CHAPTER 4 PROBLEMS AFFECTING SPECIES AND HABITATS

4.1. Assessing Problems Affecting Species and Habitats

CONDUCTING A REVIEW OF THE PROBLEMS that may be adversely affecting Species of Greatest Conservation Need (SGCN) and their habitats in Tennessee in 2024 revealed that although the problems differ across geography, flora, and faunal groups, all designated SGCN face one or more threats to their survival. These include threats to habitat health and persistence and/or population stressors such as pollution and disease.

Certain issues, often related to human activities and management of lands and waters, pose threats to a range of habitat types and SGCN across the state. It is important to note, however, that in many cases people can make adjustments or implement "best practices" to mitigate or even eliminate the threats their activities pose. To the extent practicable, this linkage between stressor and conservation action is recognized in this chapter and Chapter 6 by providing internal links in the document.

Over the past decade, conservation scientists and planners have become increasingly focused on understanding larger, or "landscape-scale," patterns of change in lands and waters as a means of evaluating challenges to habitat or population persistence. In addition, the negative impacts from volatile climate scenarios and extreme weather events are of increasing concern to the short- and long-term health of SGCN and their habitats across the US (NFWPCAP 2012).

Photo credit: OHV damage in east TN showing massive ruts and erosion on a nature trail / Scott Dykes, TWRA

4.1.1. Review and Update of Major Statewide Problems

Summary: 2025 process for identifying and prioritizing problems affecting SGCN and their habitats

1. Review and revise problems identified in 2015. The planning team determined 2015 SWAP problems are still representative of current problems for SGCN and habitats.
2. Categorize problems. Using the standardized hierarchy originally developed by the Conservation Measures Partnership, now called the Conservation Standards for the Practice of Conservation (2016), the team cross-walked 2015 problems to the most recent updated threats classification 2.0 from 2016. Two problem categories were added: a) Climate Change & Severe Weather and b) Removing/ Reducing Human Maintenance.
3. Prioritize threats. The team focused on the most consistently highly-ranked problems from 2015 and, when possible, for a particular problem, added a spatial assessment component to help identify the location of problem sources relative to priority SGCN habitats. Problem rankings for individual species were not changed or updated from 2005/2015.
4. Incorporate climate change as a major new source of stress. A separate chapter in this plan (Chapter 5) focuses on Climate and Resilience and was prepared for Tennessee by members of the Southeast Climate Adaptation Science Center (SE CASC), building on the 2015 climate change vulnerability assessment for Tennessee conducted by The National Wildlife Federation and TNC. The chapter examines data on species vulnerability (due to both inherent factors and potential landscape/habitat changes) and landcape resilience, as well as case studies, to gain a better understanding of the range of SGCN vulnerabilities across the state.
5. Summarize threats, their sources and impacts, and major species groups affected. The major categories of problems in the 2025 Tennessee SWAP are Statewide Land and Water Uses (for economic and recreational purposes), Biological Resource Use and Natural System Modifications, Invasive and Problematic Species and Pathogens, and Pollution (See Table 4.1).

The 2025 SWAP team used the Best Practice recommendations (AFWA 2012), as well as the *Voluntary Guidance for States to Incorporate Climate Adaptation into State Wildlife Action Plans and Other Management Plans* (AFWA 2022) to assist with the review of problems facing species and habitats. In the 2005 planning effort, Tennessee followed a best practice, using a standardized process and hierarchy for identifying stresses and sources of stress aligned with broader categories defined by the Conservation Measures Partnership (CMP) (Salafsky et al. 2008). Over 33 "sources" or problems, were identified and linked to 10 major ecological stress types. The stress and source combinations were linked to every SGCN and then evaluated for the scope, severity, timing, reversibility, and contribution to potential population declines in different regions of the state.

These evaluation assignments were captured in the SWAP database and summarized to create cumulative ranking scores to identify the major problems facing SGCN distributed in the major terrestrial, aquatic, and subterranean regions of the state (see Ch. 1, State of Tennessee).

The 2025 SWAP team reviewed the 2015 SWAP major stresses and potential sources of stress hierarchies and determined that they were still representative of current problems (Appendix G). The team also determined that the 2015 stresses to new SGCN identified as part of the update

Agricultural conversion causes loss of native habitat, and some agricultural practices can be detrimental to wildlife. On the other hand, loss of prime farmland is also a conservation issue in Tennessee. / Greg Wathen

process remain the same. One additional major problem as defined by CMP was added during the 2025 revision process: Climate Change & Severe Weather. In addition, Removing/Reducing Human Maintenance, which is one of the threats listed under the major category Natural System Modifications, was added. A crosswalk exercise was completed between the 2015 sources of stress and the more recent CMP Open Standards (hereafter Conservation Standards) threats classification (Version 2, Beta – February 2016). Appendix G provides a summary of the crosswalk exercise and shows the addition of the new potential source of stress for 2025. A summary of major problems and threats is provided in Table 4.1.

Stressors and threat categories listed below follow the Conservation Standards classification to the extent possible, retaining the names of key threat categories and subcategories. However, the presentation of threats is organized in a manner that corresponds to their extent and location across the state, as well as commonalities in management approaches to address them. (For example, addressing the issues of "Overuse of Biological Resources"—e.g., collection—as well as "Recreation" usually requires public education, signage, rules, enforcement, and/or physical barriers to entry. They are both listed under the major category "Biological Resource Use and Natural System Modifications," whereas the CMP puts Recreation in its own category, "Human Intrusions & Disturbance.")

Urbanization, agricultural land management, forestry practices, water management, energy development, transportation and utility corridors, biological resource use/natural system modifications, and invasive and problematic species and pathogens are top issues in 2025.

Documenting and prioritizing sources of stress

In reviewing the 2015 prioritization assessments for the terrestrial, subterranean, and aquatic regions, the 2025 planning team identified patterns in which sources of stress consistently emerged as top issues across all the regions and grouped these sources by general category (for more details, see TWRA 2005, pp. 84-146). The team also documented which of these 2015 problems, and any emerging issues since 2015, warrant the greatest focus moving forward.

In assessing problems for the 2025 revision, the planning team chose to focus on the major sources of stress across the state, using new spatial information and analyses (see Chapter 3) to understand where major problem sources intersect with priority SGCN habitats (See Ch. 4 maps in Appendix B, the

Table 4.1 Summary of CMP level 1 and 2 threats to SGCN and SWAP-identified priority habitats in TN

CMP Level 1	CMP Level 2 Descriptor
1. Residential & Commercial Development	Housing & urban areas - Primary residential development
	Commercial & industrial areas
	Tourism & recreation areas
2. Agriculture and Aquaculture	Annual & perennial non- timber crops - Incompatible row crop agricultural practices
	Wood and pulp plantations
	Livestock farming & ranching - Incompatible grazing/pasture management practices
3. Energy Production & Mining	Oil & gas drilling
	Mining & quarrying
	Renewable energy
4. Transportation & Service Corridors	Roads & Railroads
	Utility & Service lines
5. Biological Resource Use	Hunting & collecting terrestrial animals
	Gathering terrestrial plants
	Logging & wood harvesting
	Fishing & harvesting aquatic resources
6. Human Intrusions & Disturbance	Recreational activities - non-vehicular
	Recreational activities - vehicular
7. Natural System Modifications	Fire & Fire suppression
	Dams & water management/use - Channelization of rivers/streams
	Dams & water management/use - Construction of dams/impoundments
	Dams & water management/use - Construction of ditches/dikes/drainage/diversion systems
	Dams & water management/use - Excessive groundwater withdrawal
	Dams & water management/use - Excessive surface water withdrawal

Table 4.1 Summary of CMP Level 1 and 2 threats to SGCN and SWAP-identified Priority Habitats in TN

CMP Level 1	CMP Level 2 Descriptor
	Dams & water management/use - Operation of dams/reservoirs
	Dams & water management/use - Operation of drainage/diversion systems
	Other ecosystem modifications - Incompatible species management practices
	Removing/Reducing Human Maintenance
8. Invasive & Problematic Species, Pathogens & Genes	Invasive non-native/alien species plants & animals
	Problematic native plants & animals
	Pathogens & Microbes
9. Pollution	Household sewage & urban wastewater - Municipal wastewater treatment/stormwater runoff
	Industrial & military effluents
	Agriculture & forestry effluents - Incompatible Forestry Practices
	Agriculture & forestry effluents - Incompatible grazing/pasture management practices
	Agriculture & forestry effluents -Incompatible row crop agricultural practices
	Garbage & solid waste
	Air-borne pollutants - Acid rain
	Air-borne pollutants - Low-level ozone air pollution
10. Climate Change & Severe Weather	Habitat shifting and alteration
	Droughts
	Temperature extremes
	Storms and Flooding

2025 TN SWAP Atlas) rather than conducting new species-by-species rankings. Examining problems in this fashion allowed the team to focus on the highest priority issues and the major landscape-scale drivers of change in Tennessee to better inform conservation investments and collaborations with conservation partners.

Signs of Hemlock Woolly Adelgid infestation: small cottony sacks at the base of needles / Nicholas A. Tonelli

As detailed in Section 3.2 and elaborated further in Section 4.2, the SWAP GIS database design allows for flexible assessments of habitat priorities and sources of stress to SGCN at a variety of scales in Tennessee when spatially relevant data are available. For example, urbanization issues were identified as a major problem in the 2005 SWAP; however, the specificity of where urbanization pressures intersected with SGCN and habitats was not specified. By using spatial analyses for the 2015 and 2025 updates, the planning team has identified where urbanization pressures in Tennessee must be addressed to protect SGCN and habitats. In addition, the associated database features allow planners to identify which SGCN, how many occurrences, and which habitat types are under pressure at a given location when that type of information is needed for project-specific work (see the SWAP Relational Database Highlight).

The most frequently documented potential source of stress listed in each COA in 2025 was natural system modifications, which includes water management, followed by agricultural land management, and urbanization (its associated infrastructure and water uses). In addition, biological resource use/forestry practices, energy development, transportation and utility corridors, and invasive and problematic species and pathogens appeared frequently as threats. These land and water use issues typically have a landscape-level footprint across one or more regions of Tennessee, and effectively managing for better habitat outcomes requires education and active engagement of the private sector and government agencies involved in land and water management, transportation, and compensatory mitigation decisions (AFWA 2012).

Fire suppression is a significant issue for multiple grassland, forest, and woodland habitat types statewide, and managing certain recreational activities remains a challenge for protecting species and habitats in specific locations. The collection of particular plant and animal species in different regions of the state must be monitored, and regulations enforced, to prevent overharvest and declines in species populations. Additional areas receiving increased emphasis for the 2025 update are problems associated with the ongoing spread of several disease pathogens and invasive exotic species, particularly those affecting cave-dwelling bat species, reptiles, amphibians, and forest habitats. Airborne pollutants remain a challenge, as acid rain and deposition of bioaccumulative toxic metals, such as mercury, damage both terrestrial and aquatic habitats, particularly in the eastern two-thirds of Tennessee. Water pollution is also an issue, as runoff from agriculture and forestry can carry chemicals and contribute to stream siltation, and microplastics are now a known concern in the Tennessee River.

4.1.2. Climate and Resilience

Topographical variation creates landscape diversity, which contributes to resilience. Savage Gulf, western edge of Cumberland Plateau / Greg Wathen

In 2009, TWRA published an update report for the SWAP entitled *Climate Change and Potential Impacts to Wildlife in Tennessee* (TWRA 2009). This report served as the first comprehensive review of the scientific literature on climate change at the time, as well as its potential impacts on fish, wildlife, and habitats in Tennessee.

In 2015, the *Climate Change Vulnerability Assessment for Tennessee Wildlife and Habitats* was prepared by the National Wildlife Federation and The Nature Conservancy, under contract with TWRA (Glick et al. 2015). The primary emphasis of the 2015 assessment was to examine three major aspects of climate change impacts: species vulnerabilities, terrestrial and aquatic habitat changes, and landscape resilience.

Some amphibians may suffer disproportionately from a shifting climate in Tennessee. Long-tailed Salamander (E*urycea longicauda*) / Daniel Istvanko, TWRA

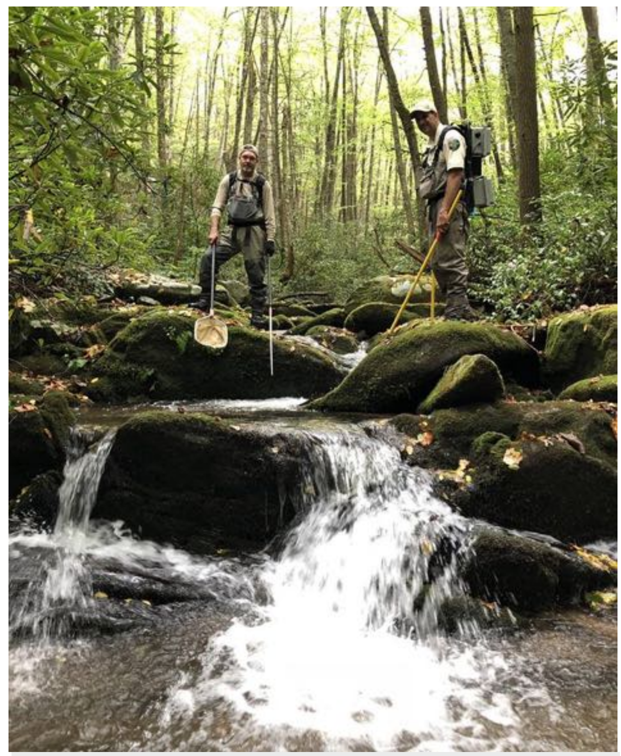
In 2025, an entire chapter on Climate and Resilience has been included, focusing on species vulnerability and landscape resilience alongside current temperature and precipitation projections for Tennessee and the surrounding Southeast Region. Species vulnerability is assessed using existing Climate Change Vulnerability Index analyses combined with Ecological Niche Models, which focus on habitat suitability for each species.

4.2. Updates to SWAP GIS and Database Information on Major Problems

In the decade since the 2015 SWAP was developed, through a variety of different project collaborations, TNC and TWRA have compiled a wide array of additional GIS data and spatial analyses to improve understanding of the major landscape-scale problems facing SGCN and habitats across the state. These improvements allow mapping, for the first time ever, at a 10-meter resolution. Additional GIS data used in the 2025 SWAP analysis include:

- 2011 GAP/LANDFIRE, the basis for SWAP terrestrial mapping
- FATHOM, a proprietary dataset that shows wetland and riparian ecological systems based in part on a model of flood frequency
- The National Inventory of Dams
- The USDA Cropland Data layer (which provides landcover data nationally at a 10-meter resolution, not just for croplands)
- FUTURES, a model for predicting future urbanization
- The US Office of Surface mining/Tennessee Division of Geology permitted lands.

In addition, field survey and planning efforts conducted by many partners to track the spread of pathogens, such as white-nose syndrome in bats and Hemlock Woolly Adelgid in native hemlock forests, have also been used to map the current spatial extent of these problems.



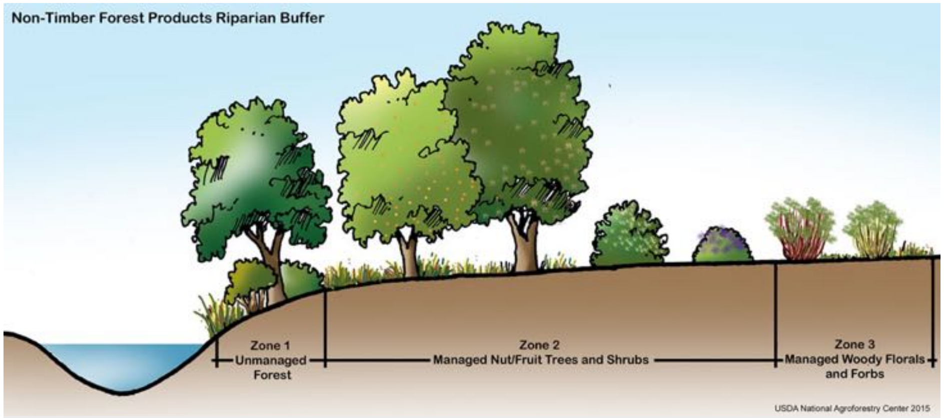
TWRA biologists surveying for Southern Appalachian Brook Trout, now found in only the coldest, clearest headwater streams of the eastern part of the state. The water quality these fish rely on is affected by surrounding land use. / Sally Petre, TWRA

The 2025 SWAP Section 3.2.4. *Updates to Habitat Mapping Units* describes the basic unit of assessment for terrestrial, subterranean, and aquatic habitat priority maps (nested hexagons of roughly 8928-, 1275-, and 182-acres in size for terrestrial and NHDPlus v2 catchments for aquatic and subterranean). These same mapping units are used for assessments of potential problems. The GIS and relational database capacity makes it possible to look at the intersection of different types of land and water uses with the priority habitats identified for SGCN, and the mapping units allow for these data to be summarized at a variety of different spatial scales.

Understanding the current and potential spatial footprint of major land and water uses, as well as how these uses intersect with priority habitats, is critical to identifying habitat protection, restoration, and management needs and opportunities.

The maps and data summaries provided in this 2025 SWAP are intended to represent the scope and distribution of major potential problems including urbanization, agriculture, river and stream management, and non-renewable energy development. Also included are example distribution maps of various pathogens with ranges that have changed significantly since 2015.

It is important to emphasize that these assessments are intended to direct attention to *potential* problems for habitats based on known issues with land and water management practices in general; they do not provide information on the presence or absence of best management practices in a given situation. The existence of actual problems always must be verified in the field with site specific knowledge and assessments.



Improving agricultural management practices in priority areas can improve outcomes for freshwater SGCN and overall water quality. / USDA National Agroforestry Center

For example, improving agricultural management practices in priority areas can improve outcomes for freshwater SGCN and overall water quality. These investments are being made by state and federal partners and private landowners across the state. However, Map 4.4 Potential Risk from Agriculture to Downstream Aquatic Habitat Priorities is associated with agricultural land management but does not contain information about where actual on-the-ground agricultural practices are being used. Instead, these maps emphasize where BMPs may be targeted to achieve better outcomes for SGCN.

In addition, the data associated with permitted activities are not intended to substitute for the standard reviews and decision-making performed in a regulatory context by both state and federal agencies. Rather, these data should be complementary to those reviews, as it can provide both a local- and a landscape-scale context of the associated activities with respect to important SGCN habitats.

SWAP data is becoming integrated with models for renewable energy. While no renewable energy analysis is included in the 2025 SWAP threats analysis, the **Geospatial Energy Mapper** contains maps that show the potential for the development of both solar energy farms and wind turbine farms across the region. Additionally, TNC is conducting a renewable energy siting assessment for the Southeast using terrestrial priority data from the TN and KY SWAPs; aquatic priority data from TN, KY, and the Southern Appalachians; and karst priorities from TN. See Table 6.3 within the Conservation Actions & Strategies chapter for a compilation of principles and best practices for renewable energy site selection.

Actual problems always must be verified in the field: MTSU conducting research on snake microbiome/fungal disease. / Rob Colvin, TWRA

PINESNAKE IN TENNESSEE

Very little is known about the **Eastern Pinesnake (*Pituophis melanoleucus*)** in Tennessee. Named from the Greek words meaning black (melano) and white (leukos), this handsome snake is both cryptic and shy. Those qualities, combined with habitat degradation and loss, have reduced the snake to a handful of small populations about which little is known.

While pine and mixed pine forests cover approximately one third of the southeastern United States, loblolly pine (*Pinus taeda*) is the most abundant species. Loblolly has spread beyond its historic range because it is popular as a forest plantation tree, often grown as a monoculture with low tree species diversity and low diversity in the understory. Lower habitat diversity generally supports lower wildlife diversity.

The flip side of this situation is a significant potential to restore and maintain ecologically beneficial pine savanna habitats within stands of *P. taeda*. Tennessee's abundance of pine forests could provide ample opportunity to restore and maintain pine savannas important to at-risk species of wildlife like the pinesnake.

At least one landowner in Tennessee is enthusiastically working to restore Eastern Pinesnake habitat after a hunter on his property found one in 2021. Aware that this was a rare species, the hunter posted his find on the Tennessee snake identification and education page on Facebook, which is monitored by the Tennessee Wildlife Resources Agency (TWRA).

Eastern Pinesnake with shy demeanor on display / Jesse Eaker, TWRA

CROWD SOURCING CONSERVATION

TWRA Biodiversity staff Jesse Eaker and Mallory Cogburn were notified of the pinesnake Facebook post almost immediately. They both rushed to the site where they found the hunter waiting for them near a tree stump in which the snake had holed up. The location was a private property with acreage leased out to hunting clubs, as well as loblolly pine planted and harvested for pulpwood.

Adult Eastern Pinesnake in the hand / Jesse Eaker, TWRA

John Ross, the landowner, expressed interest in managing his land to benefit the snake. "It's rare to find someone with so much property, and it's rare to find someone with the interest to set aside some of their land for conservation—it's doubly rare to find both," says Eaker. Studies have shown that pinesnakes prefer an "open" (i.e., less dense) canopy (less than 50% canopy cover). Ross was able to obtain management support via the EQIP and Conservation Stewardship Programs (CSP), both offered by the Natural Resources Conservation Service. Since 2022, he's had a habitat improvement project ongoing on over 600 acres, which includes forest thinning and prescribed burning. The added light that reaches the forest floor rejuvenates the herbaceous understory, which springs back from the seed bank. Ross said that the project absolutely benefits many types of wildlife in the savanna, including deer and Wild Turkey.

Eaker is studying this elusive species, state listed as threatened in Tennessee, by relying on citizen science: sightings of the snake shared by the public through social media or email that include a georeferenced photo voucher. He is also using museum specimens from Austin Peay State University. These locations across the state will provide insight on landscapes preferred by this species.

A drift fence, whose undulating shape across the landscape echoes the pinesnake itself, with funnel traps placed at each end. / Jesse Eaker, TWRA

PINESNAKE TELEMETRY

Eaker designed his project to get a better idea of the range and specific habitats used by Eastern Pinesnakes (as well as to serve as his Master's thesis at Tennessee State University). Agencies and conservation NGOs can use that information to guide restoration and management. To study these snakes, step one was to find them. Unlike salamanders that can be difficult to find as well, pinesnakes can cover a lot of ground. Eaker's project revolves around drift fences and funnel traps to catch snakes, and telemetry to monitor their movements and habitat use. He has placed a total of 26 funnel traps across the managed habitat. His design includes a perpendicular arrangement of drift fences (bottom right).

Partners for Eastern Pinesnake Conservation

Austin Peay State University
Landowner John Ross
Nashville Zoo
Tennessee Dept. of Agriculture Division of Forestry
Tennessee State University (TSU)
Tennessee Tech University
Tennessee Wildlife Resources Agency (TWRA)
USDA Natural Resources Conservation Service

That first pinesnake in 2021, an adult male, was implanted the same day with a small transmitter 1.7 inches long (which involved surgery in the field by a researcher from Tennessee Tech). The transmitter emits a constant pulse for ~two years, which Eaker can pick up using a handheld antenna. He explains, "You turn on the receiver and try to get a beep, and usually you can. It's kind of like a geiger counter, with the signal getting louder as you get closer."

Rob Colvin, TWRA installing a drift fence / Jesse Eaker, TWRA

Eaker's research includes tracking snakes once per week and recording micro habitat data at each relocation, including percentage of litter, bare ground, vegetation, rocks, slash, and coarse woody debris, as well as weather, temperature, and canopy density. To date, the male pinesnake, known as 681Pm (a reference to his frequency number), has roamed over 150 acres. Another male came into his home range, then left. A female with overlapping home range was also found, but her transmitter died prematurely (which could have indicated predation). Pinesnakes mate in spring, and females lay eight to nine eggs in an excavated nest or existing burrow. Eaker wants to know if they actually dig their nests and what they do if the soil isn't sufficiently sandy to do so. He hasn't yet found a nest, but he has found a male digging!

