water temperature decreases the occurrence of this disease therefore it is unclear the impact climate change will have on the frequency of ranavirus in Tennessee.

Over collection for food, the pet trade, and biological supply houses has also been suggested as having had an impact on some amphibian and reptile populations (Dodd 1997). The negative effects of these types of threats are compounded by climate change. The pet trade appears especially hazardous for some turtle species such as the Eastern Box Turtle (Gibbon et al. 2000). This is also listed as a Very High level threat for Bog Turtles in the TN State Wildlife Action Plan. As stated earlier, Bog Turtles are also threatened by loss of wetland habitat. Legal turtle harvests at Reelfoot Lake account for a reported 3,813 to 21,339 Pond Sliders (*Trachemys scripta*) removed from the wild each year (Cobb, 2008). This turtle harvest could be prohibited or a size limit could be placed on turtles to decrease the removal of sexually mature females from the population (Cobb, 2008). One approach to addressing climate change will be to decrease known stressors to wildlife populations such as the illegal and over collection of species.

Many amphibian populations and species are thought to be declining but they have not been studied over long periods of time, making short-term changes in population size difficult to evaluate (Gibbons et al., 2000). However, many of the species that are thought to be declining are seasonally active anurans that arrive over restricted periods of time at limited breeding locations where they congregate in greater numbers than at any other time of the year. Researchers are familiar with this life history and when the animals fail to appear as expected, a problem is suspected. If such absences are protracted then a decline is presumed to be real (Gibbons, et al. 2000). The phenology of these amphibians permits detection of breeding activity, therefore determination of whether the absence of breeding adults is a short-term aberration or an indication of a real decline becomes a matter of accumulating the data necessary to demonstrate a statistically significant trend. Evidence suggests that recent climate change is causing some anuran species to breed earlier (AmphibiaWeb, 2008). *Hyla versicolor* (Gray Treefrog), *Pseudacris crucifer* (Spring Peeper), *Rana catesbeiana* (American Bullfrog) and *Rana sylvatica* (Wood Frog) have been shown to be breeding earlier in Ithaca, New York by Gibbs and Breisch, 2001. TAMP (Tennessee Amphibian Monitoring Program) has been collecting data on amphibian advertisement (breeding) calls since 1997. This data is being analyzed to determine if any frog species in Tennessee are calling earlier than when this data was first collected. The spring peeper in Michigan did not show a statistically significant trend toward breeding earlier but did show a significant positive relationship between breeding time and temperature. Fowler's toads (*Bufo fowleri*) in eastern Canada did not show a trend toward breeding earlier and there was no positive relationship between breeding and temperature. It did show a strong but statistically insignificant trend toward breeding later. This could be important because this could prevent increased hybridization between American toads (*Bufo americana*) and Fowler's toads (Balustein, et al. 2001).

Species range expansions or contractions may demonstrate another affect of climate change. The bird-voiced treefrog is known from the Coastal Plain of West Tennessee and along the lower Cumberland River in Middle Tennessee to near Ashland City (Tennessee Amphibian Atlas – APSU). The author of this chapter has been observing *Hyla avivoca* in Cheatham County since 1995. Initially one had to go to specific locations such as the Neptune Slough or Herbert's Bottom area of Cheatham County to find this species. On a recent field trip to the Bicentennial Trail near Cheatham Reservoir Wildlife Management Area there was an abundance of Bird-voiced Treefrogs. According to researchers from Austin Peay State University (Nathan Parker, per communication) this species has occurred at this new local in such numbers for the last 2 years.

The Green Treefrog (*Hyla cinerea*) inhabits bottomland swamps and sloughs, primarily in the Coastal Plain of West Tennessee where it is especially common around Reelfoot Lake (Scott and Redmond, 1996). This was the assessment of the range of this species when the Atlas of Amphibians in Tennessee was first published in 1996. Currently, this species has been documented as far east as Hamilton County in 2007. Other recent accounts have it as far east as Anderson County near Clinton, Tennessee. This range expansion may be due to climate change, anthropogenic interference or the release of pet Green Treefrogs.

At the writing of the Amphibian Atlas in 1996 the following was the assessment of the distribution of the Barking Treefrog *Hyla gratiosa*. "In Tennessee, the distribution and habitat requirements of *H. gratiosa* are poorly known. The species is currently known from only three possibly disjunct geographic units." Those geographic units included a dolomite pond in Franklin County, a specimen on a screen door in White County and a population breeding in farm ponds in Montgomery County. Since that writing, Barking Treefrogs have become abundant in West Tennessee and are common in Coffee and Franklin counties. Their populations in Montgomery County however have not been documented for over 10 years (Floyd Scott, per communication). The Tennessee Wildlife Resources Agency (1994a) lists *H. gratiosa* as a species in need of management.

Anecdotally, it appears that coastal plain species, species that are more abundant in warmer climates, are doing well. It is the species that are at the southern extent of their range in Tennessee such as the Wood Frog, *Rana sylvatica* that warrants close observation. A suggested study is the range expansion or contraction of *Rana sylvatica* (Wood Frog), a species more abundant in northern, mountainous and colder climates. The populations of this species on the Western Highland Rim are on the edges of its range. A study will get underway at Cheatham

Wildlife Management Area where large numbers of this species were documented in 1995 to determine if this population on the southwestern edge of *R. sylvatica's* range is still abundant.

The Northern Cricket Frog, *Acris crepitans,* is thought to be a common frog in Tennessee. However, in Amphibian Declines, The Conservation Status of the United States' Species, edited by Michael Lannoo, it is stated that Northern Cricket Frogs are listed as Endangered in Minnesota and Wisconsin, Threatened in New York and as a Species of Special Concern in Indiana, Michigan, and West Virginia. Dr. Malcolm L. McCallum of Texas A&M University predicts with fuzzy regression that climate projections expected by Arkansas by the year 2100 could reduce total reproductive investment in the Northern Cricket Frog by 33-94%. Since Arkansas is just a hop or swim across the Mississippi River it would be prudent for Tennessee to take notice and begin seriously monitoring this species.

Natural fluctuations and local extinctions are common in herpetofaunal populations. So, first of all are amphibians and reptiles declining in Tennessee and if so are these declines within the natural range of variability or is it a consequence of such ominous causes as climate change. The only way to answer these questions is to conduct long-term surveys that demonstrate true trends. "When long-term and wide-spread monitoring becomes the norm, declines are more likely to become less equivocal and the causes less mysterious (Gibbons et al. 2000)."

Tennessee's Climate Change Plan for Amphibians and Reptiles includes the following:

1. Analyze TAMP data to determine if Tennessee anuran breeding periods have shifted with temperature changes.
2. Continue monitoring Tennessee amphibian population trends through TAMP.
3. Document range expansions and contractions through TAMP and the Amphibian Atlas of Tennessee paying particular attention to species at the southern extent of their range such as the Wood Frog, *Rana sylvatica*.
4. Conduct Green Salamander habitat study as described in the Tennessee State Wildlife Action Plan.
5. Categorize Northern Cricket Frog (*Acris crepitans*) as a GCN species and monitor Tennessee populations.
6. Continue to decrease known amphibian and reptile threats and stressors such as habitat loss by protecting and conserving wetlands and illegal herpetofaunal collecting by enforcing captive wildlife laws.
7. Continue monitoring legal turtle harvests at Reelfoot Lake and evaluate the impact on native turtle populations. Consider advocating size limits to decrease the removal of sexually mature females from the population.
8. Protect turtle nests and eggs on public lands by establishing buffers between nesting areas and large bodies of water. Where possible establish travel corridors between nesting areas and aquatic habitats.
9. Analyze accumulated turtle data to determine current sex ratios and continue documenting the sex ratios of turtles in ongoing research.
10. Continue to monitor amphibian diseases such as Ranavirus and document deformities that may be symptomatic of diseases.

11. Remain alert for signs of amphibian chytrid fungus and explore response strategies including “arking” arrangements with zoos across the state.

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Table 8. Tennessee GCN Amphibian and Reptile Species

Common Name	GRank	SRank	FedStatus	TNStatus
Hellbender	G3G4	S3	MC	D
Black Mountain Salamander	G4	S3		D
Junaluska Salamander	G3	S2	MC	D
Tennessee Cave Salamander	G2G3	S2	MC	T
Berry Cave Salamander	G2G3T1	S1		
Big Mouth Cave Salamander	G2G3T1	SNR		
Southern Cricket Frog	G5	S4		
Streamside Salamander	G4	S2		D
Green Salamander	G3G4	S3S4		
Seepage Salamander	G3G4	S1	MC	D
Pigmy Salamander	G3G4	S2	MC	D
Four-toed Salamander	G5	S3		D
Barking Treefrog	G5	S3		D
Gray Treefrog	G5	S5		
Tellico Salamander	G2G3	S2S3		
Red-cheeked Salamander	G2	S2		
Ravine Salamander	G5	S2		
Wehrle's Salamander	G5	S1		D
Weller's Salamander	G3	S1		D
Yonahlossee Salamander	G4	S3		
Mountain Chorus Frog	G5	S4		
Mud Salamander	G5	S5		
Crawfish Frog	G4	S4		
Gopher Frog	G3	S1	(PS)	
Lesser Siren	G5	S5		
Mole Salamander	G5	S4		
Cumberland Dusky Salamander (new species = Allegheny Mountain Dusky Salamander)	G?	S?		
Black-bellied Salamander	G5	S4		
Northern Zigzag Salamander	G4	S4		
Red-legged Salamander	G2	S2		
Smooth Softshell Turtle	G5	S4		
Spiny Softshell Turtle	G5	S5		
Alligator Snapping Turtle	G3G4	S2S3	MC	D
Green Anole	G5	S3		
Timber Rattlesnake	G4	S4		
Coal Skink	G5	S1		D
Bog Turtle	G3	S1	T(S/A)	T

Common Name	GRank	SRank	FedStatus	TNStatus
Eastern Hognosed Snake	G5	S4		
Coachwhip	G5	S2S3?		
Green Water Snake	G5	S2		D
Yellowbelly Water Snake	G5T5	HYB		
Eastern Slender Glass Lizard	G5T5	S3		D
Northern Pine Snake	G4T4	S3	MC	T
Western Pigmy Rattlesnake	G5T5	S2S3		T
Eastern Box Turtle	G5	S4		
Rough Earth Snake	G5	S2S3?		
Copperbelly Water Snake	G5T2T3	HYB	(PS:LT)	

Potential Effects of Climate Change on Tennessee Caves and Karst

Tennessee is one of the nations most karst rich states. It is estimated that Tennessee has more than 9,000 caves. The karst regions extend from the Tennessee River in the western part of the state to the Blue Ridge Mountains in the east. The presence of caves has long been recognized as important habitat for rare and often threatened/endangered macrofauna, including bats, salamanders, fish, and many invertebrates (Culver et al. 2000). In the Tennessee Wildlife Action Plan there were 197 subterranean species selected as Greatest Conservation Need Species. When looking at the cave density and biodiversity in the subterranean regions, the Cumberland Rim region has the largest number of number of known caves and the highest number of subterranean GCN species followed by the Ridge and Valley, the Nashville basin, the Central uplands, and the Southern Blue Ridge (Figure 22).

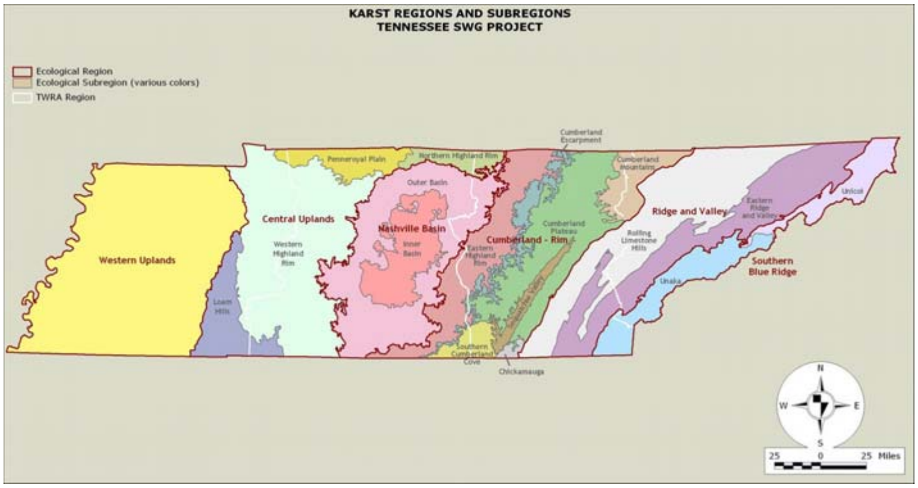

Figure 22. Karst regions and subregions of Tennessee.

There are 34 known caves in Tennessee that provide critical habitat for the federally listed Indiana bat. There is one priority one cave, six priority two caves, 16 priority three caves and eleven priority four caves. Indiana bats prefer cold air caves and will only hibernate in caves that have stable winter temperatures ranging from 37 - 43 degrees F. Caves that are currently at the upper end of this range could become unsuitable for Indiana bat use if mean temperature of the outside environment increased 2 – 6 degrees. Indiana bats also select high humidity caves (60-90 %). A changing climate could negatively effect these parameters at of some of these hibernacula. While Tennessee only accounts for 1.6% of the range-wide population, the threat of white-nose syndrome being observed in the northern parts of the range are making the southern populations more significant.

Lavoie et al observed that cave crickets exhibited extreme thermal sensitivity and suggested that even a modest increase in cave ambient conditions could have a profound negative effect. Since caves maintain the average annual temperature of the area where they are located, global warming would result in increased cave temperatures. Even a modest increase of 2-6 degrees Celsius over the next 50 years (Schneider, 1989) would greatly increase metabolic demands and evaporative water loss, which would force cave crickets to make more frequent foraging bouts and exposure to surface conditions and predators (Poulson 1991). This could result in loss of cave cricket populations in many caves which would eliminate a major energy input. Cave systems are resource limited and are dependent upon energy inputs from cricket and bat guano. Cave crickets and their eggs are a major food source of many cave organisms such as beetles. With out this food source the persistence of many rare cave obligates would be jeopardized.

The importance and sensitive nature of karst aquifers, both to the surface and subsurface ecology of a region (Graening and Brown 2003) and domestic water supplies has been documented. Many residents utilize water that travels through karst systems. Some climate change models are suggesting that precipitation patterns will change. If drought cycles increase in regularity and intensity these ground water resources could become dry. This has implications not only for stygobitic (live in water) organisms but also for humans dependent on these resources for water supply.

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Potential Impacts of Climate Change on Tennessee Nonvolant Mammals

Tennessee has a rich mammalian diversity with 78 species inhabiting the state, of which 29 are greatest conservation need species. In general, a significant change in forest vegetation and community composition could also impact these forest mammals. The expected change to savannah like conditions under some climatic conditions good impact several GCM mammalian species dependent on forested conditions (Table 9). The degree of impact will be dependent on mammalian species dependence on specific forests and forest conditions and the time required for the vegetative community shifts to occur.

Of special note, several species are endemic to the higher elevation habitats of the Appalachian Mountains in the eastern portion of the state. These species include the rerd squirrel (*Tamiasciurus hudsonicus*), Star-nosed Mole (*Condylura cristata*), Water Shrew (*Sorex palustris*), Rock Vole (*Microtus chrotorrinus*)and the Carolina Northern Flying Squirrel (*Glaucomys sabinus*). Warming and/or drying of this cool humid mountainous climate could restrict, even further, the distribution of these species to the point of extirpation. Dependent on conditions, a warmer drier climate would also allow other mammalian species to expand their ranges into the lower or mid elevations. Mortiz et al. documented the alteration of mammalian communities along an elevational gradient in Yosemite National Park which coincided with a 3 degree C warming of minimum temperatures over the last 100 years. They observed contraction of ranges in higher elevation species and expansion of range in lower elevation species. Similarly, modeling mammalian distributions in response to climate change conditions, Burns et al. (2003), suggests the Great Smoky Mountains National Park could loose 8 species of mammals and gain 29 species of mammals.