Scarlett Kingsnake / Jesse Eaker, TWRA

Jesse Eaker shown with perpendicular drift fences installed on the Ross property / Michaela Zaidan, TWRA

As of summer 2025, Eaker has captured and implanted transmitters in five pinesnakes on the Ross property with the help of Dr. Bill Sutton from Tennessee State and veterinarians from the Nashville Zoo. His results so far confirm that Eastern Pinesnakes prefer the less dense forest areas. He has also found other rare open pine species in his traps, such as Scarlett Snake (*Cemophora coccinea*), Scarlett Kingsnake (*Lampropeltis elapsoides,* at right), Eastern Spadefoot (*Scaphiopus holbrookii*), and a diversity that is represented by 43 species of reptiles, amphibians, small mammals, and birds identified to date—proving that management targeted to one rare species can benefit many others.

Eaker, Jesse, R. Colvin, J. Ross, and W. B. Sutton. 2025. Private Lands, Ecological Restoration, and Herpetofauna as Ecological Indicators: A Pinesnake Case Study from Tennessee. Southeast Partners in Amphibian and Reptile Conservation annual meeting.

Compared to 2015, the data development effort for the 2025 update allows TWRA and its many partners to conduct a variety of more detailed problem assessments to serve specific project needs. Efforts already in progress include collaboration with the Southeast Aquatic Resources Partnership to identify dams that would yield the greatest benefits to aquatic SGCN, if removed. Another example is the use of SWAP priority habitat data in combination with the Resilient and Connected Network data layer, which will help conservation practitioners identify the most resilient sites to focus on for the long-term conservation of SGCN. A more detailed methods explanation for the landscape analyses of major problems will be available in The Nature Conservancy's publication Database Development and Spatial Science in Support of Tennessee's State Wildlife Action Plan (Wisby 2025, in draft).

4.3. Major Statewide Land and Water Uses

This plan is a statewide plan focused on conservation of Tennessee's immense biodiversity. From this perspective, some economic or recreational uses of land—especially those occurring in places where populations of species exist—pose significant threats to SGCN. While numerous land and water management strategies have their positives, some forms of management pose significant threats to SGCN and are identified as such in this document.

This section describes land and water uses that have large footprints in Tennessee and can result in widespread detrimental impacts to species and habitats. Threats—even when beneficial economically (such as some forms of production forestry) are still threats. The main point to take away from highlighting a threat related to a specific user group or industry, is not to point the finger at these groups, but to identify ways in which their practices can and are being improved to reduce or eliminate the threats that some of their management approaches create. Some of these beneficial practices are described in Chapter 6.

4.3.1. Residential and Commercial Development

Residential, commercial, and industrial development can lead to a host of impacts to habitats, wildlife, and plants. Developmental sprawl consumes land and puts pressure on surface and ground water resources to provide drinking water and dilute wastewater (Thurman and Terry 2011). These negative effects can include:

- direct loss of habitat through land conversion to other uses or stream habitat destruction
- habitat fragmentation
- increased runoff as a result of increasing levels of impervious surface, leading to erosion, reduced groundwater recharge, and water pollution
- increased flooding
- expanding transportation or service corridors that can fragment habitat or block the movement of smaller, less mobile species.

Specifically with respect to forest habitats, urbanization can

- introduce exotic pests when people travel from urban areas to rural communities for outdoor recreation
- cause increases in mismanaged forest areas that are typically used for recreation
- result in a decreased probability of timber harvesting practices (TDF 2020) that can benefit people and wildlife
- decrease the ability to conduct prescribed fire and fight wildfires, due to the location of buildings in the wildland/urban interface.

A study conducted in 2022 (Hogue and Breon) determined the relative magnitude of five major threats worldwide to species identified by the International Union for Conservation of Nature (IUCN) as threatened with extinction. For the 20,784 species for which data were available, threats constituting the main factor pushing each species toward extinction were ranked as follows: habitat destruction 71.3% of species, overexploitation 7.4%, invasives 6.8%, pollution 4.7%, and climate change and weather 1.8%.

According to the National Wildlife Federation, sixty percent of the rarest and most imperiled species in the US occur in metropolitan areas, especially the fastest growing large metro areas. From 2021 to 2022, Nashville was among the nation's top 10 largest gaining metro areas countrywide (Wilder and Mackun 2024).

Impacts to terrestrial habitats

Urbanizing land use patterns affect terrestrial species and habitats in a variety of ways (Middle Tennessee) / Greg Wathen

Urbanizing land use patterns affect terrestrial species and habitats in a variety of ways (see Box 4.1.). For example, urbanization can result in a shift in the types of species that live and thrive in a region, with non-native species often competing with or replacing native species. A review of 105 studies on the effects of urbanization found trends of increasing proportions of nonnative species toward urban cores in plants, birds, mammals, and insects. The effects of moderate urbanization (i.e., suburbs) varied significantly, with most studies indicating an increase in plant species richness, due in part to exotic species introductions, whereas most studies of invertebrates and non-avian vertebrates show decreasing species richness with increasingly intense urbanization (McKinney 2008). In a systematic review of 159 studies on soil invertebrates, abundance showed an increase, whereas species richness significantly decreased with increasing urbanization (Szabó et al. 2023).

Box 4.1. Three SGCN Impacted by Urbanization in Davidson and Williamson Counties

The Mill Creek COA consists of approximately 100 square miles of the Mill Creek watershed of Davidson and Williamson counties. Long known as the flagship drainage of the federally endangered Nashville Crayfish (*Faxonius shoupi*), the watershed has experienced significant landscape alterations since the species was listed in 1986. Most obvious is the conversion of forest and farm in greater Nolensville—the origins of Mill Creek—from a more agricultural setting to urban/suburban cover types.

Mill Creek's headwaters are also unique in Tennessee and the world for being the only known landscape where three legally protected SGCN co-occur, the other two being Redband Darter (*Etheostoma luteovinctum*) and Streamside Salamander (*Ambystoma barbouri*).

While the rapid expansion of residential and commercial spaces in its headwaters seems contraindicated for the persistence of Nashville Crayfish in Mill Creek, data collected at multiple mainstem monitoring sites suggest that local populations remain stable or increasing during the last decade (Nashville Zoo, 2024).

However, the influences of urbanization are more readily apparent in Mill Creek's numerous unnamed feeder streams where more localized landscape and watershed alterations can be more easily detected. While the federally protected Nashville Crayfish is well-known from Mill Creek proper and its larger named tributaries, it also ekes out an existence in smaller, unnamed perennial feeder streams with numerous related species competing for the same spaces and resources.

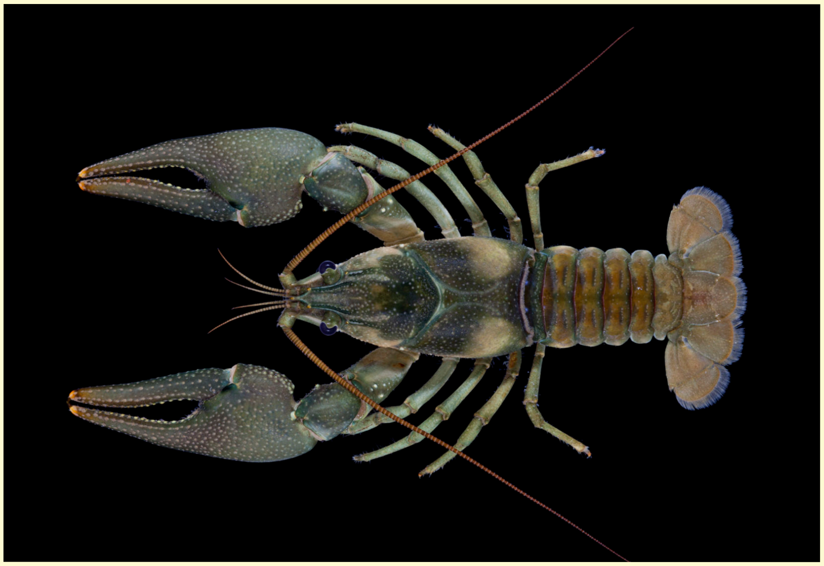
As smaller tributaries are impacted by nearby development more immediately than Mill Creek itself, the persistence of the Nashville Crayfish in such waterways remains unclear. Moreover, as Nashville Crayfish appears to be less tolerant of smaller streams with less reliable flows, they are generally displaced in such systems by more robust cousins – most notably the Saddle Crayfish (*Faxonius durelli*).

Additionally, the Tennessee endemic Redband Darter, a species In Need of Management reported infrequently from unnamed perennial streams in Nolensville, is periodically observed alongside or near Nashville Crayfish. (The darter is named for the vertical red and blue bands associated with males as they enter the springtime breeding period.)

Though most commonly reported from perennial segments, the species can also extend into seasonal, intermittently flowing streams during breeding season. In such instances they may share habitats with yet another area SGCN, the state endangered Streamside Salamander.

First reported in Nolensville in 2015, the seasonal breeding streams used by this mole salamander have been severely impacted by area development, most notably from improper sediment discharges to its occupied streams (smothering of eggs and habitat) or dewatering of critical stream segments, or both. While the persistence of the species under such circumstances remains dubious, evidence from other parts of its range in Tennessee suggests that recovery may be possible once occupied landscapes are stabilized and returned to proper hydrology (see White Oak Stream Restoration Highlight).

The presence of these three protected species at the head of Mill Creek illustrates the complex impacts of urbanization and drives home the importance of Conservation Opportunity Areas (see Ch 6 Conservation Actions and Appendix I) and the conservation focus they may bring to these under-appreciated landscapes.



The “triumvirate” of SGCN concentrated in Mill Creek and its tributaries, from top:

Nashville Crayfish / Carl Williams

Redband Darter / Mark Blakewell, N.A. Native Fishes Association

Streamside Salamander / Matt Niemiler, Univ. of Alabama

Land fragmentation and changes in land use

The concept of landscape connectivity was first introduced in 1984 (Merriam 1984). After several years of research, Merriam and colleagues defined it in 1993 as, "the degree to which the landscape impedes or facilitates movement among resource patches" (Taylor et al. 1993). Connectivity provides the ability for species to move across optimal habitats unimpeded. This ability to move is necessary for aquatic and terrestrial species alike. Without connectivity, natural ecological processes and animal movement are greatly hindered.

Natural processes like migration, food/water availability, gene flow, predator-prey and other species relationships, colonization, disease spread, and movement to resting and breeding areas are critical to species survival. As natural processes (e.g., fire, drought, precipitation patterns, temperature) and habitats change, a shift in the abundance and distribution of species occurs. In Tennessee this often takes the form of changing species composition in forests and the herbaceous understory. As more habitat is fragmented, these animals are faced with potential isolation and an inability to conduct vital life processes (Collinge 1996).

For example, landscape changes are considered a major threat for amphibian populations (Gibbs 1998, Green 1997, Dodd and Smith 2003, Cushman 2006). Snyder et al. looked at the effects of landscape connectivity on the movement of Red-backed Salamanders (2021). These species have much lower vagility and are not often evaluated for the effects of interruption in habitat connectivity compared to other species such as birds and large mammals. Their findings showed that recapture rates of individual salamanders were statistically higher in open forest, compared to forested habitat with obstacles that broke the connectivity of the habitat.

Likewise, habitat loss is at the top of the list of threats to butterflies, which the US is losing at a rate of 1.3% per year in the contiguous US and .25% per year in the Southeast (an almost 5 percent decrease between 2000 and 2020) (Schultz et al. 2025).

Recreation, vacation homes, and continued timber harvest near public lands can disrupt habitat connectivity used by a variety of species. / Sarah Stitch

Even plants, which are intrinsically less mobile, may be susceptible to habitat fragmentation and succession. Fragmentation can occur in a variety of settings, including development in and around existing public lands. For example, development in the eastern mountains of Tennessee on steep mountain slopes and ridges can damage viewsheds and decrease tree cover, leading to erosion and habitat fragmentation (Thurman and Terry 2011). These areas are becoming more popular for recreation, vacation homes, and continued timber harvest. Such activities in and around public lands can disrupt habitat connectivity used by a variety of species. This creates the need for greater attention to planning and proper management strategies on public lands.

On the other hand, a fragmented landscape may still support viable populations of wildlife depending upon where habitat has been lost and where species tend to aggregate (May et al. 2019). For this reason, it is still important to maintain habitat quality in a fragmented landscape.

There are a variety of threats to connectivity. Development, changes in climate, deforestation, energy production, and changes in noise and light levels are a few. Another problem associated with loss of habitat connectivity is an increase in human-wildlife conflict, as humans and wildlife compete for the same space and resources. The connection of vital habitat that allows wildlife to move to areas less inhabited by humans is becoming more and more scarce. The World Wildlife Fund stated that, "our planet will only survive if our ecosystems are connected" (WWF 2025).

According to new data from the University of Tennessee, the state lost 1.5 million acres of farmland from 1997 to 2022. That equates to the loss of six counties worth of pasture and forestland across the state. In rural areas, development is converting farmland to other uses at a rate of 237 acres per day, which is almost ten acres every hour (Kessler et al. 2023). Land development is one of the top threats associated with loss of habitat and landscape connectivity. An increased risk of land development can also be associated with forestland ownership.

Tennessee lost six counties worth of pasture and forestland in the 25 years from 1997 to 2022. (Williamson County) / Gregg Elliott, K Gregg Consulting

For example, on the Cumberland Plateau, much forestland held for decades by timber companies has been sold to institutional investors, with various plans for both development and conservation. However, depending on the income planning horizon and expectations, increased pressure may be placed on harvesting forest products and selling land assets for other types of development. Reduction of forestlands can also negatively impact water quality and quantity, the health and diversity of habitats, and other land values such as recreation, timber, and forest products (Thurman and Terry 2011).

In addition, as development fans out into rural areas—also called rural sprawl—a phenomenon known as parcelization can occur, in which larger landholdings are subdivided into smaller and smaller ownership units. Even in the absence of habitat fragmentation (in terms of actual land use change), parcelization increases the difficulty of providing coordinated and coherent habitat management on a scale suitable for many wildlife and plant species. For example, when private lands with a history of conservation management using prescribed fire are subdivided, it will take far more effort and coordination among multiple landowners to conduct prescribed burns over the same acreage (EGCPJV 2014). The result is not only fragmented habitat, but also the inability to effectively manage remaining habitat.

Unplanned development

Unplanned development patterns also have a high cost to local communities, their economies, and cultural heritage. From 1982 to 2007, the state's percentage of cropland decreased by more than 25%. From 2001 to 2016, 148,100 acres of Tennessee's agricultural land was converted to "urban and highly developed land use" (American Farmland Trust 2022).

Under a "business as usual" scenario, Tennessee is likely to lose 1,014,600 acres of farmland by 2040. Smart growth policies, which help cities and towns grow more compactly, implemented in just four states—Texas, North Carolina, Tennessee, and Ohio—would save over a million acres of Nationally Significant farmland (the most important land for long-term food security and environmental health) (Hunter et al. 2022). Local governments, taxpayers, and utility rate payers often subsidize the real cost of sprawl through expensive and inefficient infrastructure expansions (Thurman and Terry 2011).

Tennessee farmland can help provide connectivity between preferred habitat patches for various species of wildlife. / Joel Kramer

The fastest growing part of the state is in the counties surrounding Metropolitan Nashville-Davidson County. Approximately one million additional people will live in the greater Nashville region by 2035, according to projections made by the Nashville Area Metropolitan Planning Organization (TACIR 2024).

Light pollution

Artificial light at night (ALAN)—commonly referred to as light pollution—has emerged as a significant environmental threat, particularly as human development expands into formerly dark and natural areas. While artificial lighting provides safety, security, and convenience for people, it severely disrupts ecosystems and poses critical risks to wildlife. Light pollution alters natural biological processes that have evolved over millions of years, influencing species' sleep patterns, feeding behaviors, reproductive cycles, migration routes, and habitat use. If not addressed, the increasing prevalence of artificial light will continue to degrade ecosystems and contribute to global biodiversity loss. This plan outlines the key ecological issues caused by light pollution and presents targeted conservation actions that can help mitigate these impacts.

One of the primary effects of light pollution is the disruption of circadian rhythms in wildlife. Many species rely on natural light-dark cycles to regulate essential behaviors, including sleep, feeding, and breeding. ALAN can disturb these cycles, leading to increased stress, behavioral changes, and lower survival rates. This is especially harmful to nocturnal species such as bats, moths, amphibians, and small mammals, which depend on darkness to forage and avoid predators. Disorientation caused by artificial lighting can interfere with their ability to navigate or hunt, making them more vulnerable and less effective in their ecological roles.

Insects, particularly flying species, are among the most visibly impacted groups. Drawn to artificial lights, many become trapped in a cycle of circling until they are exhausted or predated upon. This phenomenon—sometimes called the "vacuum cleaner effect"—not only reduces insect populations but also disrupts entire food webs. Species that rely on insects for food, such as birds, bats, and frogs, suffer as their prey base declines. Migratory birds are also highly vulnerable. Many species navigate using the moon and stars, and bright urban lights can disorient them, resulting in fatal collisions with buildings, communication towers, and other structures. Others may become trapped in illuminated areas, flying in circles until they collapse from exhaustion or are preyed upon.

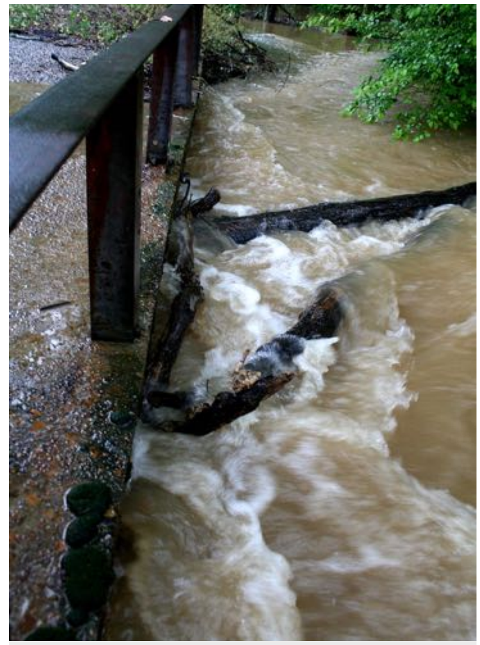
Artificial light can also alter predator-prey relationships by giving visual predators an advantage. In well-lit areas, predators can more easily locate and capture prey, while prey species tend to avoid these areas, leading to habitat loss and reduced access to resources. Additionally, reproduction in several species is tied to natural darkness. Sea turtle hatchlings, for example, use moonlight to orient toward the ocean, but beachfront lighting can lead them inland instead, greatly reducing survival. Amphibians like frogs and toads may cease their nighttime mating calls in lit environments, further impacting reproduction. The cumulative effects of light pollution can also fragment habitats. Continuous lighting across urban and suburban areas creates barriers to movement, isolating wildlife populations and limiting their access to mates, food, and safe shelter.

Impacts to aquatic habitats

The complex relationship between land use and stream/wetland health means that land urbanization will likely continue to contribute to declines in the state's water resources and its aquatic species. Tennessee's growth adds to the demand for water supply, placing additional stress on the state's aquatic resources at a time when freshwater conservation efforts are already needed. Urban development can alter the streamflow, habitat quality, and water chemistry of streams in both direct and indirect ways (USGS 2019b). It may also have greater potential to impact wetlands in the future (see Map 4.3 in **Appendix B, the TN SWAP Atlas**).

Urban development often results in direct alterations of streams, either to accommodate development of a specific site, improve site drainage, or access a site. Direct stream alteration can degrade the physical habitat and contribute to downstream channel erosion, sedimentation, or lower stream flows. All of these changes can impact reproductive success, feeding, and living spaces of aquatic organisms (USGS 2019b).

Faster and more frequent runoff, i.e., stream "flashiness," from paved and built surfaces also increases and destabilizes normal stream flow, which also alters streams and increases erosion. In urbanized areas, small streams are often overlooked or forgotten, but these streams can provide habitat (see Box 4.1), reduce contamination, ease flash flooding, and improve the aesthetics and livability of the daily environment (USGS 2019b).



Runoff and flooding, Saltillo, TN / Lindsey Turner

Rapid runoff carries surface pollutants directly to streams and reduces natural water infiltration and aquifer recharge. Lowered aquifers may then contribute to lower stream flows, particularly in summer months (USGS 2019b). Flooding can be exacerbated by both development in the floodplain and the failure to plan for stormwater management. For example, a study of 21 stream sites in the Ridge and Valley ecoregion of Tennessee and Georgia revealed that watersheds with increased levels of urbanization were characterized by increased proportions of fine sediments and pool areas, coupled with reduced variation in stream channel complexity. Urbanized watersheds exhibited declines in biotic integrity, species diversity, richness, and evenness (Smith 2009). Table 4.2 shows some of the top impacts of stream and lake impairment in Tennessee, and Table 4.3 shows the top sources. "Over time, the most common causes of pollution in rivers and streams have been found to be habitat alteration, siltation, pathogens and nutrients coming primarily from agriculture, hydrologic modification and municipal dischargers. The most common causes of pollution in lakes and reservoirs have been found to be metals and toxic organics such as PCBs and dioxins" (TDEC 2024a). Waters can have pollution from more than one source and totals in the tables are not additive. Illegal dumping and roadside litter are significant issues across the state as well, and they impact both waterways and terrestrial sites.

Wetlands

Development can also impact wetlands, particularly in the wake of the May 2023 US Supreme Court decision Sackett v. Environmental Protection Agency. The court found that the federal Clean Water Act no longer applied to adjacent wetlands that lacked a continuous surface connection with navigable waters. This overturned the long-standing interpretation and enforcement of the country's primary law protecting wetlands (Schaeffer 2024).