Terrestrial Habitat Type	No. of Dependent Mammalian GCN Species.
Southern and Central Appalachian Oak Forest	23
Appalachian Hemlock-Hardwood Forest	23
Central and Southern Appalachian Northern Hardwood Forest	22
Allegheny-Cumberland Dry Oak Forest and Woodland	15
Southern Appalachian Low Mountain Pine Forest	15
South-Central Interior Mesophytic Forest	18
Southern Appalachian Montane Pine Forest and Woodland	17
Central and Southern Appalachian Spruce-Fir Forest	9
Southern Interior Low Plateau Dry Oak Forest	9
East Gulf Coastal Plain Northern Mesic Hardwood Forest	8
South-Central Interior / Upper Coastal Plain Flatwoods	8
East Gulf Coastal Plain Interior Shortleaf Pine-Oak Forest	7
East Gulf Coastal Plain Large River Floodplain Forest	7
East Gulf Coastal Plain Limestone Forest	7
East Gulf Coastal Plain Northern Dry Upland Hardwood Forest	7
East Gulf Coastal Plain Northern Loess Bluff Forest	7
East Gulf Coastal Plain Northern Loess Plain Oak-Hickory Upland	7
East Gulf Coastal Plain Small Stream and River Floodplain Forest	7
Lower Mississippi River Bottomland and Floodplain Forest	6
Lower Mississippi River Bottomland Depression	6
South-Central Interior / Upper Coastal Plain Wet Flatwoods	6

Table 9.Terrestrial habitat type and number of dependent GCN species in Tennessee.

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Physical Impacts of Climate Change on Aquatics

Hydrology

Tennessee covers a relatively narrow latitudinal range and its climate is considered mild and temperate. Despite this, the unique landscape of the state, its range of elevation, and its geology create a multitude of aquatic habitats that may be affected if temperature and weather patterns are disrupted by changes in global climate. Some effects on aquatic habitat will be direct, such as de-watering and water temperature increases. Other effects will occur as exacerbations of other factors such as deforestation, urbanization, increased surface evaporation, and water demands (Burkett et al. 2001). Generally, higher water temperatures and increased runoff predicted for the Southeastern United States over the existing GCMs, are predicted to alter the ecological sustainability of aquatic species (IPCC 2008). Fish, mussel, and amphibian communities may shift to those species that prefer warmer water and are more tolerant of turbidity and low dissolved oxygen.

Although the GCM models have not yet been analyzed to make predictions at the State of Tennessee scale, regional studies have indicated that temperatures in the Southeast will increase by 2–4˚C during the reminder of the 21st century. Climate variability will also increase over this century. The Tennessee River Basin is expected to have greater water stress over this time period than other regional basins. Episodic, high-intensity rain events will continue to become more common causing increased turbidity in 65% of streams in the Alabama, Cumberland, Tennessee, and Mobile river basins (Treasure et al. 2008). Although increased rainfall and flows in many parts of Tennessee may result in improved stream water quality, increased erosion and flushing of contaminants may also result (Jacobs et al. 2001).

The two most profound climate changes for Tennessee derived from analyses of existing GCMs are increased temperature and rainfall. Increased temperature will affect water temperatures and associated water quality parameters including dissolved oxygen (EPA 1999). Increased air temperature causes increases in surface evaporation of streams and rivers which will likely cause seasonal limitations on flows and pool habitat abundance, particularly on lower order streams. Effects on fish and mussel populations are expected to be greatest in mountainous parts of the Cumberland Plateau and east Tennessee where large numbers of endemic species exist. Increased water withdrawals may also be anticipated if demands for irrigation and other forms of human consumption respond to rising temperatures and longer growing seasons. Increases in direct stressors and exacerbations of current stressors on aquatic ecosystems will result in changes to Tennessee's biodiversity, aquatic community structure, population abundances, and likely result in extinction for species with limited habitat requirements.

Water levels and flows at Tennessee's many regulated reservoirs may also be affected through increased evaporation which can cause subsequent changes to fish community composition and losses of sport fishery value. GCM predictions of increases in temperature and storm intensity will affect reservoir water levels and flow dynamics as regulators respond to increased demands for hydropower and flood storage capacity. Higher variability in Tennessee's climate will result in less predictable management for reservoir hydrology affecting fish habitat abundance and population dynamics. Rapid changes in water temperatures coupled with changes in water quality (e.g., dissolved oxygen) and variable hydrodynamics will cause changes in physical habitat in reservoirs and tailwaters of varying duration. Seasonal and long-term habitat alterations are likely to cause fish kills, disruption of spawning, and wide swings in the abundance of required habitat for various life stages of important sport fish species.

Impacts on Fishes and Recreational Fisheries-Alteration of Fish Habitats

The suitability of habitat for aquatic species is determined by the quantity (or flow) of water that surrounds them, the chemical and physical properties of that water, and physical structures in the substrate or water column. Predicted climate trends forecast three patterns that will affect aquatic habitat: warmer mean annual temperature; increased frequency of intense rain events; and drier summers with more intense droughts.

Warmer Temperature- Streams and rivers generally transition to warmer temperatures as water travels downstream. For example, the headwaters of the Tellico River have cold water that supports wild trout populations, downstream it warms up to become warmwater habitat the supports a smallmouth bass population. Between these reaches there is a transition zone that is not well suited for either species due to water temperature. In a warming scenario we might expect the habitat for warmwater species to shift upstream, along with a corresponding shift in the transition zone, and ultimately there would be a loss of cold water habitat. Independent of other changes, the warming of riverine surface waters by a 2-4 ^{o}C may not have a substantial impact on the majority of fishes in Tennessee because many habitats that exist at current temperatures can be substituted by upstream habitat where conditions are cooler. It is only the coldest headwaters and spring influenced habitats that risk being lost due to temperature alone. However, due to longitudinal variation in stream morphology, it is likely that not all species will be able to make the shift upstream because suitable physical habitat may not be present. For example, if a species relies on a specific gravel substrate for spawning and that habitat is not present in the upstream area, then that species will decline in abundance or become extirpated.

In large tributary reservoirs an increase in temperature will negatively affect cool to coldwater fish habitat and possibly benefit some warmwater species. For cool or cold water species (trout, walleye, striped bass) the critical reservoir habitat occurs in the summer, when beneath the warm surface water there is a band of cool water that has ample oxygen. Depending on the reservoir, a 4 ^{o}C increase in temperature could force fish to migrate deeper to find suitable temperature, and suitable water temperatures will be available, but at some dept oxygen will not be sufficient. This habitat restriction known as a dissolved-oxygen squeeze has been documented as a limiting factor for fish populations (e.g. striped bass, Coutant 1985). At some reservoirs (e.g. J.P. Priest and Dale Hollow reservoirs), this squeeze has been intensifying over the past decades as a result of an increase in oxygen-consuming nutrients entering the reservoirs. In a worst case scenario the reservoir can no longer support the species. For example by 1998, a popular fishery for lake trout in Dale Hollow Reservoir disappeared due a lack of sufficiently oxygenated coldwater habitat. An increase in temperature will tighten the temperature-dissolved oxygen squeeze and reduce critical habitat for cool and cold water fishes in reservoirs.

Despite a 4 ^{o}C increase in temperature, warmwater reservoir habitat in tributary impoundments would still be within an acceptable range for most warmwater species, such as largemouth bass, crappie, catfish, and bluegill. Warmer conditions presently support these species in southern Alabama and Texas. In Tennessee, thousands of ponds and small lakes provide fisheries for bass, bluegill, and catfish. Higher temperatures will lower dissolved oxygen levels in these small systems. Poorly managed ponds (constructed too shallow or with nutrient levels) can expect more frequent and severe fish kills during the summer months.

Warmer winter temperatures will also make rivers and reservoirs more suitable to non-native species that already inhabit waters to our south. Florida, Alabama, and Georgia are inhabited by dozens of non-native aquatic plants and animals that could immigrate to a warmer Tennessee. Even native species may become problematic as habitats change. Some have speculated that recent outbreaks of Didymo which have suffocated substrate in trout tailwaters in the southeast are linked to climate change. Warmer waters may also intensify outbreaks of native and introduced diseases, such as largemouth bass virus.

One naturalized species that will benefit from an increase in temperature is threadfin shad. Historically several Tennessee reservoirs experienced winter "shad-kills" as these non-natives were exposed to temperatures less than 8^{o}C. These events were so destructive to the population, that early managers felt the need to restock this important forage species. Lately, kills are less common and less severe. If winter temperatures were just a bit warmer, which is possible under the 2-4^{o}C scenario, these winter shad kills would be rare. Depending on the reservoir, a stable more shad population can create a variety of fisheries management opportunities and challenges.

Dry summers to severe drought - Droughts are historically common in Tennessee and are an important part of interannual habitat variability in rivers. Low water years benefit some species and have negative affects on others. Under ideal conditions, we would expect most native species to survive these natural conditions. However, populations that are already stressed (such as many T&E species) may not be able to withstand a severe drought. A severe drought could occur naturally, but we are most likely to observe severe drought conditions in rivers as a result of a mild drought combined with increased water demand for human uses. Severe droughts will reduce flows in river and stream habitats resulting in hydrologic changes in microhabitats, reduced wetted area and degraded water quality. Droughts reduce invertebrate production, disrupt fish migrations, and expose all fauna to higher water temperatures, and lower dissolved oxygen resulting in stress and mortality.

Reservoir lake levels and dam operation and the habitat they support are greatly affected by drought. Declining lake levels dewater the available habitat for juvenile fishes, resulting in poor recruitment of important sport fishes (Sammons et al. 1999). Fish and mussels rely on steady releases from dams to maintain water quality, provide nutrients and flow for habitat. The need to conserve water will limit the amount of water operators can release to maintain downstream habitats. Retention times in reservoirs will increase, increasing nutrient concentrations, and reducing available oxygen in some habitats. During the drought in the late 1980's Kentucky Lake experienced stratification and anoxic conditions that resulted in stress and mortality for fish and mussels.

Intense rains- High spring flows provide important reproductive cues and habitat (flows) for several riverine species, such as river redhorse and sauger. In contrast, high flows can reduce scour nests and reduce nursery habitat for other species such as trout (Harson and Waters 1974) and smallmouth bass (Reynolds and O'Bara 1991). In reservoirs, extremely high water levels combined with quick drawdowns for flood control, greatly affect spawning and nursery habitat for littoral species, and reduce productivity of reservoirs. Maceina and Bettoli (1998) observed that the recruitment of largemouth bass on main-stem reservoirs throughout the Tennessee Valley was inversely related to June/July discharge. Conversely, high spring lake levels were beneficial to crappie, walleye, and white bass in Normandy Reservoir (Sammons et al. 1998).

The timing of the rainy season will greatly affect reservoir and tailwater habitats. Tributary impoundments will be required to release any runoff that accumulates during the flood season. If intense rains occur late in the spring during flood control season, when rain temperatures get warmer and reservoirs start to mildly stratify, then water must be released for flood control. At this time, warm runoff stays on the surface of the reservoir while deeper cold water is discharged via the turbines. As this cold water is discharged, it cannot be replaced until next winter, thus coldwater habitat is lost for that summer season. Depending on the depth of the reservoir and the intensity of the storms it is possible for reservoirs to loose the all cold and coolwater habitat. In addition, some of Tennessee's trout tailwaters (such as the South Holston and Caney Fork rivers) that rely on coldwater releases are vulnerable to running out of cold water late in the summer.

The biggest problem for all aquatic communities is that more intense rain will increase non-point run off issues that are already plague aquatic habitats. Due to the value of riparian zones for farming and development, many streams and rivers in Tennessee do not have an adequately forested buffer zone along the stream corridor. As such, streams and receiving rivers and reservoirs can expect to receive additional sediment and other pollutants during intense rain events. Excessive sedimentation is the number one non-point pollutant in Tennessee. Excessive sedimentation smothers stream substrate that is critical habitat for numerous species of fish and mussels. Sources of sediment include natural subsidence, poorly-managed construction zones, poorly-managed agricultural lands, and actively eroding stream banks in locations where the some aspect of the stream or its riparian zone have already been disrupted.

During storm events household chemicals, garden pesticides and excess fertilizer are often delivered to streams in the runoff. Stormwater management systems can prevent much of these harmful pollutants from reaching streams, but only if they are designed to handle the more intense rains that are expected to come.

Many stream banks have been modified to accommodate typical high flows and multiple uses within the floodplain. As more intense rains redefine the definition of 'typical', we might expect to see some catastrophic failures of levies and other armored structures. These failures would affect the stability instream habitat (location of riffles and runs) both above and below the failure site until the stream channel was able to regain equilibrium within the floodplain. While some of these failures may result in a more natural connectivity to the floodplain, it is also likely there will be demand to 'fix' the streambank with additional armoring.

Increased flooding will increase the likelihood that aquatic invasive species will spread to new rivers, streams, and lakes. For example, snakeheads (fish of the Family Channidae) are already in Arkansas could move eastward across Tennessee.

At-Risk Species

The diversity of fishes in Tennessee is well known. Etnier and Starnes (1993) estimated that there were between 302 and 319 native and introduced species of fish in Tennessee. Warren and Burr (1994) listed 257 native species 40 of which were considered imperiled. In State of the States (NatureServe 2002), Tennessee was ranked 2nd nationally for number of fish species. Even without the threat of climate change the level of imperilment of fishes in Tennessee is very high. Tennessee has the largest number of at-risk freshwater fish species in the United States (Master et al. 1998). There are 20 fish species state-listed as endangered, 17 as threatened and 40 species considered INOM. There are 85 fish species considered to be of Greatest Conservation Need in Tennessee's State Wildlife Action Plan. Of these 85 there are 22 that have preference for headwater systems (Table 10). All of these fish have some level of imperilment assigned.

Table 10. Species of Greatest Conservation Need that rely on headwater habitat and listing status.

River System	Common Name	Federal Status	State Status
Conasauga	Amber Darter	Endangered	Endangered
Conasauga	Blue Shiner	Threatened	Endangered
Conasauga	Coldwater Darter	Management Concern	Threatened
Conasauga	Conasauga Logperch	Endangered	Endangered
Conasauga	Holiday or Ellijay Darter		Threatened
Conasauga	Southern Brook Lamprey		Deemed
Conasauga	Trispot Darter	Management Concern	Threatened
Cumberland	Barrens Darter	Management Concern	Endangered
Cumberland	Barrens Topminnow	Management Concern	Endangered
Cumberland	Blotchside Logperch	Management Concern	Deemed
Cumberland	Cumberland Johnny Darter	Candidate	Endangered
Cumberland	Flame Chub	Management Concern	Deemed
Cumberland	Mountain Blackside Dace	Threatened	Threatened
Cumberland	Silverjaw Minnow		Threatened
Mississippi	Golden Topminnow		Deemed
Tennessee	Chucky Madtom	Candidate	Endangered
Tennessee	Crown Darter	Management Concern	Endangered
Tennessee	Laurel Dace		Endangered
Tennessee	Scaly Sand Darter		Deemed
Tennessee	Slackwater Darter	Threatened	Threatened
Tennessee	Smoky Madtom	Endangered	Endangered
Tennessee	Striated Darter	Management Concern	Threatened

Even under present conditions these species are a risk of being lost due to various threats to their habitat and they are particularly vulnerable to climate change. While relatively little is known about physiology of these rare species, it is not unreasonable to suggest that increases in mean annual temperature could disrupt the reproductive success and bioenergetics of individual organisms resulting in depressed population numbers, or even local extinctions. Unlike species in higher order stream, populations of headwater and spring species have no opportunity to migrate upstream to find cooler temperatures. In a severe drought scenario, headwater habitat and springs are vulnerable to becoming dewatered. The likelihood of springs drying up will be further exacerbated by competition for groundwater for human consumption in a severe drought. To further confound the problem many of these species, such as barren's topminnow, have a very limited geographic distribution, meaning that an extreme drought in one relatively small part of the state could wipe out the only population of the species.