Table 4.2 Top Impacts of pollution to impaired rivers, streams, reservoirs, and lakes in Tennessee (TDEC 2024a)

RELATIVE IMPACTS OF POLLUTION IN TENNESSEE			
In Impaired Rivers and Streams		***In Impaired Reservoirs and Lakes***	
pH	1%	*E. coli*	1%
Organics	1%	Other**	2%
Flow Alterations	2%	Flow Alterations	4%
Other*	2%	Siltation	7%
Metals	3%	Nutrient Related	10%
Nutrient Related	17%	Organics	38%
Siltation	25%	Metals	53%
E. coli	31%		
Habitat Alteration	38%		

Table 4.3 Top sources of pollutants to impaired rivers, streams, reservoirs, and lakes in Tennessee (TDEC 2024a)

% POLLUTANT CONTRIBUTION OF POTENTIAL SOURCES IN TENNESSEE			
In Impaired Rivers and Streams		***In Impaired Reservoirs and Lakes***	
Atmospheric Deposition	2%	Hydrologic Modifications	1%
Land Application/Waste Sites	2%	Industrial Permitted Discharge	2%
Permitted Resource Extraction	2%	Habitat Alteration	3%
Legacy/Historical	2%	Construction	3%
Construction	3%	Agriculture	4%
Other	7%	Legacy/Historical	24%
Municipal Pointand Non-point Dischargers	15%	Other	27%
Hydrologic Modification	19%	Atmospheric Deposition	36%
Agriculture	47%		

*Includes golf courses, military bases, ORVs, and unknown

**Includes internal nutrient recycling, sources outside state borders, and unknown

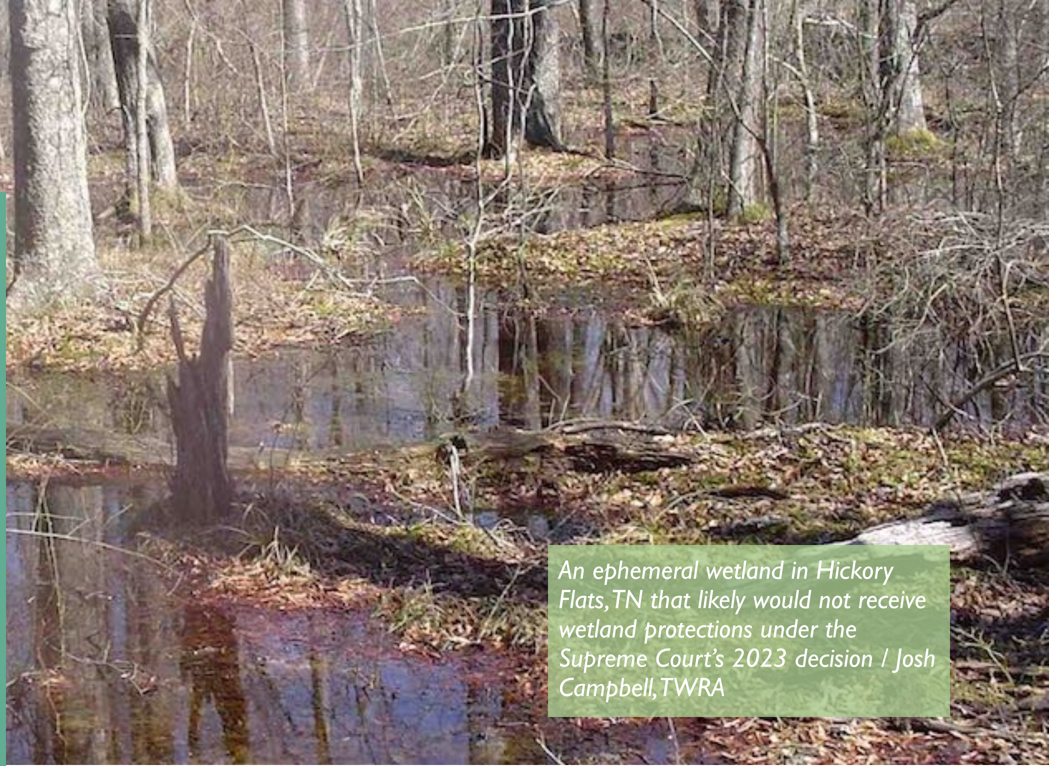
Tennessee has wetland protections that extend beyond the Clean Water Act. TDEC is charged with protecting the wetlands of the state of Tennessee. The Division of Water Resources carries out this mission by requiring any activity that may alter a wetland to obtain an Aquatic Resource Alteration Permit (ARAP). In 2025, the Tennessee State legislature passed into law a bill maintaining regulations for large and/or higher habitat value wetlands, while creating a less restrictive regulatory framework for smaller/lower resource value wetlands. "Isolated wetlands" in Tennessee are often hydrologically connected with underground waterways and aquifers. While this may not be the case with every isolated wetland (due to the karst geology found in much of the state), even though an isolated wetland may not be adjacent to surface water, they can reduce stormwater runoff and allow water to seep into groundwater flows which are critical to recharge of surface waters (Zedler 2003; Calhoun et al. 2017). They also perform a variety of important functions, such as supporting water quality and supply, flood protection, and above all from the standpoint of the SWAP, wildlife habitat (see the Wetland Highlight).

Reelfoot Lake, site of some of Tennessee's most famous wetlands / Nathan Reed via Flickr Creative Commons

Impacts to karst habitats

Karst landscapes are characterized by caves, sinkholes, underground streams, and other features formed by the slow dissolving, rather than mechanical eroding, of bedrock (Veni et al. 2001). With more than 11,000 documented, Tennessee has the greatest number of caves in the country

A large cave room in Blount County, TN / Matt Tomlinson



An ephemeral wetland in Hickory Flats, TN that likely would not receive wetland protections under the Supreme Court's 2023 decision / Josh Campbell, TWRA

WETLANDS IN TN AFTER 2023 COURT DECISION

In May 2023, the US Supreme Court held in *Sackett v. Environmental Protection Agency* that the federal Clean Water Act no longer applied to adjacent wetlands that lacked a "continuous surface connection with that water, making it difficult to determine where the 'water' ends and the wetland begins"—overturning the long-standing interpretation and enforcement of our primary law protecting wetlands (Schaeffer 2024).

Yet, in talking about "isolated wetlands" scientists caution not to conflate the concepts "continuous surface connection" and "hydrologically isolated." The vast majority of wetlands in TN that do not drain to streams are in fact hydrologically connected because they drain to groundwater or karst features like sinkholes or caves. Hydrologically isolated locations such as bogs are rarities in the state. Moreover, "isolated" wetlands without a direct *surface* connection to navigable waters are among the most important wetland types for wildlife and rare plants.

Following the Supreme Court case, a bill was introduced in the Tennessee State legislature proposing to remove state level regulations for geographically isolated wetlands. In 2025, the bill was amended and a version passed into law maintaining regulations for large and/or higher habitat value wetlands, while creating a less restrictive regulatory framework for smaller/lower resource value wetlands.

WETLAND VALUES FOR PEOPLE

Wetlands are crucial ecosystems that harbor high biodiversity, improve water quality, help to recharge surface and/or groundwater supply, mitigate flood impacts, and store carbon—whether or not they are connected to navigable waterways. In fact, scientific studies have shown that small, geographically isolated wetlands are powerful water purifiers due to the increased amount of time that water is retained in these systems, compared to those with a surface water connection (TDEC 2024).

The Streamside Salamander is dependent on "isolated wetlands" / Matt Niemiller

In addition, these same wetlands play an important role in groundwater movement and aquifer recharge, critical to the water supply of areas in karst-rich Middle Tennessee, such as the Duck and the Stones Rivers. When distributed throughout a watershed, especially in the upper reaches, geographically isolated wetlands mitigate flood potential by capturing and gradually releasing stormwater runoff (40%-50% reduction) (TDEC 2024).

WETLANDS FOR WILDLIFE & PLANTS

Wetlands are important for many forms of wildlife and plants. Both bogs and geographically isolated wetlands often host rare plant communities, which include species such as the federally-endangered green pitcher plant (*Sarracenia oreophila*) and the exquisite white fringeless orchid (*Platanthera integrilabia*) (Estes et al. 2016).

Amphibians, in particular, require geographically isolated wetlands because they provide breeding pools absent of fish, which prey on eggs and larvae (TDEC 2024). A 2003 scientific study (Semlitsch & Bodie) estimated habitat buffers based on the biological requirements of amphibians and reptiles that use wetlands (often "isolated") as part of their breeding cycle. Buffer size ranged from 127 to 290 m from the edge of aquatic sites. The clear biological interdependence between aquatic and terrestrial habitats that is essential for the persistence of these wildlife populations shows how elimination of such wetlands would have impacts to wildlife over an area orders of magnitude larger than the wetland's size.

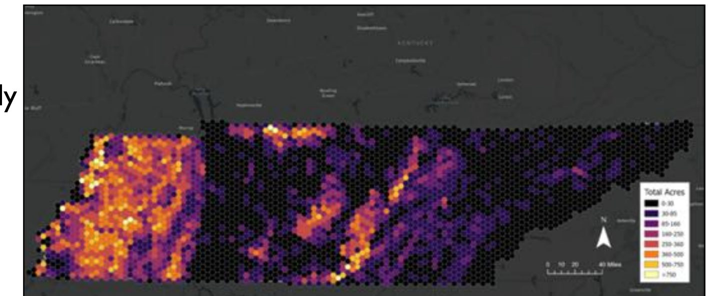
Wetlands also provide direct economic values in the form of recreation. Wetlands of all types provide habitat, food, and water for many waterfowl and fish species popular among hunters and anglers. They also attract a wide diversity of bird species, which is a draw for bird watchers as well.

Wetland Conservation Partners Across the State
(Not a comprehensive list)

Harpeth Conservancy
Hatchie River Conservancy
Protect Our Aquifer
Southern Environmental Law Center
Skytec LLC
Tennessee Dept. of Environment and Conservation
Tennessee Wildlife Resources Agency
The Nature Conservancy
Tennessee Wildlife Federation
Tennessee Ecological Restoration Association

WETLAND REGULATION IN TENNESSEE

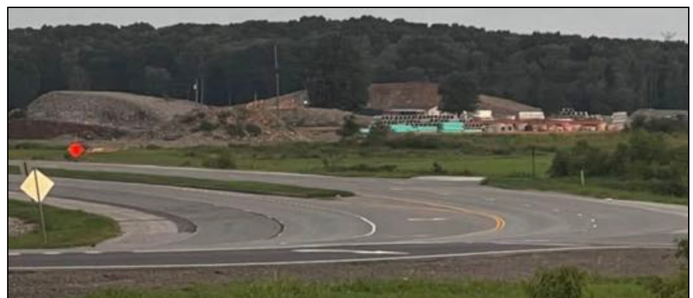
TWRA plays a regular role in the issuance of Division of Water Resources permits, specifically when a permit application occurs in proximity to a rare species record. In this way, the current (as of 2024) wetland regulatory structure allows the agency to address impacts to waters of the state, which is extremely helpful in preserving rare aquatic species. Reducing TWRA's ability to offer protective measures for wildlife species that are listed or Species of Greatest Conservation Need (SGCN) would negatively impact those species.



Summary of isolated wetland areas within 15-square-mile hexagons, as predicted by Skytec LLC's Enhanced Wetland Identification Model.

"Isolated" wetlands also provide habitat for many aquatic species that are still common, but likely to become less so as such sites are impacted. To keep common species common, the ability to mitigate for impacts to even small, "isolated" wetlands must be retained.

The US Fish and Wildlife Service's *Wetlands Status and Trends Report* makes it clear that US wetland protection policies and laws are already insufficient. Of a total 116 million acres, 221,000 wetland acres were lost from 2009 to 2019 (Lang at al. 2024). In Tennessee, loss of wetland protections could threaten not only wildlife, but also the drinking water supply, the integrity of rivers such as the Hatchie (at risk from filling of wetlands and increased deposition), stormwater retention, and farmland—which would be easier to develop without such protections (TDEC 2024).



Wetlands and ephemeral streams at this site support what may be the largest and most robust population of a state-endangered salamander species, but review and mitigation to reduce impacts were provided and the development was implemented. / TWRA.

In 2025, TDEC released a predictive model of wetlands in Tennessee created by Skytec LLC. This screening tool should prove valuable to stakeholders in evaluating conservation priorities, development potential and costs, permit submittals, and wetland restoration or mitigation suitability. In September 2025, the model estimated >320,000 acres of "isolated" wetlands in Tennessee.

Estes, D., M. Brock, M. Homoya, A. Dattilo. 2016. A Guide to Grasslands of the Mid-South. Published by the Natural Resources Conservation Service, Tennessee Valley Authority, Austin Peay State University and the Botanical Research Institute of Texas.

Lang, M.W., Ingebritsen, J.C., Griffin, R.K. 2024. Status and Trends of Wetlands in the Conterminous United States 2009 to 2019. US Department of the Interior; Fish and Wildlife Service, Washington, D.C. 43 pp.

Schaeffer. E. 2024. One Year After Key Supreme Court Decision, Almost Half of States Leave Many Wetlands Unprotected. Environmental Integrity Project Report.

Semlitsch, R.D. and J.R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology 17: 1219-1228

[TDEC] Tennessee Department of Environment & Conservation. 2024c. Wetlands Report: Stakeholder Engagement & Commissioner Recommendations and Appendix D, Written Comments Provided by Steering Committee Members.

equaling about 20% of all known US caves (Wisby and Palmer 2015). Most Tennessee caves are associated with karst composed of limestone in the central and eastern regions of Tennessee. Karst areas present unique challenges because so many of the processes key to their formation and stewardship are located underground, invisible from the surface. For this reason, the complex hydrology of karst aquifers and other processes critical to their integrity require specialized monitoring and assessment (Veni et al. 2001).

Karst regions are rich in water and mineral resources, providing unique habitats and spectacular recreational opportunities. Problems associated with living on karst can threaten both people and natural resources. Risks for people include sinkhole collapse, sinkhole flooding, and easily polluted groundwater that rapidly moves contaminants to wells and springs. Problems for the unique biota associated with caves and aquatic habitats include sediment and pollutants that infiltrate from the surface and alteration of drainage conditions that impact the aquifer itself (Veni et al. 2001).


The nature of karst: an unreported cave in Cumberland County, TN / Matt Tomlinson

A variety of BMPs exist to help reduce these types of potential impacts. BMPs rely on knowledge of the location of karst and aquifers, combined with practices designed largely to avoid impacts from contamination or hydrological alteration. BMPs for living and working in karst regions cover the following activities:

- buffers around sinkholes and sinking streams to minimize polluted runoff into groundwater (USFS [date unknown])
- development and road construction
- wells and groundwater mining
- septic and sewage systems
- timber harvest

(Veni et al. 2001)

Insufficient delineation of sinkholes and incomplete knowledge of their characteristics can result in development patterns that exacerbate sinkhole flooding (Bradley and Hileman 2006). Since many of Tennessee’s growing urban areas are located in karst regions, the understanding and mapping of these habitats is critical.

The caves, sinkholes, and underground streams of karst areas are threatened not only by habitat loss and degradation, but also groundwater contamination, and climate change. Yet few studies have quantitatively evaluated their potential impacts and best means of mitigation. Indeed, the state of knowledge of cave-dependent species (both troglobiotic, i.e. cave-dwelling and stygobiotic, groundwater-dwelling) is poor compared to other taxa, with clear biases toward particular taxonomic groups that specialize in caves (i.e., bats, salamanders, fishes, and crayfishes). A 2025 assessment of troglobiotic and stygobiotic taxa in the United found 1,460 species: 930 troglobionts and 530 stygobionts, dominated by arthropods and crustaceans. All groups exhibited high levels of extinction threat, while threat information was lacking for most species of nearly all major taxonomic groups (except for decapods, fishes, and salamanders). Comparatively few species have been listed under the Endangered Species Act. After Texas (at 274), Tennessee had the greatest number of cave-dependent species (215). "The under recognition of invertebrate subterranean taxa listed under the ESA is particularly striking but mirrors trends for invertebrates in general in which > 90% of IUCN-listed invertebrates are not listed in the United States under the ESA" (Niemiller et al. 2025).

Mapping urbanization in Tennessee

Tennessee's population increased by 16.7% from 1990 to 2000, and by 11.5% from 2000 to 2010 (US Census 2000 and 2010). The 2020 US Census recorded Tennessee's population at 6,910,840 (over 7 million in 2025) representing an 8.9% increase since the 2010 census (US Census 2020).

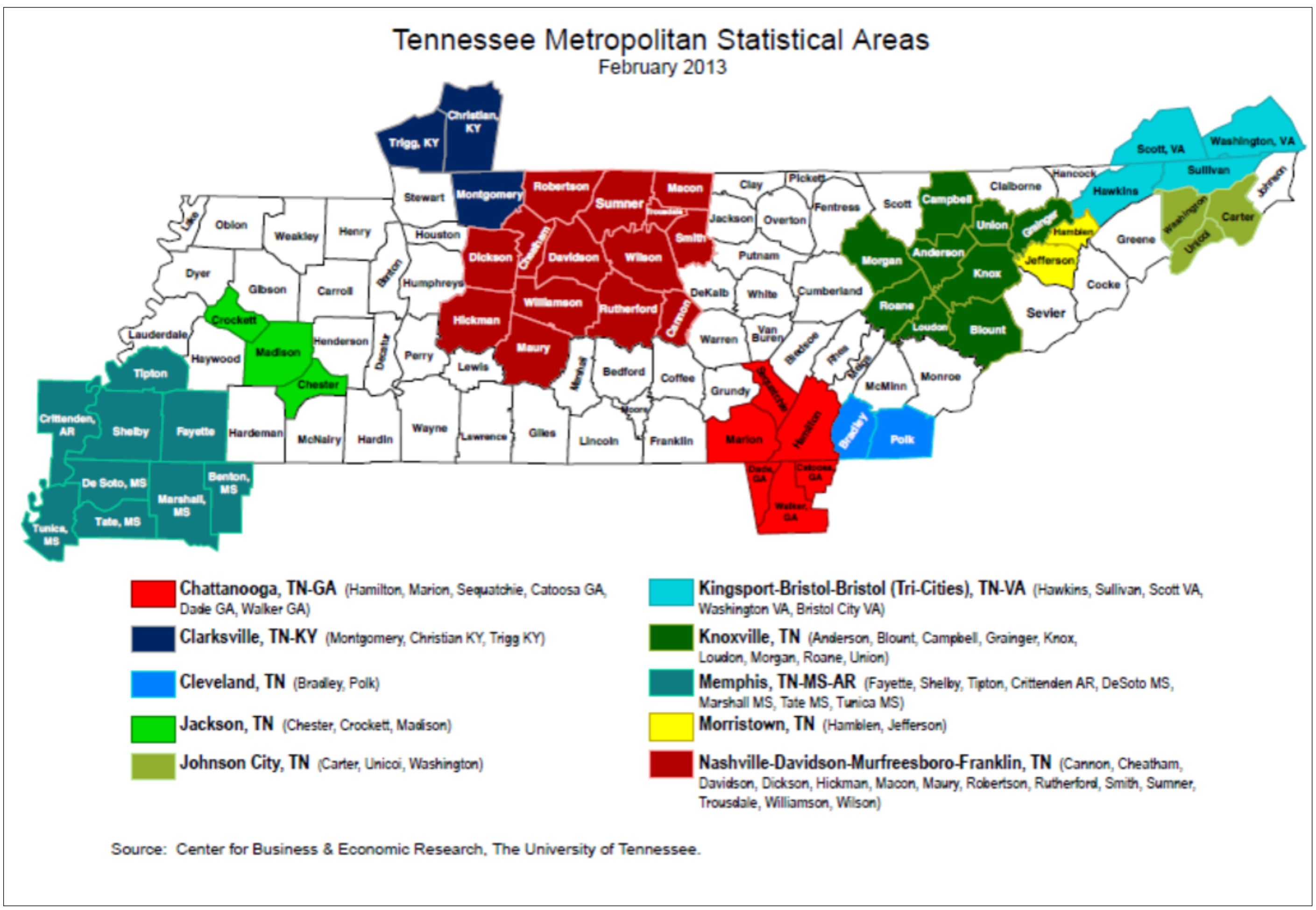


Figure 4.1 Tennessee Metropolitan Statistical Areas

The 2005 SWAP identified development-related issues as the most consistently high-ranked stressors to terrestrial, aquatic, and subterranean SGCN. In 2025, development is the second most high-ranked stressor after natural system modifications (e.g., dams and fire suppression).

Map 4.1. in **Appendix B, the 2025 TN SWAP Atlas** shows the probability of new development by 2100, using the FUTURES model. Map 4.2. shows the potential risk from future development to terrestrial habitat priorities in Tennessee—essentially assessing risk by multiplying habitat importance (priority) by the stress level (development).

The result in Map 4.1 is a colored heat map that shows locations across the state where SGCN habitats and species are predicted to be at risk without proper planning for habitat protection. These maps, and the underlying species and habitat data, can help inform decision-making so that conservation strategies can be implemented in advance. While the potential expansion footprint may not appear visually large in some places, such as far eastern Tennessee, urbanization can result in localized habitat fragmentation effects that can interrupt habitat connectivity at larger scales. Fig. 4.1 also shows the boundaries of Metropolitan Statistical Areas (MSAs) of Tennessee. The maps group the ten MSAs of Tennessee into a smaller subset of 5 combined areas. For planning collaborations with SWAP conservation partners, the data can be analyzed and presented for any specific MSA or combination of MSAs at the desired spatial scale.

4.3.2. Agriculture

Agricultural conversion and incompatible management practices pose challenges to sustaining populations of certain wildlife and plant species. Opportunities exist to improve agricultural practices in a way that will benefit a variety of SGCN. In fact, certain forms of agricultural management can be beneficial for wildlife and plant conservation or can be managed to lessen negative impacts. Many such practices are promoted through incentive programs for landowners administered by the US Department of Agriculture Natural Resources Conservation Service (NRCS) and the Tennessee Department of Agriculture (TDA). Agriculture as a conservation solution is described in both Ch. 6 and Ch. 8.

Habitat loss from conversion to agriculture / Rob Colvin, TWRA

Impacts to terrestrial habitats

Changes in land use can pose a threat to terrestrial species when important grasslands or forests are converted to cropland or pasture, contributing to overall loss or fragmentation of habitat. This is especially true when natural plant communities are replaced with introduced species of grasses, such as fescue. Loss of riparian habitat impacts avian SGCN such as Prothonotary Warblers, Swainson's Warblers, and many others.

Wetlands provide important services such as water filtration and groundwater recharge, and they provide critical habitat to many species at various points in their life cycle as well. As with so many wetland areas of the United States, these highly localized habitats have been vastly reduced due to human activity. Tennessee lost 59% of its wetlands from the 1780's to the 1980's, according to estimates by the US Fish and Wildlife Service (Dahl 1990) (see Wetland Highlight). There is historical context exacerbating the loss of wetlands in the United States. Although the American Beaver (*Castor canadensis*) is currently not a conservation concern in Tennessee, overharvest to supply the European fur trade caused these large rodents to be almost eliminated from the state by the late 19th century. Informally described as "nature's engineers" due to their ability to build highly complex wetland ecosystems by damming streams, reduced populations of Beaver resulted in corresponding loss of wetland generation, which was (and continues to be) compounded by practices of drainage and clearing "would-be" wetlands for agriculture. The rate of loss of US wetlands even increased by 50% from 2009 to 2019 (Lang et al. 2024).

Contemporary estimates of Tennessee's wetland area range from approximately 1,065,000 to 1,800,000 acres (Skytec 2025). Wetlands are ecologically and economically valuable to Tennessee, despite making up a relatively small percentage of the state. The state's 430,000 acres of isolated wetlands alone have been estimated to provide ecosystem services totaling approximately $21.5 billion (UT Institute of Agriculture 2024). Bottomland forests are the state's most common type of wetland, located primarily in west Tennessee. Major causes of modern day wetland loss or degradation in Tennessee include:

- agricultural conversions
- logging
- reservoir construction
- channelization
- sedimentation
- urbanization

(USGS 1997b).

Agricultural land uses can also impact habitat for wildlife and plants, such as through the application of pesticides or herbicides. "Since 1974 in the US, over 1.6 billion kilograms of glyphosate active ingredient have been applied, or 19% of estimated global use of glyphosate (8.6 billion kilograms). Globally, glyphosate use has risen almost 15-fold since so-called 'Roundup

Ready,' genetically engineered glyphosate-tolerant crops were introduced in 1996" (Benbrook 2016).

Milkweed and many other flowering herbs and shrubs that serve as sources of seed and nectar for birds and other pollinators have suffered collateral damage from the widespread use of herbicides. One study in 2012 showed a direct correlation between declining Monarch Butterfly (*Danaus plexippus*) numbers and increasing adoption of herbicide tolerant soybeans and corn (Pleasants & Oberhauser 2013). Also, studies by Purdue University have shown that herbicides making their way into streams have the potential to adversely affect SGCN such as Eastern Hellbenders (*Cryptobranchus alleganiensis alleganiensis*) by altering growth and development of larval stages (Solis et al. 2007).

Impacts to aquatic habitats

Incompatible agricultural management practices are the number one source of damage to streams across Tennessee (see Table 4.2). One reason for this ranking is that a relatively large proportion (41%) of Tennessee's landscape is covered by some form of agriculture. Management practices that can impair stream health include streamside vegetation removal; grazing livestock along stream banks with unrestrained access to the stream; poor farm nutrient, waste, and herbicide management; channelizing and dredging streams; creating impoundments on streams; and unsustainable surface water or groundwater withdrawals for irrigation (USGS [date unknown]).

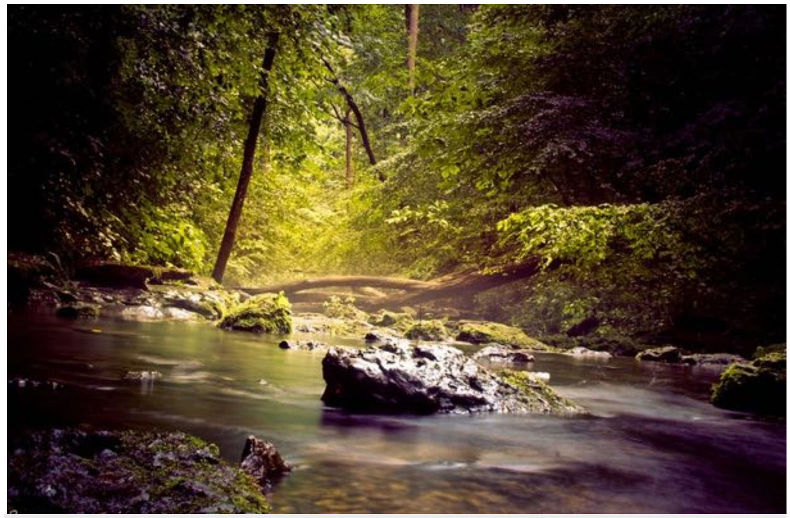

Agricultural runoff / Chris Lee, NRCS

Insufficient farm nutrient and waste management can contribute to pollution by *Escherichia coli* (*E. coli*) pathogens as well as nitrogen and phosphorus inputs to streams and rivers. Excess nutrients result in stream eutrophication, which lowers the dissolved oxygen in water available for freshwater animals, including insects, to breathe.

Excess sedimentation from farm fields and eroding stream banks may well be the greatest threat to freshwater SGCN in Tennessee. Map 4.4 shows the potential risk from agriculture to downstream aquatic habitat priorities.

According to a USGS study of 20 streams in Tennessee's Eastern Highland Rim ecoregion, nutrient concentrations, stream gradient, width, and substrate embeddedness (the degree to which fine particles surround coarse substrates) were all related to cropland density in a particular watershed. However, results suggest that fish communities respond primarily, and negatively, to the cumulative effects of sedimentation (Powell 2003). Channelization of streams and rivers to increase land available for agricultural production is a major contributor to sedimentation. This increase in sedimentation covers clean gravel used by many SGCN for spawning habitat and also leads to floodplain disconnection. It has eliminated seasonal flooding that is important to several species in west Tennessee (see White Oak Restoration Highlight).

Impacts to karst habitats


Bobo Creek, fed by springs at Short Springs State Natural Area / Brenton Rogers

Tennessee's landscape is dotted with thousands of natural springs, most of which are associated with karst composed of limestone in middle and eastern Tennessee. Enhanced interactions between surface and groundwater processes occur in karst. Caves are considered subsurface extensions of karst landscapes, with most caves forming at or just below the water table. Caves above the water table are tributaries to caves below the water table. Water percolating downward passes through caves, which serve as "natural pipes" and the water can often re-emerge at the surface as springs or seeps (Veni et al. 2001).

In rural and agricultural areas, karst aquifers are subject to contamination from numerous sources. Chemical fertilizers, pesticides, herbicides, and elevated pathogen concentrations can be flushed through soils into aquifers beneath farmland, pastures, and feedlots. In addition to the impacts of sedimentation listed previously, sediments can affect the flow of groundwater through karst and may also carry contaminants, making programs to minimize soil loss critically important for many karst areas.

Another improper practice common in rural areas is dumping of refuse, construction materials, and dead livestock into sinkholes. Common harmful products include bacteria from dead animals; used motor oil and antifreeze; and empty herbicide, solvent, and paint containers. These substances readily enter the aquifer and rapidly travel to nearby water wells and springs. "Few people would throw a dead cow into a sinkhole if they realized that the water flowing over the carcass might be coming out of their kitchen faucet a few days later." (Veni et al. 2001).

Mapping agricultural land use and priority freshwater habitats

Improving agricultural management practices in priority areas can improve outcomes for freshwater SGCN and overall water quality across Tennessee. For the 2025 update, the SWAP team used a similar but more sophisticated approach compared to 2015, in which important watersheds for freshwater species conservation were intersected with different agricultural land uses that may degrade habitat or water quality (see Map 4.4). In 2025, using the Cropland data layer, all nonpoint sources of agricultural runoff were identified, and impacts were assumed for priority stream segments downstream. However, no point sources of pollution (such as permitted outfalls) were included. The results show specific locations across the state where SGCN and their habitats may be at risk without the use of agricultural BMPs. It is important to note that these maps do not take into consideration where BMPs may already be in place; therefore, they are not representative of actual site-specific habitat conditions.

4.3.3. Forestry Issues

Lack of diversity in forest structure and age class

This is one of the most widespread issues facing Tennessee forests. Maintaining vertical structure (understory, midstory, and canopy) is critical to supporting SGCN in hardwood systems (including mixed oak-pine). Forests that include a mix of young and late-successional habitat across the landscape provide niches for a wider range of species. The lack of young and late-successional habitat has led to loss of tree species (for example, white oak, shortleaf pine, eastern hemlock, native plums and crabapples, serviceberry) and forested habitats that benefit wildlife (for example, oak, pine, hickory woodlands and savanna/grasslands). In addition, the lack of timber markets for low quality wood products makes forest management such as thinning more difficult for landowners to perform and can lead to high grading. Landscape-level coordination is encouraged.

Of the 14 million acres of forest in Tennessee, approximately nine million acres (64%) are considered fire-adapted because they contain tree, shrub, and other plant species that are adapted to frequent fire (Pers. Comm. Britt Townsend). However, much of Tennessee's public land, (as well as the surrounding region) is comprised of closed canopy forests, roughly 80-120 years old. These conditions are largely the result of industrial logging in the 1900s, followed by fire suppression policies. Forests have dramatically departed from desired ecological conditions without the proper distribution of early, mid, and late successional forest conditions.

When fire-adapted forests develop closed tree canopies, they block the majority of sunlight from reaching the ground. This suppresses the herbaceous layer. Fire intolerant trees are out-competing fire-adapted vegetation and greatly altering plant and animal communities. Unfortunately, native woodlands and grasslands have been virtually eliminated from this landscape, transformed into dense forests that lack the habitat diversity that many at-risk species require. Forest composition has also shifted, and there have been long-term declines in shortleaf pine and oak species (i.e., white oak).

Young oak-pine forests have been declining due to mesophication (a process in which fire-suppressed forests transition from being dominated by fire-adapted species like oaks to being dominated by shade-tolerant, fire-sensitive species like maple) and a lack of broadscale adoption of pre-harvest and post-harvest silvicultural treatments that establish and recruit oak-pine trees into the canopy (Pers. Comm. B. Townsend). Species like the Golden-winged Warbler that depend on early successional habitats have declined over time, and their habitat restoration has become a priority (USFSb 2015).

Conversely, there is also growing interest in restoring and maintaining late-successional forest structure throughout the southern Appalachians, with efforts focused on protecting native biodiversity and ecosystems services such as clean water and carbon storage (Pers. Comm B. Townsend).


Golden-winged Warbler / Alan Schmierer

On a landscape scale, achieving a biologically significant interspersion of young forest habitat in balance with middle-aged, open woodland, mature, and late-successional forest conditions is critical to the survival of many SGCN. Appropriate forestry practices are key (see the Woodlands and Savannas Highlight for more detail.)

Forestry practices

Forestry practices (referred to in the Conservation Standards as “Logging and Wood Harvesting”) influence the conservation of Species of Greatest Conservation Need (SGCN) in both direct and indirect ways. While certain practices can alter habitat structure or reduce native biodiversity if applied without ecological consideration, sustainable forest management offers one of the most effective tools for maintaining and restoring high-quality wildlife habitat at scale, which includes achieving the mix of young and late-successional habitat noted above. This section identifies forest conditions and land use trends relevant to SGCN, and outlines how strategic management, guided by science and supported by the 2020 Tennessee Forest Action Plan (FAP), can help address these concerns.

Chapter 6 further discusses forestry as a conservation solution in detail and provides recommendations aligned with Tennessee’s 2020–2030 FAP.

Both the SWAP and the FAP identify challenges facing Tennessee forests that decrease forest habitat extent, alter habitat structure, and contribute sediment and nutrients to streams. Specifically, challenges to the health of forests and forest wildlife habitat that have been identified in the FAP include the following.

Parcelization and fragmentation

One of the greatest challenges to long-term forest stewardship in Tennessee is the increasing parcelization and fragmentation of forestland. Parcelization refers to the subdivision of larger properties into smaller ownerships, often reducing landowner capacity to engage in active management. Fragmentation refers to the physical breaking apart of contiguous forest (or other habitat) into isolated patches, which can disrupt wildlife movement and ecological processes.

Approximately 77% of family forest ownerships with 10+ acres fall within the 10–49 acre size class, while the majority of forested acreage is concentrated in parcels over 100 acres owned by relatively few landowners (National Woodland Owner Survey). This distribution limits opportunities for landscape-scale management, reduces economies of scale for thinning or prescribed fire, and makes it less accessible for landowners to implement long-term forest management. Encouraging multiple-use management through technical assistance is essential to overcoming these challenges.

Cleared and fenced horse pasture / Joel Kramer

Impacts associated with climate change

Climate change introduces a range of stressors to forest ecosystems that directly and indirectly affect SGCN. These include shifts in species distributions, more frequent and severe drought, increased wildfire risk, and heightened activity from insects and pathogens. These changes underscore the importance of resilient forest management practices that encourage wildlife species diversity.

Non-native insect and disease pests and non-native invasive plants

Non-native pests, pathogens, and invasive plants continue to reshape Tennessee's forest composition. Emerald Ash Borer, oak decline, and other pathogens have altered canopy dynamics, while invasive understory species displace native flora and reduce food and cover for wildlife. Although only 2% of Tennessee's forest area was estimated to be at high mortality risk from pests in 2018, localized impacts can be severe. Management strategies such as targeted thinning, native species planting, mechanical and chemical control, and prescribed fire can help maintain ecological function and limit the spread of invasives.

Wildfire

While many ecosystems need fire to thrive, wildfires outside historic fire return intervals may be ecologically harmful. If burned too often, ecosystems may not have adequate time to recover. Wildfires can also impact water quality and water supply. After fires, soils may be less able to absorb water, and heavy storms can be especially dangerous then (Wibbenmeyer and McDarris 2021).

All of these threats to forest health, connectivity, and integrity likewise threaten SGCN habitats and populations.

Inappropriate timber harvest practices

Vertical structure in forests (i.e., understory, mid-story, and canopy) is important, as hardwood forests with this structure support a far greater diversity of wildlife than those without (LMVJV

2025). Maintaining the structure and diversity of late successional and young forest habitats and their connectivity across the landscape is critical to conservation of many SGCN plants and animals. Without proper planning with respect to landscape-level habitat requirements for multiple species, including those dependent on different types of habitats, management practices that lessen diversity in forest structure can be detrimental.

Inappropriate timber harvest practices or an absence of management can contribute to degraded forest structure in several ways, many of which interact with one another on the landscape:

1. ***Lack of forest management planning:*** Planning is a significant issue that affects landholdings of all parcel sizes and ownership arrangements (i.e., public lands, as well as land held by individuals and families, corporations, and other private organizations and associations). Example impacts of reduced or absent forest planning include fire suppression that may rob a forest of an important natural disturbance process and/or unchecked spread of invasive species, causing a reduction in biodiversity.

Tennessee Healthy Hardwoods field days educate forest landowners about good forestry practices / Adam Taylor

2. ***The practice of high grading* ("regeneration harvests"):** The selective removal of only high-value timber without regard to stand structure ("take the best and leave the rest") reduces species diversity and degrades long-term stand quality. This practice persists partly due to limited market options, especially in East Tennessee where pulp and low-grade wood markets have declined. Market diversification efforts, especially for pine in West Tennessee, are helping address this gap

3. ***Clear cutting and even-aged management:*** Clearcutting is a harvesting method where all or nearly all trees in a designated area are cut down. In areas with high SGCN concentrations, where regeneration goals are not clearly defined, or Best Management Practices are not followed, indiscriminate clearcutting can reduce habitat quality.

A dense pine plantation in central Tennessee / Lindsay Shaw, TWRA

5. ***Pine management:*** A pine monoculture is by definition far less diverse than a native pine or mixed pine-oak forest. Some pine plantation management may suppress the development of the understory (using chemical or mechanical means)

which contains much of the plant diversity and habitat value of an open pine ecosystem. However, contemporary pine sawtimber stands in Tennessee (especially those managed on longer rotations and thinned periodically) can support high levels of herbaceous diversity and wildlife use, particularly when managed to mimic open pine woodland conditions. While older models of dense, short-rotation monocultures were less ecologically valuable, today's pine management practices in Tennessee are increasingly integrated with habitat considerations.

6. ***Exotic tree plantations:*** The use of non-native species for afforestation or carbon offset projects can displace native vegetation and reduce habitat value. Many carbon programs in Tennessee do not allow the establishment of exotic monocultures, and best practice emphasizes planting native species adapted to the site.

To support forest and water resource sustainability, Tennessee has adopted voluntary Best Management Practices (BMPs) for forestry operations. These guidelines (to be used in road building, skidding, and harvest planning) protect soil, water quality, and habitat features. Average compliance with forestry BMPs is 89% and is monitored by the Tennessee Division of Forestry (TDF). TDEC is responsible for regulating the Water Quality Control Act (Clatterbuck et al. 2017).

Improper execution or disregard for BMPs, can, however, lead to the following:

- Soil compaction and erosion
- Impaired water quality from erosion, altered drainage patterns, and concentrated flows
- Loss of a healthy understory and wildfire-resistant forest ecosystem
- Conditions that promote the establishment and spread of invasive species or insect pests
- Lack of prescribed fire and impacts to other natural processes

(USFS 2015c).

4.3.4. Energy Production and Mining

Non-renewable energy development

Resource extraction for non-renewable energy sources includes mining for coal as well as drilling for oil and natural gas. Tennessee's coal production is relatively small (232,000 short tons), and in 2018 accounted for 1.4 percent of the state's total mineral production value. Tennessee's oil and gas production is also small by national standards (211,000 barrels in 2018) and gas production in 2018 (3.6 billion cubic feet) represented about 88% of the value of oil production. Nevertheless, these activities can involve significant impacts to natural habitats. Without proper advance planning, management, and mitigation, they can cause long-term and even irreversible damage. (See Maps 4.5 and 4.6).

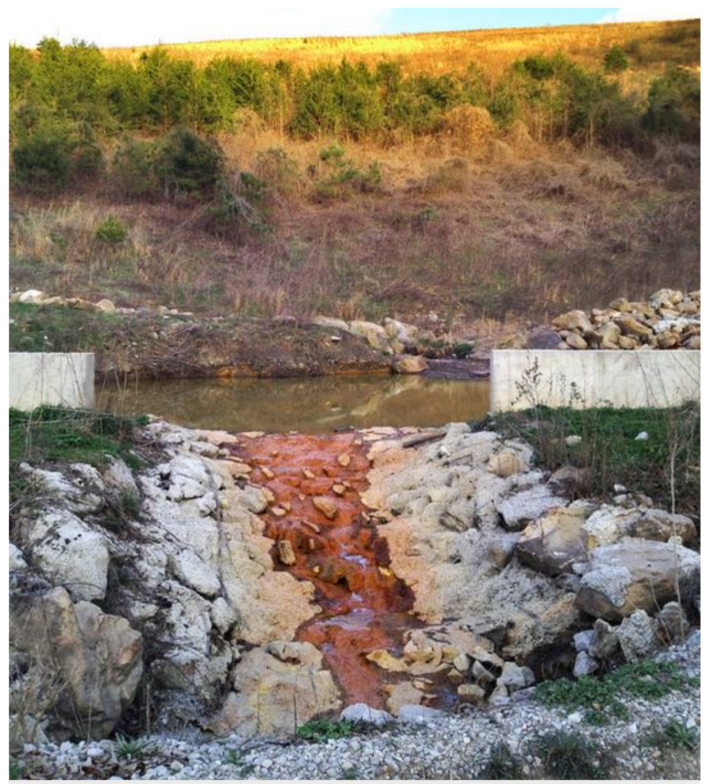
Coal mining

Coal mining activities, from site preparation to post-mining impacts, can introduce a spectrum of problems for SGCN and their habitats. For example, the Yellow-spotted Woodland Salamander (*Plethodon pauleyi*) is found in shale and sandstone rock faces in West Virginia, Virginia, Kentucky and Tennessee, the same sites sometimes targeted for mountaintop removal mining. This species was petitioned for listing under the Endangered Species Act in 2022 (Center for Biological Diversity 2024).

A 2002 Clinch and Powell Valley Watershed Ecological Risk Assessment conducted by the EPA analyzed associations between land use and in-stream habitat and their effects on fish and mussels. Their findings show that coal mining activities can cause “unacceptable losses of valuable and rare native fish and mussels” (EPA 2002).

Forest loss can fragment habitat and severely affect interior forest-dwelling birds and other species. A current threat facing the region is that of mountaintop removal coal mining, which, even with reclamation, leaves landforms permanently altered (SELC 2015, USDOI 2025).

All of Tennessee's current coal production is bituminous coal from the Cumberland Plateau and Cumberland Mountains regions. These regions have experienced decades of long-term environmental impacts from coal mining, including problems associated with contour mining, deep mining, cross-ridge mining (i.e., mountaintop removal), and re-mining of areas. Such activities destroy terrestrial habitats and permanently disrupt and degrade the hydrologic and ecological function of surrounding forests, spring seeps, streams, and riparian zones. These activities also disrupt and degrade the ecological function and connectivity of ridgeline habitat corridors.


Reconstructed stream below strip mine in TN /Appalachian Voices

Coal mining conducted prior to the passage of the 1977 Surface Mining Control and Reclamation Act (SMCRA), which required post-mining site repair activities to take place, left clear cuts, polluted rivers, and unstable slopes in its wake. Issues from older abandoned mines that were either never reclaimed or improperly reclaimed have degraded both water quality and aquatic wildlife diversity (EPA 2014c).

For example, in the Big South Fork National River and Recreation Area, numerous abandoned coal mine sites are found throughout the park. These sites have become sources of contaminated water affecting the river and its tributaries (NPS 2014).

TDEC’s Abandoned Mine Land Program reclaims open or improperly filled coal mine shafts, dilapidated mine buildings and equipment, toxic mine refuse and drainage, landslides, mine fires, highwalls and subsidence. Since its inception in 1981, the program has reclaimed over 5,000 acres of abandoned mine lands at a cost of $60 million, the majority of which came from federal and state sources (TDEC AML Program [date unknown]).

An additional land management challenge in Tennessee comes from the “split estate” ownership status separating subsurface mineral rights from surface rights. Even in many cases where the state or federal government protects and manages the land surface, the mineral rights may be privately owned. According to the US Bureau of Land Management, in these situations, “the mineral owner must show due regard for the interests of the surface estate owner and occupy only those portions of the surface that are reasonably necessary to develop the mineral estate.” (BLM [date unknown]). In addition, many coal mining operations are currently undergoing bankruptcy and forfeiting the mineral owner's or lessee's reclamation performance bonds. This results in mines that are not properly reclaimed (i.e., they are abandoned), with negative impacts left in place that affect the surface owners.

Maps 4.5 and 4.6 demonstrate where currently permitted coal mining activity intersects with priority SGCN habitats in Tennessee. Collaborative planning and management at site and regional scales may help reduce the potential for negative impacts.

Oil and gas

Both public and private lands in the Northern Cumberland Mountains and Cumberland Plateau have experienced historic impacts from oil wells and are now facing new challenges from natural gas developments. Big South Fork National River and Recreation Area and Obed Wild and Scenic River have over 300 private oil and gas operations. “Many of the past and existing oil and gas operations in these NPS units are adversely impacting resources and values, human health and safety, and visitor use and experience; most are not in compliance with federal and state regulations.” (NPS 2012, NPS 2021).

Charit Creek, Big South Fork National River and Recreation Area / Gregg Elliott, K Gregg Consulting

In 1994, 82 percent of Tennessee’s total oil production, and 60 percent of its total gas production, came from counties within the watershed of the Big South Fork River. By 2006, 50% of Tennessee’s total oil production and 99% of its gas production came from these same watershed counties (NPS 2012).

The National Park System’s Oil and Gas Management Plan for these areas states that many of these operations are not in compliance with federal and state regulations. The plan is a strategy to help park managers ensure their park units are protected from current as well as potential future threats from new development. The plan provides park-specific guidance for oil and gas owners and operators who wish to establish new oil and gas extraction sites (NPS 2012, NPS 2021).

Different processes for extracting natural gas have raised concerns about potential negative impacts to both surface streams and groundwater affecting both freshwater species and overall water quality (Entrekin et al. 2011). In addition to the drilling process itself, the infrastructure development associated with production—particularly new well pads, pipelines, and roads—poses a major challenge to long term forest habitat integrity, both locally and across broader landscapes where production is increasing (Drohan et al. 2012, Fisher 2012). Tennessee has yet to experience the landscape-scale level of development similar to other states such as Pennsylvania; however, Tennessee does retain natural gas resources that are currently being developed and may be developed more in the future. Maps 4.5 and 4.6 demonstrate where permitted oil and natural gas activity intersects with priority SGCN habitats. As with potential coal mining impacts, use of these data in a collaborative planning framework may help reduce negative outcomes for species.

Renewable energy development

The development of renewable energy resources is a stated goal for many governments across the US as a means of decreasing emissions of greenhouse gases that cause climate change. Renewable sources such as wind, solar, and biofuels/biomass, are currently being developed at smaller scales across Tennessee. Hydropower, also considered a renewable source, has been a significant provider of peak electrical power for many decades.

Solar arrays developed on the site of former coal mines in the Appalachians / The Nature Conservancy

To meet the power demands of a developing Tennessee landscape, the Tennessee Valley Authority's (TVA, whose service area includes the entirety of the state) draft 2025 Integrated Resource Plan recommendations include significant renewables expansion and a decreased reliance on coal-generated power through 2035 (TVA 2025). Each type of renewable source has its own potential conflicts with species and habitat conservation needs. Maps 4.5 and 4.6 depict areas of risk to combined conservation priorities from renewable solar and wind development, respectively, with areas most suitable for development and least harmful to SGCN habitats in blue. However, since these technologies are new, there is more opportunity and potential to address conflicts through responsible siting, construction, and management of renewable energy infrastructure (see Ch. 6). In addition, the extent to which these new technologies will expand across the state is unclear.

Well-designed approaches for overall land uses need to consider the potential of the land for all human needs as well as for biodiversity protection, placing each use in its most suitable location. Primary considerations for all renewable energy development types include eliminating or reducing direct species impacts, habitat losses, and fragmentation of habitat across the landscape.

TVA is the nation's largest public power provider, and its service area includes the entirety of Tennessee. Its long-term Integrated Resource Plan, updated every five years, provides direction on how TVA can best meet future demand for power. The draft 2025 plan, the most current at the time of the 2025 SWAP's development, noted that land requirements for new power resources increase for all potential strategies, primarily driven by solar expansion.