Tennessee has the highest diversity of darters in the world with over 90 species as of 2008. Twenty-nine of Tennessee's darters are listed by state or federal agencies as being imperiled. Darters are cued to the timing of floods during the winter and early spring each year. Water flow and water temperature provide life history cues on when to prepare to spawn. For instance, the fringed darter, *Etheostoma crossopterum*, spawns during late March through May based on higher water levels in the late winter and increasing water temperatures due to increased sunlight in the spring. Increased precipitation in the form of flash flooding earlier in the year would cause the fringed darter to spawn earlier in the year. The effects on juvenile fringed darters are not currently understood, but this increase in flow could cause juveniles to end up further downstream in less suitable habitat. Several *Etheostoma* species prefer headwater streams, and these streams will be most affected by climate change due to higher elevations and more direct contact with run-off and increasing water temperatures. Increased run-off due to more rainfall will cause increased siltation, which will cause smothering of darter eggs. Species of the *Etheostoma* complex spawn on the underneath sides of cobble and boulders. Siltation could smother the nests and with increased flash flooding, these cobbles and boulders with nests will be moved further downstream leading to the eggs not hatching. Male *Etheostoma* species provide care of the nests by tail fanning the silt away from the nests and picking off fungus from the eggs. Flash flooding could displace males from their nests leading to an un-successful spawning season for many *Etheostoma* species.

Mussels are less mobile than fish species and therefore rely on certain fish species to carry their glochidia upstream to suitable habitats. If fish are affected by flash flooding and increased temperature, this will mean less mussel glochidia making it further upstream to more suitable habitat. Mussels are filter feeders and with increased flash flooding come increased siltation leading to declining mussel populations which will be smothered by increased siltation. Intense rains also increases surface run off of pollutants. Mussels are highly effective at filtering out pollutants from the water. However these toxins can be detrimental to mussels and to higher organisms in the food chain that eat mussels.

Impacts on Fisheries

In 2006 Tennessee fisheries were valued at $600 million with most anglers targeting bass, crappie, catfish, bream (*Lepomis* spp.), striped bass, trout, walleye, and sauger (USDI and USDC 2008). All of these fisheries are at risk during extreme rain or drought events due to loss of habitat or poor water quality. Looking beyond catastrophic events, in general, we expect to see little change, or a perhaps a minor increase in the distribution of warmwater sport species (e.g. largemouth bass, bluegill, and catfish), a moderate decline in distribution of coolwater species (e.g. striped bass, smallmouth, and walleye), and a major decline in the distribution of trout species.

Barring serious degradation of water quality to the extent that would harm all bass species, we would not predict a substantial net decline in bass fishing. We would predict a shift in species composition among largemouth, smallmouth, and spotted bass. While these species are commonly sympatric in many waters, only one or two of the bass species are abundant. Preferred temperatures for smallmouth bass (21-27 °C) is cooler that that of largemouth bass (24-30 °C) (Sowa and Rabeni 1995). Sowa and Rabeni (1995) observed that maximum summer temperature and percent pool area explained most of the variability in abundance of largemouth and smallmouth bass in Missouri streams with smallmouth bass favoring cooler temperatures and less pool habitat, while largemouth preferred warmer habitat with pools. Of the three species, largemouth bass are most tolerant of turbidity (Etnier and Starnes 1993). Thermal requirements of spotted bass are not well documented, but our experience is that they use habitat that are somewhat intermediate to smallmouth and largemouth bass. As temperatures increase in streams, the first changes we anticipate are decreases in smallmouth bass and increases in spotted bass. In Tennessee warmwater habitat will expand to the advantage of largemouth bass, most likely in the colder reservoirs of east Tennessee and in upper reaches of streams and rivers. Conversely smallmouth bass will lose habitat due to increased temperature and turbidity in streams and rivers, and sections of reservoirs. All bass species will be affected by severe water level fluctuations in the spring and early summer. High water can improve recruitment of bass in reservoirs (e.g. Miranda et al. 1984). But high spring flows can negatively affect recruitment of river populations (Reynolds and O'Bara 1991; Lukas and Orth 1995).

Florida-strain largemouth bass have been mixed into northern-strain largemouth bass populations in a few impoundments located in warmer regions of Tennessee as defined by latitude and degree heating days (Churchill and Reeves 1997). The goal of this management effort is to increase genetic influence of the Florida strain in populations with an expected outcome of producing more trophy-sized bass. The mixed success of this project may indicate that Tennessee is on the northern edge of suitable habitat for this subspecies. Warmer temperatures could improve TWRA's management options for introducing Florida-strain largemouth bass.

White and black crappie are warmwater species that are widely distributed in Tennessee. White crappie are more tolerant of turbid water than black crappie (Etnier and Starnes 1993). If turbidity does increase on reservoirs we will expect to see a shift towards more white crappie in these waters. Crappie populations are notoriously vulnerable to year-class failures that are associated with water level fluctuations and turbidity. At present, TWRA routinely stocks crappie in reservoirs to supplement natural reproduction. Given even greater fluctuations of water levels in reservoirs, year class failures may be more common and on more reservoirs than presently observed. Consecutive year class failures are especially detrimental to crappie populations because longevity is rarely more than 5 years in a population. Missing a few years in a row would lead to very unstable populations.

Striped bass and Cherokee bass (striped bass x white bass hybrids) are coolwater species that inhabit most main-stem reservoirs (e.g. Old Hickory and Watts Bar reservoirs) and in some tributary impoundments (e.g. Norris and J. Percy Priest reservoirs). Striped bass inhabit waters that are cooler than 25 °C and dissolved oxygen greater than 3-4 mg/L (Coutant 1985). Cherokee bass can tolerate warmer conditions with less oxygen compared to striped bass, and for this reason the Cherokee bass is the preferred alternative for waters with limited coolwater habitat.

However, both the striped bass and the Cherokee bass can expect to loose habitat in a warming climate. The spring and summer temperature-dissolved oxygen squeeze will intensify at varied levels depending on the reservoir and the severity of global warming. Tributary impoundments that presently offer marginal habitat for striped bass, such as J. Percy Priest, will likely loose all striped bass habitat, and shift to an all Cherokee bass fishery, and even habitat for Cherokee bass will be limited.

In east Tennessee there are 621 miles of wild trout streams with 147 miles of brook trout streams. TWRA has identified 58 of the 113 brook trout populations as the native southern Appalachian brook trout. The Southern Division of the American Fisheries Society Trout Committee (2005) identified climate change among the serious threats to brook trout populations. Brook trout inhabit headwater stream reaches, with non-native brown and rainbow trout occupying lower elevations. The downstream distribution of all trout species is largely determined by temperature, but brook trout are likely to loose the most habitat. Brown and rainbows might be able to shift upstream in a warmer headwater habitat, while the brook trout will have no upstream alternative. Flebbe (1997) predicted a 45% reduction in stream miles supporting brook trout in the southern Appalachian Mountains with a 1^{o}C increase; 2+ ^{o}C resulted in a 78% reduction; at 5+^{o}C brook trout would only exist in the highest peaks of the Great Smoky Mountains National Park.

While distributions may reduce as a result of warmer temperatures, it is possible to have higher abundance and growth of the remaining populations. Clark et al. (2001) modeled the effect of warmer temperatures 1.5-2.5 ^{o}C, higher flows, and occurrence of egg-scouring storm events on rainbow and brook trout. Based on temperature change alone, Clarke et al. (2001) predicted an 80% decrease in habitat for trout in the southern Appalachians. Yet considering some of the potential advantages of warmer temperatures along with the negative effects of flow and even highly damaging egg-scouring flows, they predicted only a 10% decrease in abundance of brook trout, and a 24 % decrease for rainbow trout. The potential for increased abundance in trout populations was due increased growth, and egg to fry survival. Brook trout are relatively successful at surviving in infertile headwater streams where prey is scarce. But food availability, especially in warmer temperatures, is still a limiting factor of brook trout populations. Ries and Perry (1995) suggest that an increase of 2 ^{o}C or less could increase brook trout growth, but the effect of larger temperature increases are less predictable due to greater dependency on higher prey production.