Bioenergy

Biofuels (liquid fuels) and biomass (solid fuels) are both forms of renewable energy derived from biological materials, such as plants, vegetable oils, forest products, or waste materials. A 2010 analysis of the implications of biofuels for land use and biodiversity points out that perennial bioenergy crops could be considered an appropriate component of conservation farming systems when their use is integrated with land use planning along with rotations that improve soil quality, reduce erosion, and minimize runoff of agricultural inputs (Dale et al. 2010). Several species of perennial warm season grasses, such as switchgrass (native to the North American prairie from Mexico to Canada) provide excellent wildlife habitat.


Switchgrass, grown as a biofuel / Laura Hubers, USFWS

Continued crop breeding innovations will almost certainly expand the range of growing conditions for bioenergy feedstocks, making even more areas that are important habitats for wildlife suitable for agriculture. Also, while native warm season grasses do provide excellent habitat, the design of production fields for biofuels may not be structured to provide the spacing and pattern of habitat needed on the ground. Thus, the risk of conversion to cropland in such areas merits special attention, protection, and planning (Dale et al. 2010).

Within the last decade, more research and development projects have been directed toward understanding the potential of forest biomass to supply alternative energy sources. The US Forest Service anticipates that woody biomass can help replace up to 30 percent of petroleum consumption by the year 2030 (USFS 2010). Harvesting of forest products is also seen as a positive mechanism for improving overall forest health while providing woody biomass for fuels (USDA

2014). Proper planning and utilization of these management practices in forests will be important for conserving terrestrial and freshwater habitats at both local and landscape scales.

Wind

TVA's existing wind contracts expire in the early 2030s. Beginning in 2029, TVA will have the alternative to purchase wind power from three regional sources (Mid-continent Independent System Operator (MISO), Southeast High-Hub wind, and High Voltage Direct Current wind.) Wind additions have the potential to add more diversity and carbon-free energy to TVA's energy resource mix (TVA 2025).

Buffalo Mountain wind farm / Tennessee Valley Infrastructure Group

TVA currently purchases all of the power produced by the Buffalo Mountain wind farm in Anderson County, Tennessee, one of the largest wind farms in the Southeast, with 15 turbines and 27 MW of maximum sustained capacity (TVA 2019). TVA's potential plans for added wind power through 2038, will likely contribute to direct mortality of birds and bats as well as habitat alteration due to construction/conversion. Improperly sited or operated wind turbines can directly affect native plant populations and wildlife, particularly during aerial migration at distinct geographic locations (Fiedler 2004, Nicholson et al. 2005). Negative effects can include direct mortality of animals, habitat loss, and habitat fragmentation. Birds and bats can be attracted to wind turbines by different lighting or operational features, and management attention to such features is warranted (Nicholson et al. 2005). If wind facilities expand significantly, consideration should be given to the cumulative impacts on population sizes and species ranges (Fiedler 2004).

Mussels from the Hatchie River, an undammed river in west Tennessee with high aquatic diversity / Naomi Van Ton

Hydropower

Dam construction and operations, including hydropower and other water management practices, have already significantly degraded natural river habitats in Tennessee (see Section 4.4.3). Alteration of existing dam structures to produce hydropower or the construction of new hydropower facilities must be considered in the context of these historic resource losses and with an eye to preventing further species and habitat declines (Grimm 2002).

TVA monitors the flow of 49 dams in the Tennessee River watershed, 29 of which include conventional hydro generating units at 29 dams (National Hydropower Association 2020), along with a long-term power purchase agreement with the US Army Corps of Engineers for eight dams on the Cumberland River system. TVA has a perpetual program to invest in and maintain its hydroelectric fleet, which includes two to three modernization projects per year.

Since TVA does not anticipate the construction of additional hydro facilities, and the degradation of aquatic resources as a result of existing projects has already occurred, it is incumbent upon TVA and society to conserve aquatic species and/or reduce past and current deleterious impacts. Changes to benefit aquatic species could include water alteration (i.e., changes made to the natural flow, quantity, or characteristics of water bodies) or improvement of release/control operations at hydroelectric facilities, as well as other beneficial technologies that could be installed as part of the modernization program. All such improvements should be considered at every opportunity and coordinated with partners.

Solar

TVA's Draft 2025 Integrated Resource Plan notes that since 2019, TVA has gained experience with increasing amounts of new solar generation and is installing its first owned and operated grid-scale battery storage on the system. Four out of five of TVA's future strategies for energy supply include solar; some strategies emphasize proven carbon-free technologies like wind, solar, and storage, at both utility-scale and through customer partnerships, while others emphasize distributed energy. The plan estimates that by 2035, 3 to 20 gigawatts of energy could be supplied by solar and that land requirements for new power resources are primarily driven by solar expansion. In short, the land area occupied by solar facilities could greatly increase.

TVA's Plan includes a strategy of supporting distributed energy resources, with options that include distributed solar and storage. TVA has provided local power company partners the flexibility to generate up to 5% of their own energy to meet consumer demand for new renewables and address other local needs (TVA 2025) .

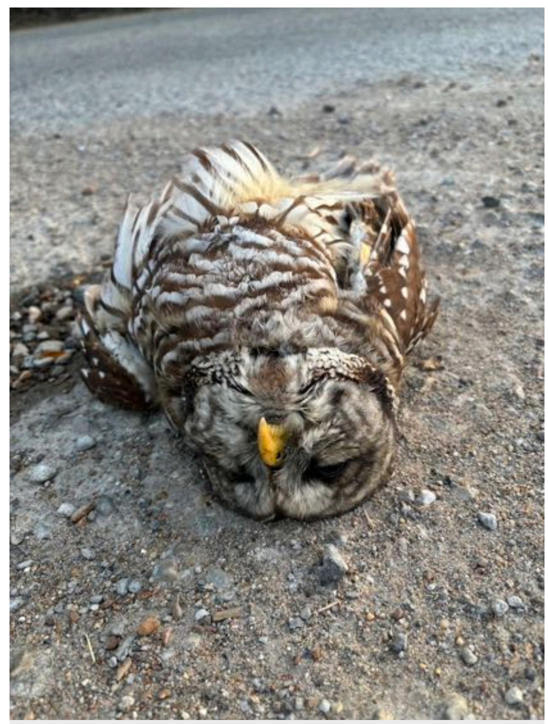

Rooftop solar / Vivint


Solar array on top of a former landfill / Wikimedia

What distinguishes distributed generation from utility-scale solar is both project size and the fact that distributed generation generally sells electricity directly to end-use consumers, not to wholesale utility buyers (SEIA 2024). Another distinction is that utility scale solar projects generally have higher environmental and social impacts due to using large land areas, which can include impacts to natural habitat, biodiversity, and water as well as increased waste, visual, or noise pollution. Distributed solar photovoltaic (PV) systems, on the other hand, generally have lower impacts because they are sited on existing structures, and they have minimal water and waste processing requirements. Distributed alternatives for solar generation that do not require land valuable as habitat include rooftop solar, solar canopies mounted over parking lots, solar thermal collectors mounted on buildings, and solar farms sited over brownfields where soil cannot be disturbed. Distributed solar may provide a win-win for the environment and people, as rooftop solar is also the most popular clean energy product among consumers (SEIA 2024). Also, distributed energy capacity enhances local resiliency (TVA 2025).

4.3.5. Transportation and Service Corridors

Roads and other forms of transport, whether for people, utilities, energy, or goods, can directly impact habitats by damaging sensitive ecosystems, fragmenting habitat, and creating barriers to movement of both species and the natural flow of water in wetlands and riverine habitats. Transportation routes are responsible for linear branch development, and the construction of highways and roads can cause rapid outgrowth from urban cores. For these reasons they are commonly considered in forecasting urban sprawl (Bhatta 2010).



Barred Owl hit by a car. Owls are regular victims of collisions with cars and trucks. / Gregg Elliott, K Gregg Consulting

Current transportation and service corridors in Tennessee include:

Highway System

- bridges: 20,034, including 8,443 state owned bridges, 11,591 locally owned bridges
- interstate miles: 1,201
- state maintained highway miles: 14,462
- total highway miles: 96,187

Rail System

- short line railroads on 817 miles of mainline rail
- class I rail lines on 2,138 route miles of rail

Transit System

28 transit systems serving all 95 counties:

- 4 large urban systems, eight small urban systems,
- 10 rural systems,
- 1 regional commuter transit system in Middle Tennessee, and
- local transit in five towns

Waterways

976 main channel miles of commercially navigable waterways and two ferries

Bicycle/Pedestrian System

- 4,557 highway miles with 4-foot or greater shoulders to accommodate bicycles
- 216 miles of state routes with designated bike lanes
- 487 miles of greenways, sidewalks and trails
- 172 miles of designated US Bicycle Routes
- 934 miles of sidewalks on state routes

(TDOT [date unknown])

Improperly designed road crossings such as bridges and culverts can fragment stream habitats, cause erosion, prevent the migration of species throughout a watershed, and impact local abundance and species richness of fishes in a stream. For example, one study in West Virginia found that in stream sections located above impassable culverts, fewer than half the number of species and less than half the total fish abundance occurred when compared with sections upstream of passable culverts (Nislow et al. 2011).

Sturgeon, an SGCN whose river bottom habitats can be impacted by dredging. / Brandon Simcox, TWRA

Dredging

In river environments, dredging for navigational channel maintenance is a key issue, particularly on the Mississippi, Tennessee, and Cumberland River mainstems—a necessity that will only become more frequent as climate-related droughts increase in frequency. Additionally, both the TDEC and USACE permit removal of dredged bed material from rivers and streams for commercial and agricultural purposes. Such material is often used in the construction of roads and other public and private infrastructure projects, and removal of such material may be necessary for various industrial and commercial operations on major waterways.

Dredging, whether to maintain riverine navigation channels (such as the Mississippi River, which has required dredging in response to droughts in recent years) or for mining gravel, destroys or degrades river bottom habitats, bottom-dwelling species such as sturgeon, and benthic organisms such as crustaceans and mollusks that live in or on the bottom sediments. Dredging also stirs up sediment, affecting downstream habitats. For these reasons, coordination with both the US Fish and Wildlife Service and TWRA are often required to avoid or mitigate impacts to rare aquatic species where dredging is permitted. Additional monitoring and the relocation of species from project sites may be necessary to protect them.

Even where dredging does not directly impact individual organisms, impacts are also realized through habitat loss, where many big river species require gravel substrates, often targeted by dredging operations. Removal of such material reduces the reproductive potential of these populations.

4.4. Biological Resource Use & Natural System Modifications

4.4.1. Fire Suppression

Many of Tennessee's upland systems, as well as some types of wetlands, have been shaped and maintained by periodic fire—a process that was historically maintained to a large degree by Native Americans and lightning strikes. Decades of fire suppression have not only degraded these systems, but have also allowed fuel loads to increase, which leads to more intense wildfires. The lack of controlled fire (i.e., prescribed fire, see 4.4.2.) on the landscape has changed the human perception of fire and its role in the ecosystem (EGCPJV 2014).

The Wildland-Urban Interface in Gatlinburg / Beaman Photography

Fire suppression, the lack of fuel load reduction, and the growing wildland-urban interface (WUI) all contribute to catastrophic wildfires. Since the 2015 SWAP was written, the state experienced its most extreme wildfire in eastern Tennessee—vast in scale and devastating to both communities and landscapes.

Moreover, the risk of wildfire is increasing annually with population expansion and rural development. Landowners residing in forested settings, as well as the public at large, are often not well-informed about the dangers of wildfire, its impact on the environment, the cost of suppression, and how to mitigate it, including through the judicious application of prescribed fire.

The wildland/urban interface or WUI (pronounced woo-ee) is expanding across the state as development proceeds in Nashville, Knoxville, Memphis, and Chattanooga. This expansion of the WUI has affected fire suppression as well as other land management techniques.

The WUI risk index rates the potential impact of a wildfire on people and their property. Significant areas of at least moderate WUI risk classifications exist across Tennessee, with dense pockets of high WUI risk evident in eastern Tennessee's mountainous terrain (TDF 2020).

Additionally, the disturbance cycle of quickly developing rural areas often leads to the rapid spread of invasive species (e.g., kudzu). Increases in housing correlate with increases in invasive exotic plants (Gavier-Pizarro et al. 2010). These plants not only degrade habitat but can also make suppression during wildfire more difficult, as they may burn even when green.

4.4.2 Removing/Reducing Human Maintenance

Fire, particularly prescribed fire that does not burn too hot and out of control, consumes vegetative debris, provides open structure at ground level, and facilitates travel and foraging for wildlife. Many species depend on the plant communities that develop following a fire, particularly birds dependent upon grasslands and woodlands (EGCPJV 2014).

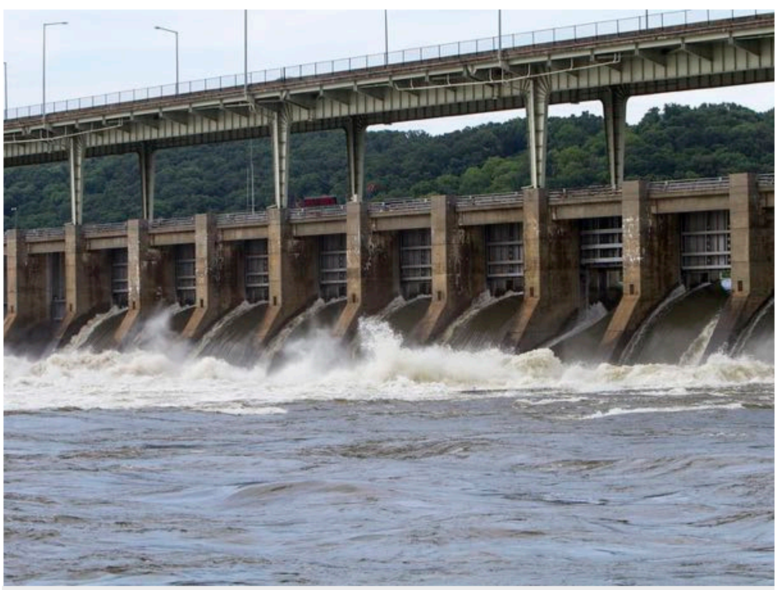
Prescribed fire at Arnold Air Force Base / Arnold Air Force Base

Prescribed fire (the controlled application of fire in selected habitat areas) is a management practice that can directly address the problem of altered fire regimes and fire suppression. By using controlled fire, fuel loads found within different habitats can be safely reduced and aid in the reduction of wildfires. Prescribed fire not only reduces the risk of wildfire, but it also costs far less. In addition, restoration of oak and pine savannas and woodlands, native grasslands, and high-quality early successional habitat require fire, although the application, timing, and intensity of fire required differs depending on the natural system (Harper and Birckhead 2012).

However, prescribed fire is not widely and publicly recognized, embraced, or supported as a beneficial practice (EGCPJV 2014, TNPFC 2015). Long-term suppression of fire over more than one hundred years contributes to the high intensity wildfires that the US is experiencing now. People in Tennessee and many parts of the South have, for the most part, lost touch with their 19th century traditions of burning for agriculture and land renewal. They may be averse to fire in general and prescribed fire in particular due to a lack of understanding of this complex topic and the science demonstrating prescribed fire's benefits.

A hopeful example of the use of prescribed fire occurs at Arnold Air Force Base in the Barrens region of Tennessee's Eastern Highland Rim. There, prescribed fire has been incorporated into the management regime to benefit natural communities while also accomplishing a highly complex military mission. The prescribed fires are used to restore barrens habitat—Tennessee's prairie ecosystems—and to manage fuel loads in the Tennessee Army National Guard's weapons firing area as a means of preventing wildfire that interrupts training (DOD 2006).

4.4.3. Dams and Water Management/Use



Chickamauga Dam, located on the Tennessee River east of downtown Chattanooga / Tennessee Valley Authority

Tennessee's rivers and streams provide habitat that supports some of the highest levels of aquatic diversity (Smith et al. 2002, Master et al. 1998) within the Southeast, which itself ranks as a worldwide center of temperate freshwater biodiversity (Bo Baxter, Pers. Comm. March 15, 2024). Additionally, the Middle Tennessee River system, followed by the Alabama River, the Upper Tennessee, and Cumberland River systems support the highest aquatic species endemism (including fishes, mussels, and crayfish) within the Southeast (Elkins et al. 2019).

Yet, for the last century, government agencies and private businesses have developed the state's water resources to provide flood control, river navigation, electricity, drinking water, agricultural improvements, and recreation benefits. While transforming state and local economic opportunities, the construction of dams and other water infrastructure has also caused significant damage to aquatic habitats and even extirpation of species from some watersheds, fundamentally changing Tennessee's rivers and tributaries from their original interconnected, free-flowing conditions. Indeed, dams and water management are listed among the stressors in more than half (nineteen) of the 36 Conservation Opportunity Areas (Appendix I). As of 2025, the total number of dams inventoried in Tennessee stands at 8,772, including 38 that have either been removed or mitigated, resulting in a gain of 1,652 miles of reconnected rivers and streams. Nationally, there are 558,203 dams inventoried, and 3,182 have been removed gaining 207,441 miles of reconnected rivers and streams (Southeast Aquatic Resources Partnership 2025).

The flow regime of a stream or river system, along with the influence of interconnected tributaries, plays a pivotal role in shaping the structure and functionality of aquatic and riparian ecosystems. However, measuring how stream flow characteristics impact aquatic systems is highly complex. A study of the Tennessee River Basin across three ecoregions, which related the species richness of 11 fish groups to hydrologic conditions, showed that cumulative departure from hydrologic reference conditions led to a decrease in species richness (Knight et al. 2014).

Tangerine Darter, a native fish species threatened by impoundments that fragment its habitat (Nolichucky River). / Sally Petre, TWRA

Dam construction can modify flow dynamics by transforming river systems into a sequence of expansive pool reservoirs. Flow alteration, as a result of dams both large and small, has significant impacts on aquatic species, fragmenting the river network, impeding the movement of resident and diadromous fish species, and eliminating or altering in-stream habitat. By preventing many species of fish and invertebrates from accessing river reaches upstream and downstream of the structures, dams essentially disconnect populations from large sections of their habitat. In addition, dams pose threats to native aquatic systems—and larger dams tend to pose larger threats--by changing several key characteristics of the streams that occur downstream of reservoirs: natural flow patterns, dissolved oxygen, temperature, nutrient loads, and water chemistry (Brown et al. 2024).

Water withdrawals are also a concern if the timing or amount of withdrawal is sufficient to alter basic flow patterns and affect ecological responses, posing a threat to aquatic wildlife and plants. Both channelization and upstream impoundments, which can affect flow patterns, are listed among the top ten sources of impairment to Tennessee river and stream health (TDEC 2012/EPA 2015) (see Table 4.3). In addition to reducing habitat for aquatic species, flow alteration can also affect water quality, water temperature, and water availability (USGS 2013).

Groundwater is water held underground in the soil or in pores and crevices in rock. Karst aquifers are a vital groundwater resource; however, features such as rapid recharge and flow make them highly vulnerable to land-surface contamination (Musgrove et al. 2023). Groundwater withdrawals for both drinking water and agriculture are increasing, which can impact both stream flows and karst habitats. More than 2000 new wells were drilled in the state each year from 2007 to 2021 (TDEC 2022). Groundwater depletion is increasing in many areas of the US, primarily caused by sustained groundwater pumping. Some of the negative effects of groundwater depletion:

- lowered water table (wells go dry)
- reduction of water in streams and lakes
- deterioration of water quality
- increased pumping costs
- land subsidence

(USGS 2018).

The construction of dams and other water infrastructure has caused extirpation of species from some places, fundamentally changing Tennessee's rivers and tributaries from their original interconnected, free-flowing conditions.

Resource management challenges of large dams and reservoirs

Rivers below dams are commonly referred to as tailwaters or tailraces. Many hydropower and flood control dams, operated by the Tennessee Valley Authority (TVA) in the Tennessee River system and the US Army Corps of Engineers (USACE) in the Cumberland River system, release cold water into the tailwaters. Cold water releases can degrade or reduce habitat for native fishes and mussels.

Likewise, some tailwaters are low in dissolved oxygen, especially by the end of the summer, because decaying organic matter in reservoirs uses up oxygen at the bottom of the reservoir, and the heavier, colder water does not mix with the surface. It is also these waters that are discharged from the dam. These are issues that TVA, USACE, TWRA, and the US Fish and Wildlife Service (USFWS) have worked to address in recent decades, by creating flow regimes and improving downstream water quality to benefit at-risk and endangered species in key river reaches.

Since 1991, TVA has spent more than $135 million constructing capital projects to address the problem of low dissolved oxygen, installing a variety of equipment and technologies designed to increase dissolved oxygen concentrations below 16 dams. TVA also monitors key aspects of ecological health in the tailwater sections to achieve biological and recreation objectives (TVA [date unknown] Tailwater Improvements).

In recognition of the importance of stream flows, TVA also changed their policy for operating the Tennessee River and reservoir system in May 2004. The policy now focuses on managing the flow of water through the system rather than storage. It specifies flow requirements for individual reservoirs, to prevent riverbeds below dams from drying out, and for the system as a whole. (TVA [date unknown] Tailwater Improvements). Their operations now maintain wetted habitat in 180 miles of river that previously were intermittently dry (Yarbrough 2013).

Similarly, the USACE has conducted watershed assessments in key watersheds where they operate. These are collaborative processes with state, federal, tribal, interstate, local government, and stakeholder organizations that produce watershed plans to balance needs for water supply, public safety (flood control), wildlife habitat, and aquatic diversity (USACE 2015).

In some cases, agencies recognize that cold tailwaters are inevitable and present an opportunity to provide a sport fishery. Because cold water released into the tailwaters below dams creates a new type of habitat, TWRA stocks trout to diversify the state's angling opportunities. TVA's monitoring program on the Elk River allows the agency to adjust the operation of Tims Ford Dam to protect the variety of life in the river, including a cold-water trout fishery, endangered species, and sport fish that require warm water (TVA [date unknown] Running hot and cold).

Resource management challenges of small dams and stream barriers

Even small impoundments, which are constructed on smaller or headwater streams for various reasons, have the potential to adversely affect aquatic life. Such impoundments eliminate flowing stream habitat in the flooded pool zone, making habitat unsuitable for native stream species. These dams also may alter the physical, chemical, and biological components of downstream reaches. They create barriers that can result in isolated populations, and with no provision for minimum flows, they may result in insufficient flow downstream, particularly during summer months (Arnwine et al. 2006). In addition, improperly placed culverts can also pose barriers to aquatic life (see Ch. 8 for examples of culvert projects to benefit species).

All of these factors combined are a recipe for reduced biotic integrity, altered flows, and negative impacts on water quality downstream of the impoundment. Results from one study indicate that small impoundments affect the biological community for at least one-quarter mile downstream (Arnwine et al. 2006).

As recognition of these impacts has grown, momentum has increased among a variety of constituents across the country to remove dams, particularly those that no longer serve their original purpose or that pose significant threats to public safety. The Tennessee Aquatic Connectivity Team represents partners interested in advancing dam removal as a restoration strategy in Tennessee (SARP 2024).

Negative impacts of stream and river channelization

Channelization of rivers and the use of levees and dikes to prevent flooding in former natural floodplains are two major contributing factors to the imperilment of many fish SGCN, particularly within the Mississippi River and its tributaries in western Tennessee. Straightening streams means removing the meanders that produce habitat structure in the form of pools and riffles, which are essential to a diversity of fish and other aquatic life. Channelization can also lead to greater erosion, sedimentation (TWRA and USFWS 2002), and bank instability (Robbins and Simon 1983) (see the White Oak Restoration Highlight).

Disconnecting streams from their floodplains through channelization, levees, or dike construction can cause the following problems:

- loss of sediment
- deposition outside of the streambed
- downcutting, headward erosion
- downstream aggradation
- accelerated scour
- bank instabilities
- decrease in groundwater recharge
- elimination of spawning and nursery habitat for fish and amphibians.

(TWRA and USFWS 2002, Robbins and Simon 1983).


Channelized stream tributary to the Middle Fork of the Forked Deer in West Tennessee / West Tennessee River Basin Authority

4.4.4. Recreation

Tennessee's landscapes provide a wonderful array of recreational activities that contribute to the quality of life of both citizens and visitors, and which support the state and local economies. Though considered less impactful than resource extraction, recreation can cause negative impacts to the natural environment (Larson et al. 2019). Proper management of recreational activities in many situations can be critical to promoting the protection of habitat and species, which are themselves one of the prime draws for visitors. When not properly managed, recreational use of managed lands can be detrimental to wildlife from overuse, defoliation of plants, erosion, pollution (including light and noise), spread of exotics and pathogens, and numerous other factors. For wildlife species dependent on those same areas, coexisting with humans is a major undertaking.


Black bear sow and cubs crossing the road at Cades Cove in Great Smoky Mountains National Park / from "Adventure is Out There"

Several studies have shown that animals will shift their patterns to avoid human interactions (George and Crooks 2006, Barrueto et al. 2014, Reilly et al. 2017, Gaynor et al. 2018). In fact, humans induce stronger fear reactions in wildlife than natural predators (Clinchy et al. 2016; Suraci et al. 2019). And when wildlife must share recreational spaces with humans, they will separate themselves from humans either in space or in time.

Animals may choose to completely avoid highly trafficked recreational areas (George and Crooks 2006, Barrueto et al. 2014, Reilly et al. 2017, Gaynor et al. 2018), resulting in being pushed from an area to find more suitable habitat where humans do not occur. Some animals will shift to complete

STREAM AND FLOODPLAIN RESTORATION

In the early 1900s, many west Tennessee streams and rivers were channelized in a misguided effort to control flooding and increase the availability of arable acreage. In fact, throughout the entire lower Mississippi Valley, there is only one tributary to the Mississippi that remains unchannelized (the Hatchie).

Over time, the problems associated with channelized streams—including massive erosion of the erodible west Tennessee soils that clogged canals and prevented them from serving their intended purpose—led to a greater awareness of the importance of stream and riparian function.

As noted by the Tennessee Division of Forestry's *Tennessee Urban Riparian Buffer Handbook,* "Healthy creeks, streams and rivers are dependent on healthy forested riparian buffers." These buffers benefit not only individual land-owners but also everyone living downstream. They help stabilize eroding stream banks, filter out sediments and chemicals before they reach the waterway, recharge groundwater, reduce flooding impacts by absorbing high-velocity stream flows, and preserve or improve wildlife and aquatic habitat, adding to the land's scenic and economic value.

White Oak Stream and Floodplain Restoration Partners

West Tennessee River Basin Authority
Tennessee Wildlife Resources Agency
White Oak Wildlife Management Area

White Oak canal in the middle of the White Oak WMA / Chad Harden, TWRA

WHITE OAK WMA STREAM AND FLOODPLAIN RESTORATION

The restoration of White Oak Creek on the White Oak Wildlife Management Area (WMA) in west Tennessee is a recent example of the trend among private landowners and conservationists around the country to "work with nature" by facilitating processes that conserve water, restore soils, cycle nutrients, improve habitat, and benefit wildlife.

White Oak Creek restoration design / WTRBA

THE LITIGIOUS HISTORY OF WHITE OAK CANAL

The White Oak WMA encompasses approximately 7,000 acres in Hardin County, straddling the outlet of 160 square miles of the creek's watershed into the Tennessee River. Thus, its location is strategic in its impact to flows from the watershed into the river, and a large percentage of the WMA (75%) is within the TVA flood easement associated with the Kentucky Lake dam.

In the early 1900s, most of the White Oak Creek and its tributaries were channelized, and adjacent landowners along the stream conducted maintenance to keep the channel clear. However, when the Clean Water Act was passed in 1972, creating a requirement for wetland permits to conduct this work, much of it stopped. As a result, the heavy sediment loads associated with the stream were confined to the canal.

In 1984, the Tennessee Wildlife Resources Agency (TWRA) began purchasing land in the area for the WMA. Erosion was a problem, resulting in sedimentation, timber loss, and diversion of stream flows into alternate flow paths. In short, the stream was no longer functioning normally, and it continued degrading over time to such an extent that in 2005 a West Tennessee River Basin Authority (WTRBA) study of the stream channel showed that its heavily silted bottom was now higher than the surrounding floodplain!

TWRA was sued three times from 1990 to 2015 over water flow through state-owned property in the White Oak WMA. Upstream landowners were dealing with floodwaters backing up from the clogged portions of the channels. TWRA staff attempted to maintain water flow using a variety of "bandaid" measures, as described by then manager of the WMA, **Chad Harden (now WMA Coordinator for Region 2 in Tennessee)**, which included backhoes and explosives to breach levees, which would allow pooled water to flow.

A PROGRAM TO PRESERVE NATURAL FLOW AND FUNCTION OF STREAMS

The Obion-Forked Deer Basin Authority was created in 1972 primarily to maintain channelized streams. It was renamed the West Tennessee River Basin Authority (WTRBA) when it became part of the Tennessee Dept. of Environment and Conservation in 1996, with an updated mandate to preserve the natural flow and function of West Tennessee's streams and rivers through environmentally sensitive stream maintenance.

White Oak stream and floodplain restoration began with a comprehensive evaluation of the watershed, including meetings with landowners, surveys of channel depths, and installation of stream gauges, with the goal of reconnecting stream meander sections and abandoning the channel (i.e., returning the stream close to its pre-channelization form). The project also intentionally focused on how water enters and exits the floodplain, with the goal of maintaining connectivity between the stream and its floodplain.

It included work on 54,000 feet of stream (>10 miles) and was completed on time and under budget in 2021. The system has definitely been tested with flows, and several adjacent farmers have commended the reduced residence time of floods after an event. Maintenance has gone from three to four times per year to zero requests on the WMA in the last four years. "It's very difficult to replicate all the benefits of a meandering channel connected to its natural floodplain. We try to restore these natural dynamics whenever possible, and White Oak is a perfect example of the results," says **David Blackwood, Executive Director at WTRBA.**

White Oak restoration with trackhoe / WTRBA

An amphibious trackhoe works on the "new" White Oak Creek meander. Through analysis of LiDAR data, the lowest point in the floodplain was selected for the location of new stream meanders. Where dredging was necessary, spoil was placed on the outside of each stream bend with the inside of the bend left at natural grade to allow floodwaters to naturally exit and return to the channel.

White Oak stream restoration by WTRBA

Lower end of White Oak project immediately post construction, facing southwest with the parallel canals of White Oak and Mud Creek still visible in the top right. This section was permanently flooded cypress, tupelo, willow, maple and buttonbush forest and marsh trapped between two parallel canals. The project restored old meanders wherever possible.

Results for recreational users have been mixed—with fishing success declining at some spots. Hunters have enjoyed improved access, but reduced waterfowl harvest (part of a statewide trend) has been attributed to the project. "We recognize restoration is causing some of our most traditionally productive locations for fishing and wildlife to go away, but new ones will develop over time," says Chad Harden. "A properly functioning stream and wetland will provide better habitat for more fish and more wildlife over the long-term, and that is our goal."

Tennessee Division of Forestry. 2015. Tennessee Urban Riparian Buffer Handbook. Accessed May 13, 2024. https://www.tn.gov/content/dam/tn/agriculture/archive-can't-be-altered-after-placed/documents/forestry/UrbanRiparianBufferHandbook.pdf

US Army Corps of Engineers, ERDC. 2013. Draft report White Oak Creek Watershed Study: Conceptual Sediment Budget.

nocturnal patterns (separation in time) because of recreational impacts (Lewis et al. 2021, Gaynor et al. 2018). These shifts in animal patterns can cause increased predator/prey overlap and greater competition among species. (Lewis et al. 2015a, Gaynor et al. 2018).

Wildlife-related recreation is important in the overall US economy. Proof of this was again shown in the 2022 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation completed by the US Fish and Wildlife Service. According to their survey results, $394.8 billion was spent on "Wildlife-Related Recreation" in 2022 in the US. The authors stated, "the Survey data demonstrate yet again that fishing, hunting, boating, and watching wildlife are part of the American lifestyle, and that these pursuits fuel economies and create enduring social and cultural bonds" (USDOI 2022). The survey included data collected from people aged 16 years and older who participated in wildlife-associated recreation.

Many types of outdoor recreation don't necessarily fall into the "wildlife-associated" category. However, the activities, equipment used, and where they occur can have huge impacts on wildlife species.

One example is the growing concern that rock climbing, which has exploded in popularity in recent decades, could adversely affect the diversity of plant species that grow in specialized environments. The Obed River Gorge is a popular rock-climbing destination, yet its sensitive vascular plants, bryophytes, and lichens make up one of the richest floras in the southeastern US (Walker et al. 2009). Research on this topic indicated some impacts of foot traffic on vascular and non-vascular species, with a slight shift in lichen species composition on the cliff faces in response to climbing (Walker et al. 2009).

Twenty percent of known caves in the United States (12,000+) are located in Tennessee.

Similarly, recreational caving can have adverse effects on bats and other species, such as crustaceans, insects, and arachnids, found within those ecosystems. Twenty percent of known caves in the United States (12,000+) are in Tennessee. Many of these caves are critical to the survival of multiple species of bats, some of which are federally endangered.

Since bats are sensitive to disturbances within caves, recreational caving has the potential to disrupt hibernation. Cave entry also has the potential to spread the invasive fungus *Pseudogymnoascus destructans* (Pd.), the cause of white-nose syndrome (WNS), an epidemic responsible for killing millions of cave-dwelling bats in the eastern and central United States.


Tricolored Bat, a species that declined 84% from 2013 to 2022, largely due to white-nose syndrome / Michaela Bass, TWRA

The origin of the fungus's introduction into the United States in 2006/07 is thought to have been unintentional spore transfer from the gear/clothing of people who had visited caves in Europe where the fungus was known to occur. Both disruption and WNS cause hibernating bats to wake up prematurely, using valuable fat stores they need to survive through the winter (see WNS Highlight).

Another recreation issue is the importance of proper planning and management of horse-riding trails. Studies have shown that damage to vegetation and stream water quality can occur when trails are not properly located, have maintenance issues, or are not appropriately followed by riders (Marion and Olive 2006). Good planning and maintenance can reduce potential damage and keep horse trails safe and enjoyable for the public.

The impacts of all-terrain vehicles (ATVs) and other off-highway vehicles (OHVs) can be significant in certain cases, but they are highly localized. TWRA allows restricted use on dedicated trails on some WMAs; however, the demand for trail access has grown significantly over the last five years. Without sufficient resources for signage and enforcement, this type of use in areas set aside for wildlife could pose a more significant threat. In addition, while most riders are responsible, as the number of riders increases, pressure on public and private lands will also increase. Additionally, irresponsible riders are creating their own trails, riding on trails that are closed, and engaging in other illegal activities, such as riding in creeks as trails or washing their vehicles in creeks.

Generally, people may not realize the extent to which ATVs and OHVs can damage the environment (TVA 2006). Mangled vegetation, destroyed wildlife habitats, severe soil erosion, and stream sedimentation are the primary impacts of ATVs and OHVs in sensitive or inappropriate areas. Vehicular impacts are most likely when use is high, when users blaze new trails, when they

Typical size of today's Off-Highway Vehicles (OHVs) / Scott Dykes, TWRA

OHV damage: Massive ruts and erosion on a nature trail / Scott Dykes, TWRA

do not use designated stream crossings, or when they ride within streambeds. The damage caused to wildlife and water quality by riding in streams has caused some states, such as Missouri, Georgia, and Alabama, and some land management agencies in Tennessee (USFS, upper Tellico)

American Ginseng (*Panax quinquefolius*) / Jacob Bigelow (1786-1879), text and coloured engravings from www.botanicus.org

to outlaw the activity. TWRA initially allowed ATVs on a small portion of North Cumberland WMA, prior to the invention of the OHVs of today.

4.4.5. Overuse of Biological Resources

This category includes Conservation Standards threat categories Hunting & Collecting Terrestrial Animals and Gathering Terrestrial Plants. The collection of certain plant and animal species in different regions of the state must be monitored, and regulations enforced, to prevent over-harvest and species population declines. Illegal poaching of desirable plants, particularly medicinal species, from both public and private lands is an issue in Tennessee.

According to the Tennessee Department of Environment and Conservation, American ginseng (*Panax quinquefolius*) is the number one poached plant (Lincicome 2015). This species has historically been used for medicine by Native Americans and is still valued for this purpose, particularly for use in Asian products. Goldenseal and orchids are also highly popular species.

Eastern Box Turtle with transmitter attached for research purposes. / Michaela Bass, TWRA

The trade of ginseng and many other plant species is regulated under CITES, the Convention on International Trade in Endangered Species of Wild Fauna and Flora. TDEC administers a licensing program to regulate and monitor the harvest and export of American ginseng from Tennessee, and collection of ginseng on the Cherokee National Forest requires a permit from the US Forest Service.

People are also putting tremendous global pressure on turtles (and most reptiles) through illegal trade. Animals are illegally caught and collected in the wild, then sold for profit. “There exists tremendous global pressure on turtles (and most reptiles) as a commodity. This demand exists for North American native species, for example, Eastern Box Turtles (*Terrapene carolina carolina*). North American species are experiencing high levels of illegal collection as a result of this demand” (Midwest Turtle workshop). Adopting wild animals is part of a web of interrelated issues. For example, as development fragments habitat, Box Turtles near urban areas increasingly encounter humans, domestic pets, and automobiles—all of which can lead to direct mortality, impacts to overall health, and removal of reproductive individuals from wild populations (Andrews et al. 2013). This is significant, as loss of adults can cause declines in turtle populations regardless of reproductive rates (Bowen et al. 2004).

4.5. Invasive and Problematic Species and Pathogens

4.5.1. Pathogens

Little Brown Bat with white-nose syndrome / US Fish and Wildlife Service

Novel pathogens are a continuing and growing problem in Tennessee as well as other parts of the US and the world. Emerging infectious diseases pose a growing threat to wildlife, yet appropriate actions to manage outbreaks before, during, and after invasion are only in the beginning stages. Researchers active in this field have proposed definitions for recognizable stages of pathogen invasion and means for control or treatment appropriate to each stage. However, one of the best means of addressing this threat will be prevention at the federal level, through quarantine and trade restrictions on common vectors for the introduction of new pathogens (Langwig et al. 2015).

White-nose syndrome

WNS is a disease that impacts hibernating bats. It is caused by a fungal pathogen, *Pseudogymnoascus destructans*, that was introduced into North America in 2006. The disease is

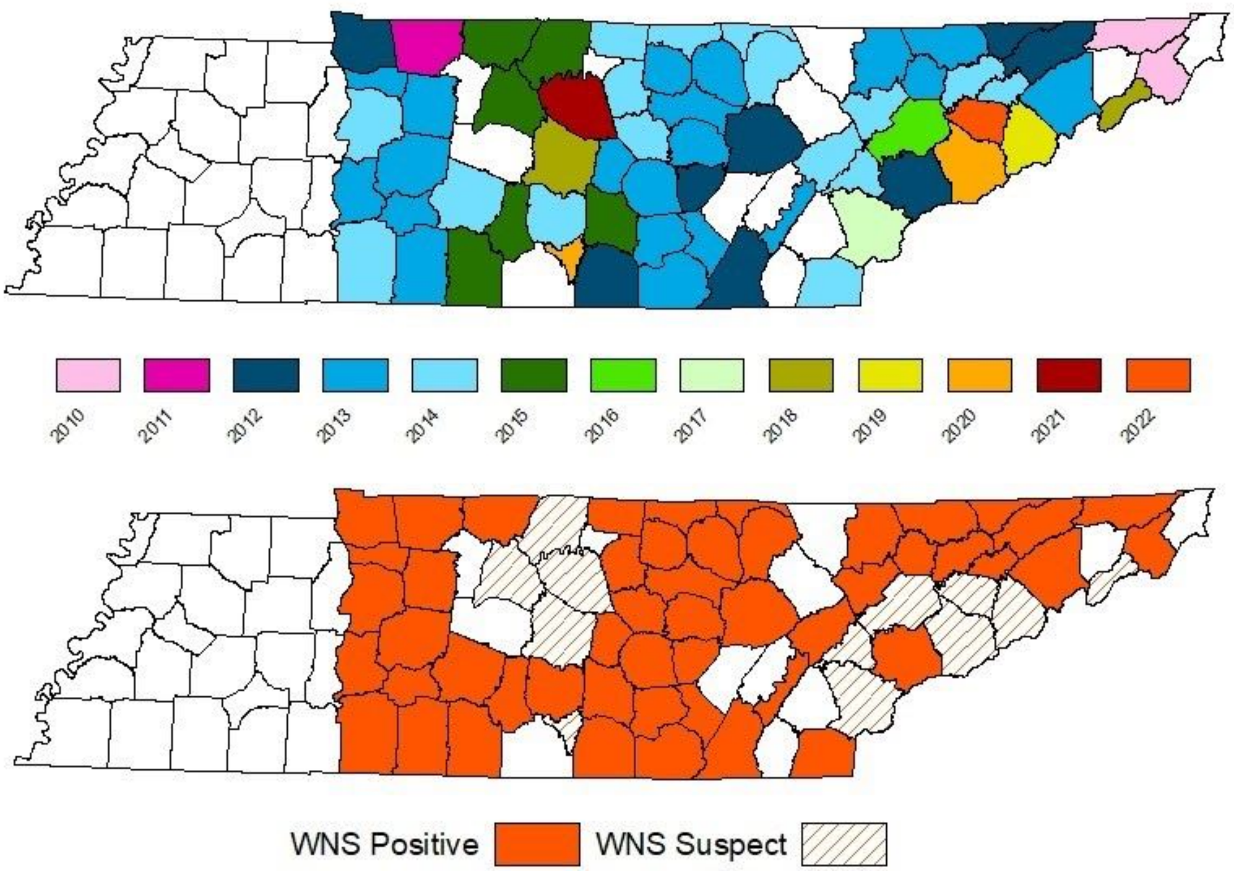


Figure 4.2 Degree of known and suspected white-nose syndrome and spread through Tennessee counties by year. Source: TWRA survey data.

called WNS because it often appears as a white, fuzzy fungal growth on the nose and other unfurred body parts of hibernating bats. WNS causes depletion of fat reserves during hibernation, among other physiological effects, leading to starvation and, in some cases, mortality. WNS and its causal pathogen were not known to science in 2005 when SWAPs were first created. It was first discovered in New York in 2006, and in 2024, it was present in 40 US states and 9 Canadian provinces. WNS illustrates how rapidly a pathogen can devastate wildlife populations (see WNS Highlight).

WNS was discovered in Tennessee in 2010. As of 2024, WNS and/or the pathogen that causes the disease has been documented in 62 of Tennessee's 95 counties (Fig. 4.2). Eighty percent of the counties in Tennessee with caves have been documented as WNS positive or suspect (presence of the pathogen or WNS field signs). Of the 16 bat species that occur in Tennessee, 7 have been confirmed WNS positive and the pathogen has been documented on 5 other species without diagnostic disease (Thames 2025). Population impacts caused by WNS differ among species. Northern long-eared bats have declined by almost 99% due to WNS. Tri-colored bats, Indiana bats, and Little Brown Bat populations have also declined substantially due to the disease (Cheng 2021, Thames 2024). Several potential treatments for WNS have been developed through the national WNS response. However, most of the treatments could disrupt the natural function of fungi and bacteria in natural cave ecosystems, and their use has primarily been confined to man-made structures such as mines.

Chytrid fungus

Another highly publicized pathogen is the chytrid fungus (*Batrachochytrium dendrobatidis*) which threatens over 350 species, but especially frogs, worldwide—including in Tennessee, where it affects the steeply declining Hellbender. Both WNS and chytrid have caused mass mortality events and extinctions or extirpations in multiple species (Langwig et al. 2015).

Ranavirus

Ranaviruses are emerging pathogens of amphibians, reptiles, and fish, which have been associated with die-offs in the Americas, Europe, and Asia. With death rates often 90% or greater during an outbreak, as well as mounting evidence that some ranaviruses can be transmitted among all three of these vertebrate classes, these pathogens pose a substantial risk to Tennessee's biodiversity (Global Ranavirus Consortium 2015).

Several populations of the wild Fire Salamander, Europe's largest, have declined by 90 to 96% due to Bsal. / Frank Lassen

Bsal

Batrachochytrium salamandrivorans (Bsal) is a pathogenic chytrid fungus that was

The gate installed at Carlton Cave in Franklin Co. to protect Tricolored Bats / Dustin Thames, TWRA

WHITE-NOSE SYNDROME: AN ONGOING THREAT

Since its introduction into upstate New York in 2006, white-nose syndrome (WNS) has become the scourge of many North American bat species. The disease is caused by a cold-loving fungus *Pseudogymnascus destructans (Pd),* which grows best in high humidity environments at 54 to 59 degrees Fahrenheit, common for caves and mines in Tennessee. Hibernating bats become the perfect petrie dish for the fungus.

This pathogen is found across a large part of Europe and Asia (the likely source of introduction), but doesn't appear to cause substantial mortality there. Bats there have likely evolved resistance over thousands of years. The core conundrum is developing solutions to fight a disease that causes high mortality and against which native species have little to no resistance.

The problem is even more complex because bats, like many at-risk species, are impacted by numerous threats such as habitat loss, improper forestry methods, and cave disturbance by humans.

Efforts to protect bat populations in Tennessee have centered on mitigating threats and monitoring bat populations closely to determine how WNS is affecting their numbers. At the same time, multiple lines of research are ongoing to investigate methods for reducing the prevalence and spread of the disease.

TENNESSEE #1 IN BAT WINTER COLONY COUNTS

Since WNS was first documented in Tennessee in 2010, the Tennessee Wildlife Resources Agency (TWRA) and partner organizations have conducted ~1,300 bat winter colony counts at over 550 sites, primarily caves, across the state. These surveys are essential to understanding both the scope of WNS, which is now considered endemic, as well as its impact on bat populations.

Carlton Cave shown prior to gating. / Dustin Thames, TWRA

The silver lining is that organizations are working cooperatively more than ever before to conserve bat populations in Tennessee and across the nation, and some species are showing resilience. Nationally, the US Fish and Wildlife Service and US Geological Survey formed the North American Bat Monitoring Program with the goal of using multiple lines of evidence to understand where, when, and how bat populations change over time. Due to the collaborative efforts of partners, Tennessee ranks as number 1 contributor of bat winter colony count data in the US.

BAT SUPERPOWERS

Bats are often viewed as potential reservoirs of disease that could spread to humans (WNS does not affect people). However, very little is shared about the amazing abilities that bats have to combat infection.

Bats are small, flying mammals whose extremely high metabolism produces high levels of free radicals with the constant potential to damage their own cells. Bat internal systems allow them to repair their cellular material quickly; they can even repair their own DNA! These adaptations also enable them to resist infections, especially viruses.

When WNS spores land on the unfurred skin of a bat's wing, the fungus starts growing directly into the bat's skin cells. The bat's response to infection is to wake from their winter torpor, which allows their amazing powers of recovery to clear the infection. However, if this happens too often, they run out of fat reserves and leave their caves to look for water and food at a time of year when there is no food, and water may be frozen. If bats with WNS can make it through the winter, they will likely survive the infection.