Several of Tennessee tailwater trout fisheries are vulnerable to changes in coldwater storage in tributary impoundments, especially during drought years. The downstream limits of some fisheries (e.g. South Hoston, Watuaga, and Cherokee tailwaters) vary substantially with the rate of daily hydropower production. In drought years, dam operators sparingly release water through turbines to avoid running out of cold water before the summer's end. As a result the lower reaches of the tailwaters, areas where anglers expect to be able to fish, become warmer to the point where fish stop biting or they can no longer live in that habitat. At the Hiwassee River TWRA commonly observes discharge temperatures exceeding 20^{o}C for short periods during spring and summer. During these warm events fishing is very poor and survival of stocked trout is poor (Luisi and Bettoli 2001). An increase of 2 ^{o}C to the Hiwasee River will likely convert this year-round trout fishery to a seasonal (fall to spring only) fishery with no opportunity for growing quality fish. To a point, the trout fishery below Center Hill tailwater may benefit from slightly warmer discharge and drought conditions. Use by anglers increases as flow decreases (Bettoli 2004) and trout abundance increases as turbine use decreases (TWRA unpublished data). However, these benefits can only be maintained if the cold water supply is not exhausted before winter. At any of these impoundments, it is possible in an extreme drought or in an extremely rainy summer, to loose the needed coldwater storage to last the duration of the warm season. In this event these tailwater trout fisheries would loose several years of trout production including highly valued trophy-sized trout.

Trout are stocked at nine reservoirs have year round cold water habitat. Our most important fisheries are Dale Hollow, South Holston, and Watuaga reservoirs, all of which are two-story impoundments that restrict trout to deep habitat in the summer that is vulnerable to a temperature-oxygen squeeze. In a simple warming scenario, this habitat will be reduced as temperature increases. In drought or rainy years, coldwater storage could be exhausted resulting in the elimination of all trout.

Tennessee manages hatchery-supported trout fisheries in over a 100 small streams. Most of these are seasonal fisheries (typically between March and June) due to warm temperatures in streams by early summer. Managers and anglers would respond to warmer stream temperatures by shifting the season to start earlier in the spring and end earlier in the summer. Based on temperature alone, there would be no reduction in recreation. However intense rains which typically occur in the spring will reduce survival of stocked trout and further reduce recreational opportunity because anglers do not fish during high flows.

TWRA trout hatcheries produce approximately 220,000 pounds of rainbow trout for stocking annually. The temperature of spring water at three trout hatcheries varies from 14 to 15 ^{o}C. The optimum range of source water for rainbow trout production is 10-16 ^{o}C (Piper et al. 1982). Even a minor increase in temperature will reduce production at these hatcheries, and an increase of 4 ^{o}C or more would require cost prohibitive measures (operating of cooling units) to maintain production year-round. Furthermore the current supply of spring water is reduced at our hatcheries during dry periods in the summer and fall. Severe droughts would greatly reduce water supply and our production capacity. Another hatchery, Tellico Hatchery, uses surface water from the adjacent streams, and temperatures range widely depending on the season. A warmer climate would improve production in winter. However during dry, hot summers as experienced in 2007 and 2008 this hatchery's source water was ~ 19 ^{o}C, which is well above optimum temperatures for trout production at hatcheries. A 4 ^{o}C increase in late summer temperatures at Tellico Hatchery would be too hot to feasibly be chilled using cooling units. The loss of any of these hatcheries for one season of the year would greatly disrupt statewide production schedules and the size of trout available for stocking.

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Fish & Wildlife Adaptation

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) is rather unequivocal – the earth's climate is warming, and is expected to continue warming for the remainder of the 21st century. It is also unequivocal that emissions of greenhouse gases (GHG) have climbed since pre-industrial times; the IPCC report states that "most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations" (Solomon et al. 2007). Given these certainties at the global scale, there is still quite a bit of uncertainty in climate change projections and impacts at the state or even regional scale. These uncertainties, particularly in the southeastern United States, suggest that for at least the short term, wildlife agencies should focus their adaptation activities and efforts on reducing the known stresses to wildlife and ecosystems from sources other than climate change.

In June 2008, the U.S. Climate Change Science Program issued a report entitled Adaptation Options for Climate-Sensitive Ecosystems and Resources (Julius et al. 2008). A key finding of this report is included in the following excerpt:

> *"Many existing best management practices for "traditional" stressors of concern have the added benefit of reducing climate change exacerbations of those stressors.* Changes in temperature, precipitation, sea level, and other climate-related factors can often exacerbate problems that are already of concern to managers. For example, increased intensity of precipitation events can further increase delivery of non-point source pollution and sediments to rivers, estuaries, and coasts. Fortunately, many management practices that exist to address such "traditional" stressors can also address climate change impacts. One such practice with multiple benefits is the construction of riparian buffer strips that (1) manage pollution loadings from agricultural lands into rivers today and (2) establish protective barriers against increases in both pollution and sediment loadings due to climate changes in the future. While multiple benefits may result from continuing with today's best practices, key adjustments in their application across space and time may be needed to ensure their continued effectiveness in light of climate change." (Julius et al. 2008)

Seven "adaptation approaches" are offered by the CCSP report, as approaches for strategically focusing efforts on enhancing ecosystem resilience to climate change (Julius et al. 2008).

TWRA will adopt these seven approaches as appropriate, as an initial response for wildlife adaptation strategies for climate change:

1. Protecting key ecosystem features – "focusing management protections on structural characteristics, organisms, or areas that represent important 'underpinnings' or 'keystones' of the overall system." (Julius et al. 2008) The Tennessee State Wildlife Action Plan (SWAP, Tennessee Wildlife Resources Agency 2005) identified key areas of terrestrial, aquatic, and subterranean biological diversity (Figures 15and 1) that should be evaluated for vulnerability to climate change impacts, and assessed for key ecosystem features. Some examples of protecting key ecosystem features would include: 1) Maintain or establish riparian buffers along streams to lessen impacts of temperature increases; 2) Protect headwater streams of priority aquatic systems (e.g., Duck River, etc.); 3) Maintain or establish corridors to facilitate migration routes for species and/or populations, and to facilitate gene flow; 4) Protect strategically important lands and waters through fee acquisition or conservation easement; 5) Manage risk of catastrophic fires through the use of prescribed burns; 6) Maintain the natural flow regime through managing dam flow releases upstream of priority aquatic systems; 7) Actively remove invasive species that threaten key native species; 8) Maintain the natural flow regime in un-regulated aquatic systems; 9) Maintain healthy, diverse, and vigorous native forest ecosystems through forest management on public and private lands including maintenance of scarce old-field habitats. With 52% of Tennessee consisting of forests, and the majority of that in private ownership, landowner assistance programs will become even more important to encourage proper forest management that can help native forests adapt to climate change.

2. Reducing anthropogenic stresses – there are many human-associated stresses that will reduce the ability of species or ecosystems to withstand a stressful climatic event. In recent memory, the drought of 2007 exacerbated already existent issues with adequate flow in streams and rivers, and competing uses from municipalities. A key issue in Tennessee and the southeastern region of the United States will be continued population growth, and the impacts of urbanization on the waters and landscapes of the region. Projections indicate that an additional 2 million people will make Tennessee their home by 2025, bringing our state's population to 8 million. Most of that growth is expected to occur around the state's metropolitan areas, including Memphis, Nashville, Clarksville, Chattanooga, Knoxville, and the Tri-cities of northeast Tennessee.

   The Tennessee SWAP identifies a number of human-associated stresses that are impacting species of Greatest Conservation Need (GCN). Examples of adaptation strategies that could be implemented to address these stresses include: 1) Work with communities and county planners to adopt smart growth policies and best management practices (BMP's) for residential and commercial developments, to reduce fragmentation and loss of habitats; 2) Reduce sediment and pollutant loads through establishment of riparian buffers, implementing BMP's, and utilizing silt fences; 3) Encourage stricter adherence to the State's Forestry BMP's for commercial harvesting of timber resources, especially on private forestlands, to maintain water quality in aquatic systems; 4) Manage water storage and withdrawals to ensure adequate flows in aquatic systems; 5) Work with

Tennessee Valley Authority, Corps of Engineers, and municipal water plants on re-allocating water to provide water supply storage; 6) Develop more effective stormwater infrastructure to reduce future occurrences of severe erosion; 7) Work with the Farm Bureau, Department of Agriculture, Natural Resources Conservation Service, tree nurseries, and the farming community to reduce wasteful irrigation practices; 8) Work with golf courses to encourage and/or require the use of drought tolerant plants for greens that are less water intensive than current golf course greens.