BOILING BOOTS AND CAVE GATES

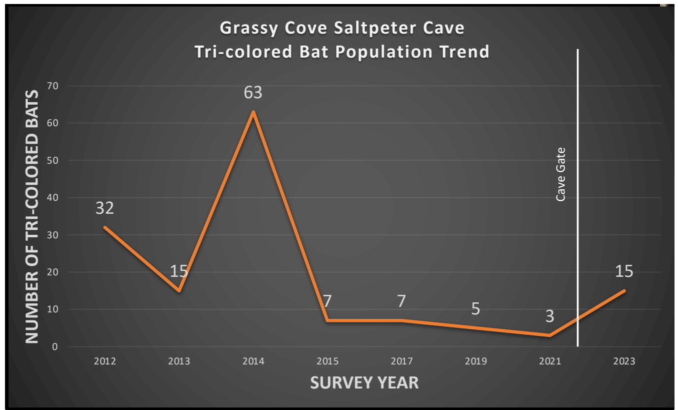
Biologists studying bats follow elaborate decontamination protocols to avoid transferring Pd spores from one cave to another. Upon exiting a cave, they bag up their gear and later use pressure washers and alcohol to decontaminate hard gear, while reserving the age-old cleaning custom of boiling in water for coveralls and boots!

Human cave disturbance threatens bats in two ways: (1) the possible direct contamination of caves with fungal spores and (2) additional disturbance (beyond WNS) that wakes bats in winter. In general, avoiding recreational caving during critical hibernation periods is recommended. All caves on state and federal property are closed to human visitation (with the exception of some permits issued when bats are absent). TWRA and partners encourage private landowners to manage visitation in their caves to limit disturbance to bats.

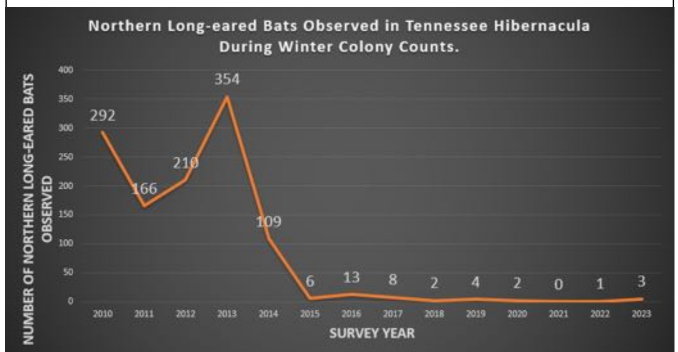
It's no wonder that a primary conservation approach to managing this disease is to install gates on the entrances to caves with significant human disturbance where overwintering bats susceptible to WNS also occur. Gating a single cave can cost from $4000 to $50,000. The data show that cave gating works and is helping to bring back populations of the bats most affected by WNS (see Grassy Cove Saltpeter Cave graph, upper right).

Additional lines of research to address WNS include

- Attempts to cool down caves past the range of preferred temperature for the spores (species like Gray Bats that roost in the cave's coldest areas are far less affected)
- Anti-fungal agents to be sprayed in caves or on bats
- The use of UV light to kill fungal spores in critical cave zones.



Grassy Cove Saltpeter Cave, Cumberland Co., Tricolored Bat population trend, 2012-2023, showing response to cave gate installation.



Northern Long-eared Bats, the species hit hardest by WNS in Tennessee, show an almost 100% decline. The graph shows bats observed in Tennessee hibernacula during winter colony counts 2010-2023.

White-nose Syndrome Conservation Partners

Arnold Air Force Base
The National Park Service
The Nature Conservancy
Tennessee Wildlife Resources Agency
US Fish and Wildlife Service (USFWS)
North American Bat Monitoring Program
Tennessee Bat Working Group
Tennessee Valley Authority

Bat Species affected by WNS	Percent Decline (TN) from 2013 to 2022	Status
Northern Long-eared Bat *(Myotis septentrionalis)*	>99%	Listed federally threatened in 2015 and federally endangered in 2022
Little Brown Bat (*Myotis lucifugus*)	80%	Listed state threatened in 2018, status assessment underway by USFWS
Indiana Bat *(Myotis sodalis)*	85%	Listed endangered since 1967
Tri-colored Bat *(Perimyotis subflavus)*	84%	Proposed federally endangered (2024)

All of these approaches are being tested in human-made mines to avoid unintended impacts to sensitive cave ecosystems. In the meantime, to buy more time for Tennessee's declining bat populations, "There are still so many caves that need gates," says **Dustin Thames, Biodiversity Coordinator** for TWRA. "Current estimates are that we still need dozens to protect our imperiled bats."

Trust, Bat Conservation. n.d. "White-Nose Syndrome in Europe and the UK - White-Nose Syndrome." Bat Conservation Trust. Accessed May 3, 2024. https://www.bats.org.uk/about-bats/threats-to-bats/white-nose-syndrome/white-nose-syndrome-in-europe.
Tennessee Bat Working Group. 2023. White-nose Syndrome in Tennessee. Available from http://www.tnbwg.org/TNBWG_WNS.html

first identified in the Netherlands in 2010 as the causal agent in the extirpations of wild populations of Fire Salamanders (*Salamandra salamandra)* (Martel et al. 2013). Many species of salamanders and newts are susceptible, but certain frogs and toads are also vulnerable (Towe et al. 2021; Gray et al. 2023).

Research suggests that Bsal originated in Asia and was likely spread to Europe via the pet trade. Due to the international trade of amphibians, both legal and illegal, the probability of Bsal introduction into North America is high, despite the regulation of injurious wildlife under the Lacey Act. If Bsal makes it to North America, lab studies and models predict that biodiversity loss is expected to be greatest in the Appalachian Region and along the west coast of the United States. It is believed that Bsal may be actively spread by carriers (e.g., salamanders, anurans) and passively spread by birds and other species, as well as by humans through means such as water, waders, and equipment (AFWA 2024).

Proactive management to prevent introduction of Bsal will be most effective at preventing or mitigating catastrophic declines in native species. As stated by Priya Nanjappa, Amphibian and Reptile Program Manager for the Association of Fish and Wildlife Agencies, "Because the pathogen has not yet been found in North America, we have a rare opportunity to redefine what it means to be proactive by planning ahead of its expected arrival. However, such planning and prevention will require concerted outreach and communication to retail pet stores, pet owners, and outdoor enthusiasts" (AFWA 2024).

Pre-detection strategies to prevent the introduction or spread of Bsal recommended by the Association of Fish and Wildlife Agencies (AFWA 2024) include:

- Establish and implement prevention protocols (such as a biosecurity protocol for work in aquatic habitats)
- Establish surveillance efforts to test for Bsal in the field and in captivity
- Engage in proactive management, which includes the above as well as area closures, habitat management, and education
- Establish a rapid response and management plan (to include notification contacts, response funding, habitat management recommendations, etc)

(AFWA 2024).

Progression of snake fungal disease in a Gray Rat Snake (*Pantherophis spiloides*) over the course of 18 days / Sam Robinson

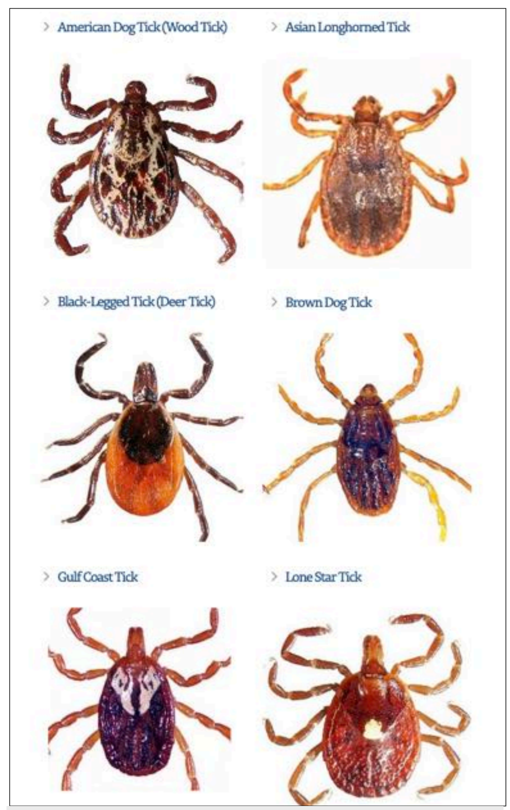
Snake fungal disease

Another prime example of an emerging pathogen threat is snake fungal disease, an infection that has afflicted populations of snakes, primarily venomous species, from the northeast through the Midwest, and the South, including Tennessee. This disease appears to be triggered by the fungus *Ophidiomyces ophiodiicola*, which is relatively new to science. It is not currently known whether this fungus has always been present in the environment, if it was introduced, or if perhaps it has recently mutated, allowing it to cause more severe disease (NEPARC 2013). Researchers at University of Tennessee at Knoxville, Cumberland University, Tennessee State University, Middle Tennessee State University and TWRA have been working to document the spread of fungal infection in Timber Rattlesnakes and other reptile species.

Recent research conducted by MTSU has observed a higher pathogen load in areas predicted to be suitable habitat for this pathogen. However, habitat suitability had no clear effect on dysbiosis (the imbalance in the skin microbiome that causes problems for snakes), suggesting that dysbiosis is a multifaceted process influenced by factors beyond presence of the pathogen (Donald M. Walker, Pers. Comm. June 20, 2024).

West Nile Virus

West Nile Virus (*Orthoflavivirus nilense*) is primarily a disease of birds that affects the central nervous system and is transmitted by the bite of mosquitoes carrying the virus. Humans and other mammals can become infected, but they are considered dead-end hosts. People cannot generally spread the disease to each other. West Nile Virus has been found in more than 250 species of birds (as well as many wild mammals), but crows, jays, and ravens are most susceptible to the disease. West Nile virus is maintained in the environment through interactions between mosquitoes and birds. Birds with West Nile Virus often show neurological signs, including loss of coordination, head tilt, tremors, weakness, and lethargy. Most infected crows and jays will die within 3 weeks (Commonwealth of PA 2024).



The six most commonly encountered species of tick in Tennessee, all of which can transmit pathogens to animals, and some of them also pose a health threat to people. / Tennessee Wildlife Resources Agency

When infected, most people do not usually show symptoms. However, it can cause febrile illness or neurologic disease, including meningitis or encephalitis. There is currently no treatment for West Nile (CDC 2024a). By sharing information, US and state agencies have been able to provide guidance on the disease and lessen its spread.

Ticks

Ticks were the first arthropods to be established as vectors of pathogens, and currently they are recognized, along with mosquitoes, as the main arthropod vectors of disease agents to humans and domestic animals globally. Tick-borne diseases are common occurrences in both medical and veterinary clinical settings (Dantas-Torres et al. 2012), and their incidence is increasing worldwide. Notorious for transmission of Lyme disease in the US, there are at least 898 recognized species of tick globally, which can transmit a wide array of diseases. Many tick-borne diseases are important zoonotic diseases, including anaplasmosis, babesiosis, ehrlichiosis, and Lyme borreliosis.

Another human illness caused by exposure to ticks is alpha galactose allergy, aka "alpha gal," a condition that, unfortunately, is becoming common in Middle Tennessee. The linkage between wildlife health and ticks is reciprocal, as healthy wildlife populations, such as snakes, help control rodent populations and associated tick populations (Beck 2016).

In addition to the constraints related to their diagnosis and clinical management, the control and prevention of these diseases is often difficult because it requires the disruption of a complex transmission chain involving vertebrate hosts (often wildlife species) and ticks. The principle of the One Health approach (see Appendix J) for the management of tick-borne diseases is to increase the level of communication between physicians and veterinarians dealing with patients with a past or present history of tick bites, particularly those with unexplained febrile illness in areas where such diseases are endemic. (Dantas-Torres et al. 2012).

Introduced tick species—such as the Asian Long-horned Tick, which has been in east Tennessee since 2019, add another layer of complexity to this picture. What will be the impacts of this new species, both in terms of serving as possible vectors of disease and their effects within native ecosystems?

4.5.2. Toxicants

Toxicants are toxic substances that are not produced by a living organism (e.g., toxins). Examples include lead, mercury, pesticides, and industrial chemicals.

Neonics threaten about 11% of the entire US endangered species list, including many pollinators and birds.

Neonicotinoids

Neonicotinoids (neonics), a class of relatively highly selective insecticides, have swept one-fourth of the global market since the launch of imidacloprid (IMI) in 1991 (Zhang and Lu 2022).

Neonics pose widespread problems to species and habitats for several reasons:

- They are extraordinarily toxic.
- They are extremely widespread in use.
- They contaminate the environment far beyond where they are applied (e.g., leach into water, contaminate non-target organisms).
- They are transmissible through the environment and highly persistent.

Unlike contact pesticides, which merely stay on the plant surface, neonics are systemic and can be absorbed throughout the plant (Simon-Delso et al. 2015). They can be released to the air along with pollen, diffuse into soil and water, or persistently exist in crops. Neonics have high water solubility (Zhang and Lu 2022), and one study in Arkansas, Mississippi, and Tennessee detected neonicotinoid insecticides in 23 per cent of wildflower samples around recently planted fields of corn, cotton, and soybean (Stewart et al. 2014). Epidemiological studies are scarce but have linked neonics exposure to oxidative stress, neurological symptoms, metabolic changes, osteoporosis, and liver cancer in humans (Zhang and Lu 2022).

While there is a need to further clarify the effects of neonics on human populations, the science is much clearer with respect to birds and pollinators: An increase in neonicotinoid use led to statistically significant reductions in bird biodiversity between 2008 and 2014, particularly for grassland and insectivorous birds (of Li et al. 2020). In 2023, an EPA assessment predicted profound impacts on over 200 threatened and endangered species, many of which are pollinators, from the three most used neonicotinoid insecticides. Neonics threaten about 11% of the entire US endangered species list—including pollinators like the Rusty-patched Bumblebee, Hine's Emerald Dragonfly, and Karner Blue Butterfly (EPA 2023b). As the most widely used insecticides worldwide, twenty years of research now identify neonics not only as a leading driver of mass pollinator losses, but also connect their use to similar bird declines, collapsing aquatic ecosystems, and significant risks to human health (Pisa et al. 2021).


Bee on echinacea / Ryan Hagerty, USFWS

While large-scale epidemiological studies may yet be needed to elucidate human health outcomes associated with neonics exposure, indirect species and ecosystem impacts are considered significant enough to monitor, regulate, limit, and/or prohibit the use of these chemicals. Since 2018, the European Union (EU) has prohibited all outdoor use of IMI, thiacloprid (THI), and clothianidin (CLO) with a few exceptions, mainly due to their risks to non-target organisms, especially pollinators.

Most countries, including the US, have not restricted their use—yet. However, in late 2023, New York became the first US state to prohibit the use of neonicotinoids on outdoor ornamental plants and turf, as well as the seeds of corn, soybeans, and wheat. (NY State Senate Bill 2023-S1856A [date unknown]).

PFAS (Per- and polyfluoroalkyl chemicals)

Per- and polyfluoroalkyl substances, known as PFAS, are a group of thousands of man-made chemicals that have been manufactured for a variety of consumer and industrial uses in the US since the 1940s. PFAS are widely used, long-lasting or "forever" chemicals, components of which break down very slowly over time. PFAS are a concern for humans, wildlife, and natural systems due to the following:

- PFAS contamination can migrate to groundwater and surface water, potentially impacting drinking water sources.
- Because of their widespread use and persistence in the environment, many PFAS are found in the blood of people and animals all over the world and are present at variable levels in a variety of food products and in the environment.
- Unsafe storage, improper disposal, inadequate containment, and illegal discharges have resulted in contamination of soil, water, and air in some locations.
- Scientific studies have shown that exposure to some PFAS in the environment may be linked to harmful health effects in humans and animals (TDEC [date unknown] PFAS, EPA 2021), including certain cancers, thyroid dysfunction, changes in cholesterol, and small reductions in birth weight (National Academies of Sciences, Engineering, and Medicine 2022).
- PFAS compounds can securely bind to soil particles and can even be taken up by plant roots and stored in varying concentrations throughout plant tissues (Xu et al. 2022).

In 2024, two reports from the Sierra Club reported that 60 percent of rivers in Northeastern Tennessee contain PFAS and that record levels of PFAS were found in Northeast Tennessee sewage sludge used as crop fertilizer (Pauling 2024).

4.5.3. Invasive Species

Invasive species, both plants and animals, pose a significant management challenge across the state, requiring substantial financial and labor resources to manage and control them effectively. Invasive plants alter the composition, structure, and function of native ecosystems, while invasive animals can directly destroy habitat and reduce species populations through predation, competition, or extirpation via hybridization (Harrington et al. 2020). Both intensive and extensive management actions are often necessary to prevent invasive species from causing undesirable ecosystem alterations and the removal of native species. These management strategies may involve direct physical removal, chemical treatments, biological control, and habitat restoration, depending on the specific invasive species and the severity of the infestation.


Bigclaw Crayfish / Zack Graham

Most invasive species are introduced non-native exotic species that have been unintentionally or intentionally translocated. Though not all invasive species come from outside of the state, some are native species that have been released into areas or drainages where they are not native, which causes the collapse of local species assemblages and alterations to the local environment (e.g., Big Claw Crayfish, *Faxonius placidus* introduced into the Obed and Emory River drainages.

Invasive and exotic plants

According to a survey and research conducted in Tennessee, invasive plants cost the state of Tennessee at least $2.6 million annually. (Pfennigwerth and Kuebbing 2012) .This figure only includes direct costs of control, mapping, and outreach. It does not include indirect costs associated with:

- Decreased agricultural yields
- Lower property values
- Diminished recreational opportunity
- Decreased diversity and wildlife habitat.

The Tennessee Invasive Plant Council lists 64 species of plants (TN-IPC [date unknown]) that are either established or emerging threats in Tennessee's natural areas, and the list is even longer for invasives in disturbed habitats. The following examples illustrate some of the current threats they pose:

Chinese lespedeza (*Lespedeza cuneata*) and **shrub lespedeza** (*Lespedeza bicolor)* are particularly challenging to manage when using prescribed fire as a management tool, as they are tolerant of fire and may even respond positively. These introduced species replace native vegetation, alter wildlife habitats, reduce biodiversity, and can limit restoration options because they can prevent grass growth and impede tree establishment (USFS [date unknown] Fire effects…).

Spines of the invasive Callery Pear / Nancy Loewenstein

Japanese stiltgrass (*Microstegium vimineum*) and **Chinese privet** (*Ligustrum sinense*) are both insidious invasive species problems. Once established, they can be resource intensive to remove or control.

Tree-of-heaven (*Ailanthus altissima*), kudzu (*Pueraria montana*), and **multiflora rose** (Rosa multiflora) are also species categorized as severe threats due to their ability to spread rapidly into native plant communities and displace native vegetation. Of growing concern is the invasion of natural habitats, particularly in Middle Tennessee, by **Callery pear** (*Pyrus calleryana).* Although the cultivated variety, the Bradford pear—which for decades was incorrectly advertised as sterile, despite producing viable seeds—has since been dispersed and distributed by birds and other wildlife, the offspring revert to the species' characteristics of aggressive growth and production of thorny spurs, further exacerbating the spread of this invasive species.

Autumn olive (*Elaeagnus umbellata)* has been actively promoted by state and federal agencies for shelter belts, erosion control, strip mine reclamation, wildlife habitat, and was widely marketed as an ornamental. The shrub has now become naturalized in suitable habitats scattered throughout the eastern and midwestern US. It is adaptive, competitive, and vigorous, especially on open, sunny sites, and it produces abundant fruit crops, which are spread by birds and small mammals (TN-IPC 2025).

TDEC is responsible for protecting and maintaining native plant species while also managing exotic invasive plant species in all state waters. In addition, the Tennessee Valley Authority (TVA) and the US Army Corps of Engineers (USACE) conduct aquatic plant management actions when aquatic invasive plant species impact navigation, flood control, or hydroelectric power generation. These agencies coordinate their efforts to mitigate the ecological and economic impacts of invasive aquatic plants. (Tennessee Aquatic Nuisance Species Task Force 2008).

Invasive species are otherwise controlled by federal, state, and municipal land management agencies, as well as private landowners, throughout the state. However, the inability of non-botanically trained individuals to identify, notice, or recognize invasive plants contributes to a lack of awareness and, therefore, a lack of prevention concerning invasive plants in cities and suburbs.

Invasive and exotic insects

Several invasive insect pests threaten Tennessee forests annually. These include the following, all of which are introduced except for pine beetles:

- Hemlock Woolly Adelgid
- Emerald Ash Borer
- Southern Pine Beetle
- European Spongy Moth (formerly Gypsy Moth)
- Spotted Lanternfly

The ***Hemlock Woolly Adelgid*** (*Adelges tsugae*) exemplifies the issues surrounding invasive insects. Hemlocks (*Tsuga* spp.) are slow-growing, long-lived evergreens critical to the ecosystems in which they occur because they provide dense shade that helps to keep forest streams cool throughout the hot summer months. Since 2002, the Hemlock Woolly Adelgid has been causing hemlock mortality across the state, killing trees that are hundreds of years old in as little as three years. The Hemlock Woolly Adelgid has caused extensive hemlock mortality in the Great Smoky Mountains National Park and the Cherokee National Forest. As of 2022, essentially all counties in Tennessee with native hemlocks have these infestations (TN Division of Forestry) (see Figs. 4.3 and 4.4).