3. Representation – ensuring that biological systems come in a variety of forms, will provide some level of resilience in the face of uncertain climate change impacts. The CCSP report on adaptation suggests that locally adapted populations of species should be fostered, as opposed to one monotypic taxon, and major habitat types should include variations on a theme with different species compositions, as opposed to one invariant community (Kareiva et al. 2008). Representation is suggested as an adaptation strategy for resilience based on the premise that "different forms of a species or ecosystem increases the likelihood that, among those variants, there will be one or more that are suited to the new climate" (Kareiva et al. 2008). Examples of adaptation strategies that focus on representation include the following: 1) In large ecosystems, maintain a broad mixture of habitat types and communities, especially for migratory birds, which utilize a diverse array of habitats at different stages of their life cycle and along migration routes; 2) Protect strategically important lands and waters through fee acquisition or conservation easement; 3)Encourage genetic diversity through the maintenance of numerous viable populations of species; 4) Increase genetic diversity through stocking of native fish and wildlife; 5) For rivers and streams, increase complexity and diversity of physical habitats to encourage diverse biological assemblages.

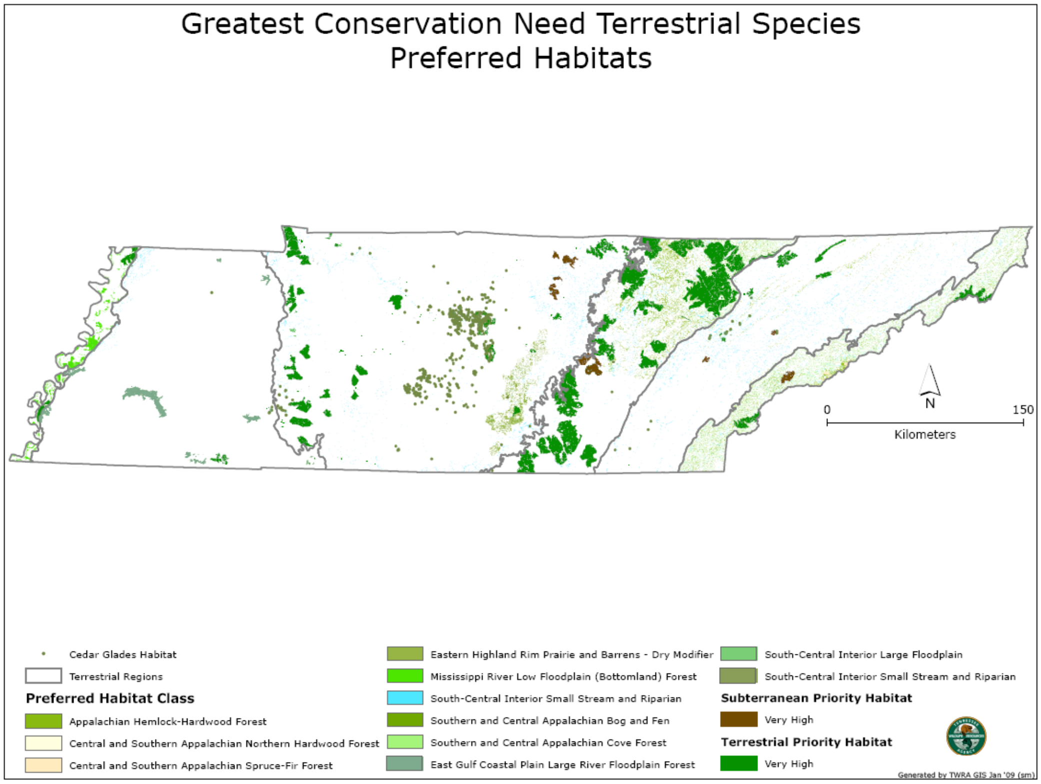

Figure 23. High priority terrestrial and subterranean systems identified in Tennessee State Wildlife Action Plan (TWRA, 2005).

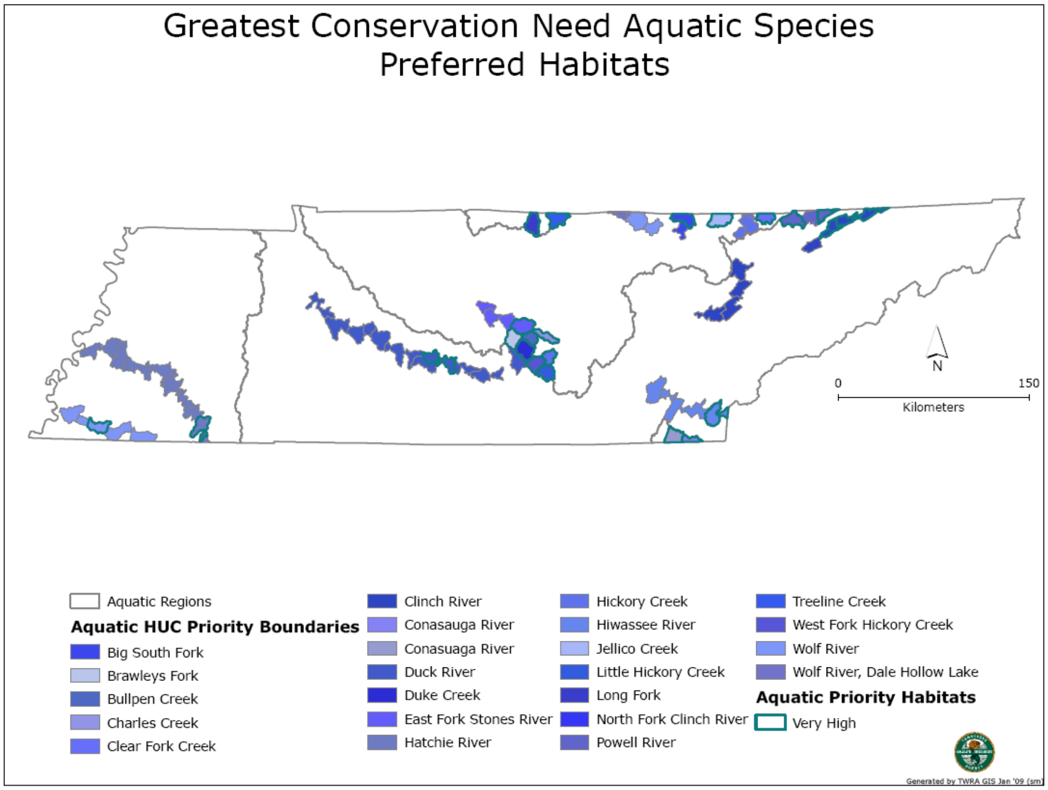

Figure 24.High priority aquatic systems identified in Tennessee State Wildlife Action Plan (TWRA, 2005).

4. Replication – Similar to the strategy of representation, maintaining more than one example of an ecosystem, or population of GCN species, helps to ensure that some of those populations or systems will survive unpredictable climate events, such as storms, or extreme drought. Some examples of replication include: 1) Provide numerous examples of ecosystems and populations of GCN species, to spread risks of loss of habitats or species; 2) For rivers and streams, protect multiple headwater reaches that support priority aquatic systems; 3) Protect strategically important lands and waters through fee acquisition or conservation easement.

5. Restoration – an important adaptation strategy for TWRA will be the restoration of habitats and ecosystems, to support GCN species and other priority fish and wildlife. Of particular relevance to climate change is terrestrial carbon sequestration, especially in bottomland hardwood systems. The potential for restoring ecosystem functions and sequestering carbon through re-foresting bottomland hardwoods has been demonstrated in the Lower Mississippi Valley Joint Venture, through work by the US Fish and Wildlife Service, Ducks Unlimited, The Nature Conservancy, and other conservation organizations active in this region. The Tennessee SWAP identifies several areas in river bottomland areas, which if restored to bottomland hardwood forests, would provide tremendous habitat benefits to GCN species in western Tennessee (Figure 25).TWRA is currently re-foresting an average of 750 acres per year on priority tracts in the Mississippi

Alluvial Valley and East Gulf Coastal Plain, but there is a need to increase this acreage two- or three-fold.

Another key terrestrial ecosystem in Tennessee that will be a priority for restoration by TWRA is native grassland and savannahs. These ecosystems have been largely lost through agricultural conversion to non-native fescue, forest succession and fire suppression, and urbanization. The University of Tennessee has a Center for Native Grassland Management, which is focusing on research and opportunities for promoting native grassland systems for livestock grazing. Support efforts to convert pasture lands to ecological functions when those conversions are sound and provide for livestock production and carbon management. There are millions of acres of pastures in Tennessee where native grasses could be restored, and their drought resistance should provide enhanced climate change resilience, along with the habitat benefits that should be derived. In addition to private land opportunities, there are thousands of acres of public lands where grasslands and savannahs should be maintained or restored. In particular, Ft. Campbell Military Reservation provides significant acreages of extant native grasslands. Public land units where grassland/savannah restoration activities are either occurring or should occur include Catoosa WMA, Land Between the Lakes National Recreation Area, Arnold Engineering Development Center, North Cumberland WMA, Bridgestone/Firestone Centennial Wilderness WMA, and a number of smaller units across the state.

For rivers and streams, the following adaptation strategies are suggested by the CCSP report on adaptation: 1) Conduct river restoration projects to stabilize eroding banks, repair in-stream habitat, or promote fish passages from areas with high temperatures and less precipitation; 2) Restore the natural capacity of rivers to buffer climate-change impacts (e.g., through land acquisition around rivers, levee setbacks to free the floodplain of infrastructure, riparian buffer repairs (Kareiva et al. 2008).

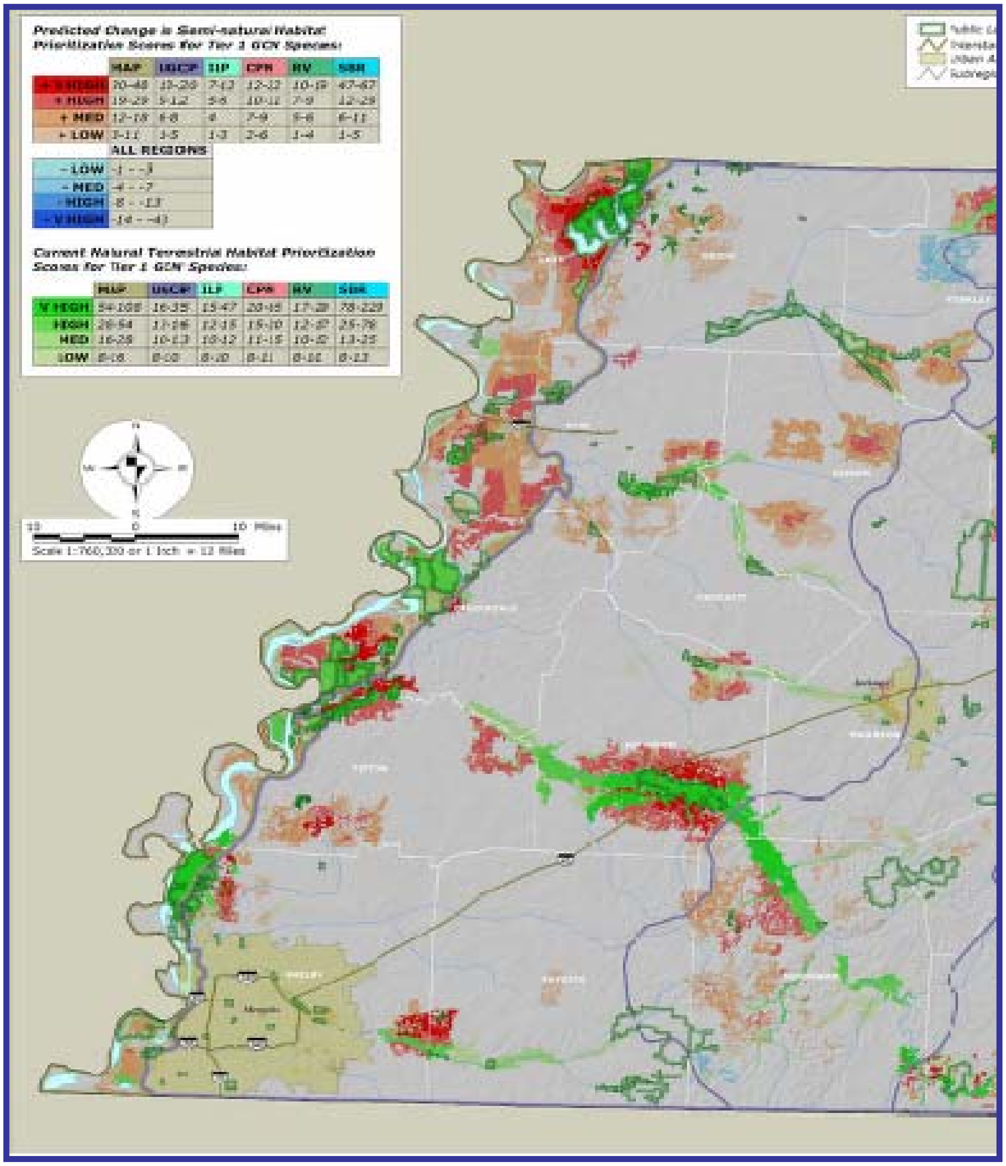

Figure 25. Priority areas for restoration of bottomland hardwood forests in western Tennessee, identified in Tennessee State Wildlife Action Plan (TWRA, 2005).

6. Refugia – refugia refers to areas or environments that are less affected by climate change than other areas (Kareiva et al. 2008). In many ways, strategies for creating refugia are included in the strategies above, such as representation or restoration. The Agency should investigate the possibility of identifying or protecting existing refugia for GCN species. In particular, subterranean systems may be good candidates for this strategy.

7. Relocation – relocation is the "human-facilitated transplantation of organisms from one location to another in order to bypass a barrier (e.g., an urban area)" (Kareiva et al. 2008). The Agency will investigate the need to employ this adaptation strategy, and implement it as appropriate.

In addition to the seven adaptation strategies listed above, TWRA suggests the following strategies to implement as a part of an overall climate change response program:

- Vulnerability Assessments – research should be conducted to determine and identify those species and ecosystems that are most vulnerable to climate change. Some of this work can be conducted through state universities or research facilities (i.e. Oak Ridge National Laboratory), and some may be conducted through collaboration with national facilities such as the National Climate Change and Wildlife Science Center, or through collaboration with bird conservation joint ventures or the Southeast Aquatic Resources Partnership.

- Monitoring and Adaptive Management – long term monitoring systems that are strategically designed to evaluate climate change impacts and wildlife responses are a high priority for TWRA. With so much uncertainty surrounding the regional impacts of climate change, and how fish and wildlife will respond to climate alterations, it is vital to design and implement monitoring programs that can provide the best science-based information possible, in order to better inform decision makers and habitat managers on the best approaches of dealing with this issue.

- Set an example to other agencies by:

    1. Seeking funding to retrofit green roofs on appropriate agency buildings and modifying structures to be energy efficient. For example, all rooms in the TWRA Headquarters building should have light switches so that lights can be turned off in unoccupied rooms.

    2. Convert lawns to native species so that public and other agencies can see low maintenance and ecologically sound ways of managing home and building grounds and minimize mowing and grounds maintenance. Native vegetation that is not mown will also capture additional carbon. The TWRA Headquarters ground, for example, should be a more savanna like vegetation.

    3. Adopt policies of using appropriate vehicles for agency travel and replace some large vehicles with for fuel efficient models that are appropriate for employee travel to meetings and other tasks where large 4WD vehicles are not needed. Encourage/facilitate employees to pool when travelling to the same destination.

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