While effective chemical treatments for these pests are available to individual landowners, they are cost-prohibitive and impractical to address the problem on a landscape scale. Researchers and natural resource managers are working to find an effective combination of chemical and biological

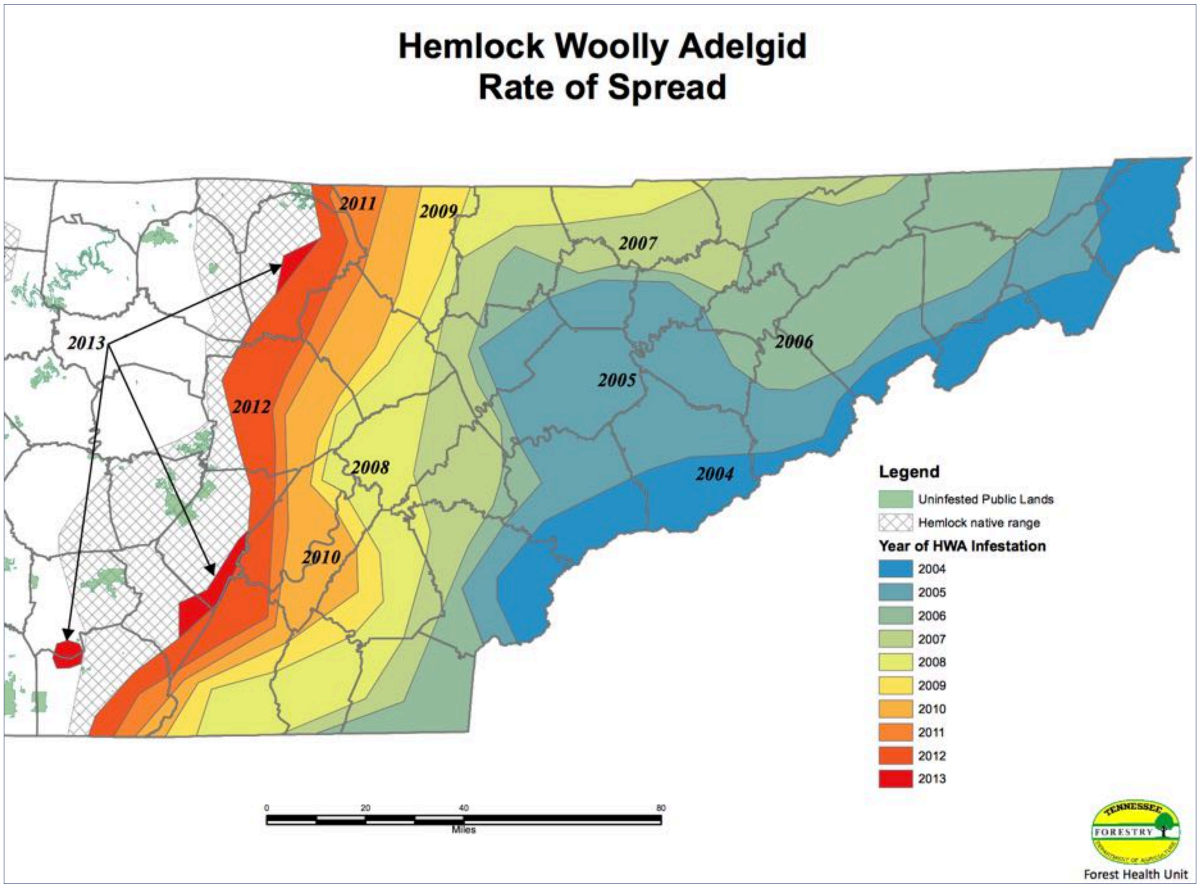


Figure 4.3 Hemlock Wooly Adelgid rate of spread

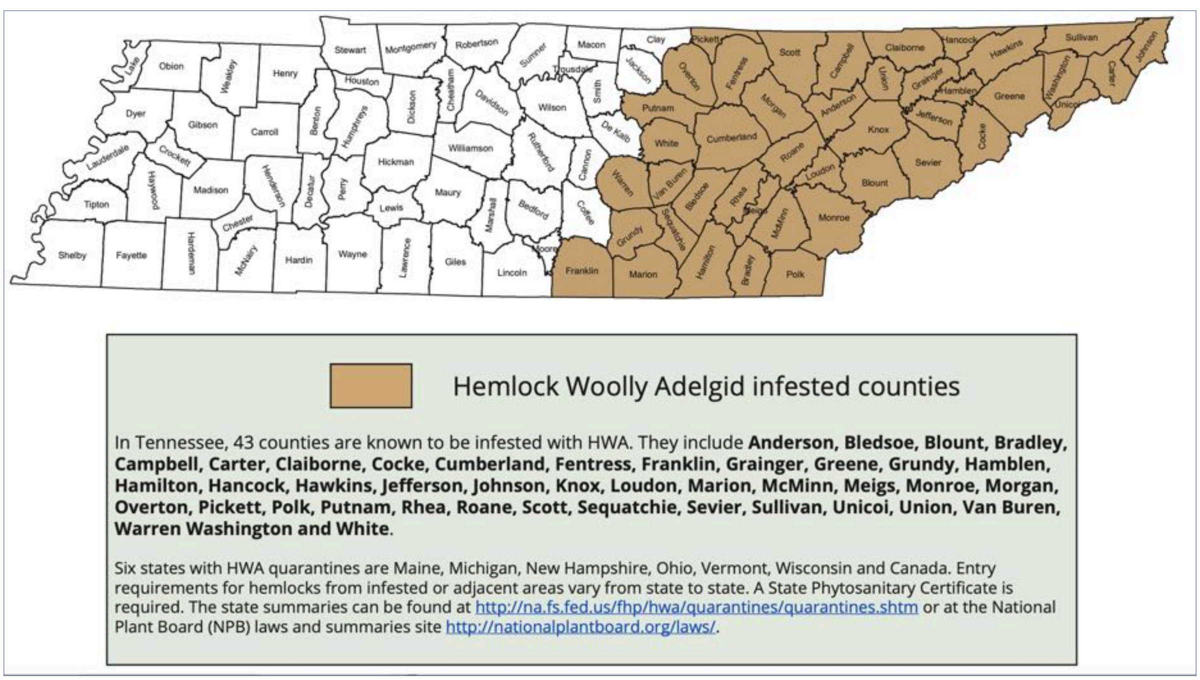
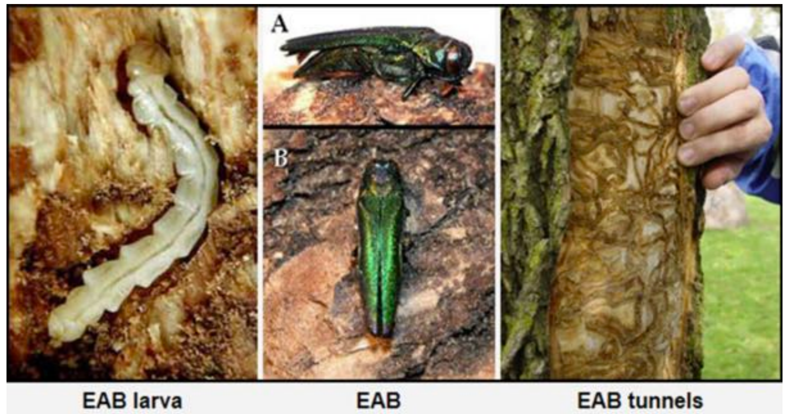


Figure 4.4 Tennessee Counties infested with Hemlock Wooly Adelgid, 2017

controls that can help protect some hemlock populations or slow down infestations (Wisby and Palmer 2015).



Emerald Ash Borer / Nebraska Dept. of Agriculture

The Emerald Ash Borer (*Agrilus planipennis*) is another example of a relatively recent insect pest that has affected Tennessee's forests. Originally from Asia, it was first discovered in Michigan in 2002. It has since caused widespread tree mortality and decline in ash (*Fraxinus* spp.) trees in 35 states, including Tennessee. The Emerald Ash Borer is transported mainly by humans through infected nursery stock, firewood, unprocessed saw logs, and other ash products. While this beetle has been a quarantined pest since its initial detection in the US, both the state and federal quarantines were lifted in 2021 following federal deregulation of this pest.

The Emerald Ash Borer was identified in Tennessee at a truck stop on I-40 in Knox County in July 2010. Since that introduction, 66 counties have confirmed the presence of EAB as it has spread across Tennessee (see Fig. 4.5). Ash trees are often planted along residential streets and in parks, and are also common in forests throughout many areas of Tennessee. Because of this, the Emerald

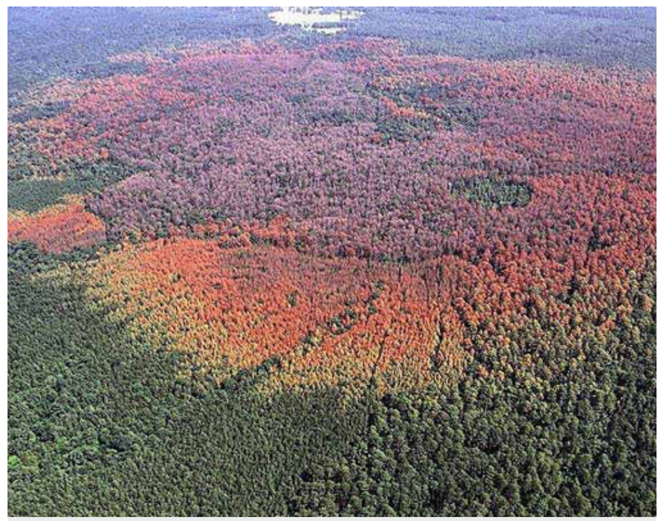
Figure 4.5 EAB county detection map 2023

Ash Borer has caused significant economic costs in both these residential and forested areas since its discovery in 2010 (Protect TN Forests [date unknown])

European Spongy Moth (formerly Gypsy Moth) (*Lymantria dispar dispar*) is a nonnative moth that has defoliated over 95 million acres of hardwood forests throughout the northeastern United States over the course of the past century. It is native to Europe and northern Africa but was brought to Massachusetts in 1869. Since then, it has spread southward through the northeastern states into southwestern Virginia and eastern Tennessee.

In 2015, at the time of the last SWAP, there were no established Spongy Moth populations in Tennessee. However, by 2022, Spongy Moth populations had surged in East Tennessee. Surveys conducted in 2022 detected significant moth presence in the region. In spring 2023, the Tennessee Department of Agriculture and USDA Forest Service began application of spongy moth mating pheromone in eastern Tennessee. The goal is to disrupt the moth's mating practices to halt population growth. "This insect pest is one of the greatest threats to Tennessee's forests," State Forester David Arnold said. "High populations of this moth can result in widespread tree defoliation and over consecutive years, that can lead to tree decline. This treatment will protect the forest by reducing the population of this invasive pest" (TDA 2023). The lack of established populations in more of Tennessee has been primarily due to the success of the extensive preventive trapping and treatments that have been conducted over the past 50 years.

The ***Southern Pine Beetle*** (*Dendroctonus frontalis*) is one of the most widespread and destructive insect pests of pine. Loblolly pine (*Pinus taeda*), shortleaf pine (*Pinus echinata*), pitch pine (*Pinus rigida*), pond pine (*Pinus serotina*), and Virginia pine (*Pinus virginiana*) are the favored host species, although other pine tree species may be susceptible during outbreaks. The Southern Pine Beetle population gradually built to outbreak levels in 1998 and killed approximately 350,000 acres and $358 million of pine tree stock in the succeeding years. These die-offs drove pine prices down as markets were flooded with salvaged pine sawtimber and pulpwood (ProtectTNForests.org [date unknown]). While this pest is native to North America, its periodic outbreaks have caused significant economic losses in Tennessee and many other states in the southern and eastern US.



Southern Pine Beetle forest damage / Ronald F. Billings, Texas A&M Forest Service, Bugwood.org

The ***Spotted Lanternfly*** (*Lycorma delicatula*) is an invasive plant hopper native to China, India, Japan, South Korea, and Vietnam and was first detected in the United States in Pennsylvania in September 2014. Since the initial detection, this pest has spread to 14 states, with recent detections in southwest Virginia and western North Carolina, and as of 2024, in Davidson and Wilson Counties in Tennessee.

This pest is primarily known to attack its preferred host, Tree of Heaven (*Ailanthus altissima*), itself an invasive exotic species--although well over 70 species of plants can be impacted. Some of these other host plants include apples, grapes, and hops, and a variety of other fruit and ornamental trees, shrubs, and vines. This insect also feeds on maple, walnut, and poplar.

Spotted Lanternflies are invasive and can spread rapidly when introduced to new areas. While the insect can fly short distances, its long-distance spread is facilitated by people who move infested

Spotted Lanternflies from left to right: Nymphs, fourth instar / Stephen Ausmus, USDA-ARS; Adult Lanternflies / Lance Cheung, USDA; Newly laid egg mass with an adult nearby / Lance Cheung, USDA

material or items containing egg masses. Given its current limited distribution, Tennessee's focus is on monitoring and surveying for Spotted Lanternfly so that managers can respond to any new detections in the state.

Invasive and exotic animals

Exotic animals pose similar problems to invasive plants and insects, and in addition they can directly impact native animal populations through competition, predation, and displacement from their habitat. The following are examples of current threats posed by exotic animals.

Invasive crayfish pose a significant ecological threat in many areas of the state, as highlighted in the Tennessee Aquatic Nuisance Species (ANS) Management Plan (TANSTF 2008). Competition from both translocated native crayfish, often introduced to new drainages through bait bucket releases, and nonnative crayfish species can displace or contribute to the decline of native populations, reducing overall biodiversity. For example, the invasive Kentucky River Crayfish (*Faxonius juvenilis*), Rusty Crayfish (*Faxonius rusticus*), and Virile Crayfish (*Faxonius virilis*) are all known for aggressive behavior and ability to outcompete native species. The Surgeon Crayfish (*Faxonius forceps*) has been outcompeted and extirpated from such a large area of its total range it was elevated to Threatened status on the Tennessee State Threatened and Endangered list.

Asiatic Carp species (*Hypophthalmichthys* and *Ctenopharyngodon* spp.), also noted in Tennessee's ANS Plan, are a problem for big river SGCN. Invasive nonnative populations escaped from aquaculture facilities or were in shipments of stocked grass carp. Silver carp (*H. molitrix*) compete for food with native plankton-eating species including Paddlefish (*Polyodon spathula*), Bigmouth Buffalo *(Ictiobus cyprinellus*), Gizzard Shad (*Dorosoma cepedianum*), the larval fishes of many species, and freshwater mussels. The noise of boat motors cause Silver Carp to leap out of the water, creating the potential for human injury or fatality. Commercial fishermen have abandoned fishing sites on the Missouri River due to the high numbers of invasive carp in their nets (TANSTF 2008).

Alabama Bass (*Micropterus henshalli)* introductions have the potential to significantly disrupt native black bass (*Micropterus spp.*) populations. In areas where they have been illegally introduced, Alabama Bass have also hybridized with Smallmouth Bass (*Micropterus dolomieu*) and drastically reduced some populations, leading to the possible extirpation of native Smallmouth Bass fisheries of great cultural and economic importance. Alabama Bass are nearly identical in appearance to Tennessee's native Spotted Bass. Physical characteristics are often indistinguishable between these species and can require genetic analysis to properly identify. In instances of hybridization with Smallmouth Bass, visual identification can be nearly impossible, creating issues for anglers and law enforcement when following or enforcing regulations, respectively. Recent introductions in North Carolina and Georgia have altered bass populations and significantly reduced their numbers through competition and hybridization. In the case of Georgia's Chatuge and Blue Ridge lakes, the introduction of Alabama Bass has decimated the local Smallmouth Bass fishery. Likewise, North Carolina's Lake Norman has seen dramatic declines in Largemouth Bass (*Micropterus nigricans*) populations. In Tennessee, reservoirs on much of the Tennessee River system have been impacted, including resources such as Ft. Loudon, Watts Bar, Chickamauga, Nickajack, and Pickwick. Further introduction of Alabama Bass to Tennessee's premier Smallmouth Bass fisheries, such as Dale Hollow, could be devastating. Tennessee has initiated efforts to evaluate baseline genetics of Black Bass and will continue to monitor the impact of Alabama Bass introductions and work to educate anglers about the negative impacts of illegal fish stockings. Additionally, Tennessee has had to make changes to Black Bass regulations as a result of the introduction of Alabama Bass.


Alabama Bass (*Micropterus henshalli)* / TWRA

Mosquitofish (*Gambusia* spp.) are widely introduced as mosquito control agents. According to the Tennessee ANS Plan, critical reviews of the literature do not support the view that they are very effective in reducing either mosquito populations or mosquito-borne diseases. Depending on what they choose to eat, Mosquitofish introductions can lead to algal blooms or even cause an increase in mosquitoes (USFWS 2016). Mosquitofish are extremely aggressive and can affect native fishes through direct competition and often attack, kill, or eat other fishes. In Tennessee, they pose a threat to imperiled Barren's Topminnow (*Fundulus julisia*) causing the extirpation of multiple populations and threatening others in the few remaining sites where this species occurs (TANSTF 2008).

Feral Swine (*Sus scrofa*), also known as feral hogs, were introduced to North America by European settlers and are hunted in the US; however, they also have extremely destructive impacts on the habitats of native wildlife and agriculture. They cause extensive damage to agriculture, wildlife habitat, and plant populations; contribute to erosion and water pollution; and carry diseases harmful to livestock and other animals as well as humans. (They can carry at least 30 diseases, including Brucellosis, and nearly 40 types of parasites, such as toxoplasmosis and trichinosis, which may affect people, pets, livestock, and wildlife. (USDA APHIS 2024a).

Swine brucellosis is an infectious disease caused by the bacteria *Brucella suis* (*B. suis*). It was eliminated from commercially raised swine in the US in 2011, but pigs are still at risk of contracting the disease from feral hogs (USDA 2024b) In some areas, feral swine have been the cause of elevated waterborne bacteria levels in streams and irrigation canals, which is another risk for human health (USDA APHIS 2024a). Feral swine are prolific reproducers and do massive damage to the land through feeding and wallowing. They are also omnivorous and will eat just about anything they can find. Feral swine depredation can cause turkeys, ground-nesting birds, amphibians, and reptiles to suffer population decreases (Cox 2014). Feral swine also root up acres of land, including native plant populations, which requires significant time and money to repair. The damage that feral swine cause has become more common as they have spread from approximately 15 Tennessee counties in 1982 (TWRA unpublished data) to 89 counties in 2013 (Jerrolds & Derroch 2014). Nationwide, they range has increased from 17 to 39 states in the US in the last 30 years (Bevins and Franklin 2014). (Ch. 6 and Appendix J both discuss control of Feral Swine).


Feral Swine rooting in a stream / USDA APHIS WS Ohio

Double-crested Cormorants *(Phalacrocorax auritus)* in Tennessee illustrate that, in some circumstances, even native species can become invasive and cause damage to other wildlife species or conflict with humans. To learn more, see the Managing Populations That are Too Large Highlight.

4.6. Pollution

4.6.1. Air Pollution

Acid Rain

Acid precipitation is caused by air pollution, primarily nitrogen oxides and sulfur dioxide from the burning of fossil fuels for electricity production and, to a lesser degree, nitrogen oxides in automobile exhaust. These chemicals react in the atmosphere to form nitric and sulfuric acids, which fall to earth as both wet and dry deposition (EPA 2024a).

MANAGING POPULATIONS THAT ARE "TOO LARGE"

The **Double-crested Cormorant** (*Phalacrocorax auritus*) is one of nine colonial nesting waterbird species that breeds in Tennessee. Colonial nesters tend to nest together, often with other similar species, in colonies called rookeries.

The Double-crested Cormorant (DCCO) is also a species whose populations in the state and across the country have exploded over recent decades, for reasons uncertain. The bird has expanded its breeding range in Tennessee from a few nests in two counties in the 1980s to over 3700 nests at 25 sites across the state in 2018.

The cormorant is a diving bird that fishes for a living, and as such it is considered far too successful by some. "Conflicts are wide-ranging but are most often associated with the need to reduce predation-related losses of wild or stocked fisheries (both private and commercial) and stocks at aquaculture facilities and hatcheries" (USFWS 2022).

In 2016, a US District Court vacated two depredation orders issued by the US Fish and Wildlife Service (USFWS) to control DCCO populations (through lethal means) until a more thorough environmental assessment (EA) could be prepared, which would take a "hard look" at the effects of the orders on cormorants and fish as well as examine other potential management alternatives (USDOI 2018).

Black-crowned Night Heron, an SGCN believed to be suffering from competition with Double-crested Cormorants in Tennessee / j van cise photos

"TAKE" - HOW MUCH IS TOO MUCH?

In 2021, after developing a new Environmental Assessment (EA) of its DCCO depredation orders, the US Fish and Wildlife Service stated, "To meet obligations under the Migratory Bird Treaty Act, all Service actions must be compatible with the conservation of migratory species. Therefore, to allow *this level of take*, the Service must ensure the cormorant population data are sufficient to assess the cormorant populations in the future" (USFWS n.d.).

Two Great Blue Herons / David Hanni, TWRA

"This level of take" refers to the new maximum allowable take levels developed by the USFWS in the new EA. The continental (US and Canada) DCCO population in 2020 was estimated at from 870,000 to >1 million birds. Under the final rule that establishes the new permit, the maximum allowable take of cormorants totals 121,504 cormorants per year within the lower 48 states. The new depredation order is dependent on good monitoring data so that all concerned will understand the impacts to cormorants and other species.

The new EA allows take for reasons related to health, human safety, and aquaculture. To accomplish the monitoring required, a "cross-flyway" monitoring team was established to coordinate information among all four continental flyways. Prior to this, coordinated monitoring with shared objectives and standardized methods (allowing comparison of data across states and flyways) did not exist.

The cross-flyway team recommended next steps for the years 2022 - 2026. The rigorous collection of data is meant to accomplish three goals:

- Adequately assess cormorant abundance and ensure the populations remain at sustainable levels;

- Test the model used for developing the "maximum allowable take";
- Ensure that the regulation of take allows maximum flexibility to manage cormorants when needed.

David Hanni, Tennessee's Bird Conservation Coordinator said TWRA opted to begin its monitoring program with a census of all colonial waterbird sites. For this work, **Maddy Buckner** was hired as a seasonal **Colonial Waterbird Coordinator**, and in 2024 she conducted >170 surveys. The Tennessee DCCO population seems to be leveling off or decreasing. TWRA's 2024 effort, part of a nationwide survey, counted approximately 3400 nests in Tennessee. Final national, regional, and state-specific surveys were reported in September 2025, and USFWS decisions on annual allowable take will follow. These reported numbers will be used for future management decisions related to DCCO.

Double-crested Cormorants on the nest / David Hanni, TWRA

Double-crested Cormorant/Colonial Nesting Survey Partners

DCCO Cross-Flyway Monitoring Teams
Tennessee Wildlife Resources Agency
US Fish and Wildlife Service

Nesting Double-crested Cormorant and Great Blue Heron sharing rookery habitat / David Hanni, TWRA

WHAT DCCO HAVE IN COMMON WITH PEOPLE

Double-crested Cormorant numbers in Tennessee have grown, and in some cases are impacting other Species of Greatest Conservation Need (SGCN). Hanni is concerned that cormorant fecal matter in rookeries can be so great (creating a "whitewash" effect on vegetation) that it kills the shrubby layer or all the vegetation beneath their nesting trees. "This may be affecting Black-crowned Night Herons, which nest in the shrubby layer and have been declining in recent years. For example, their nest sites on Little Elder Island have been almost completely destroyed. While these birds occupy different habitat niches, they nest in the same places."

Threats to human safety also arise after rookery vegetation dies. Since colonies are concentrated on islands or peninsulas (for protection from predators), they are often near areas of heavy boat recreation use. Wave action from boats erodes the islands that have lost vegetation, and as the island subsides, the barely submerged vegetation poses a navigational risk to boaters. Hatchery trout pit tags recovered from beneath a cormorant rookery also seem to indicate heavy cormorant predation of these fish.

No one really knows why DCCO numbers have taken off in Tennessee. Questions that Hanni would like to answer include, did the birds stop migrating further north to nest, and if so why? Is habitat to the north saturated? What are the juveniles doing? What is their foraging range? Has their diet changed? Hanni believes that "take is not going to solve the problem, it will be more habitat manipulation and controlling productivity [such as oiling eggs or destroying nests]. The overarching issue is how can we all live together?" So many of the issues that affect birds come from human use of the landscape (habitat loss, window strikes, cat predation, hatcheries). "As our use of the landscape changes and species' use changes to take advantage of that, we usually focus on species, not our own impacts and behavior."

The reality is Double-crested Cormorant numbers are taking off and causing huge problems for other species—kind of like people.

USFWS. 2022c. US Fish and Wildlife Service Final Report: Recommendations for Implementing a Monitoring Strategy for Double-crested Cormorant Subpopulations in the United States.
USFWS. ("Expanding Management of Conflicts Associated with Double-crested Cormorants | US Fish & Wildlife Service," n.d.) https://www.fws.gov/regulations/cormorant/populations
USDOI. 2018. ("Cormorant Mismanagement | US Department of the Interior" 2018) https://www.doi.gov/ocl/cormorant-mismanagement

Decades of research have made it clear that acid rain causes slower growth, injury, or death of forests by:

- damaging leaves
- limiting the nutrients available to plants
- exposing plants to toxic substances that are slowly released from the soil.

(EPA 2024a, USFS 2013)

Acid rain has contributed to forest and soil degradation in many areas of the eastern US, particularly high elevation forests of the Appalachian Mountains that include areas such as the Great Smoky Mountains National Park (EPA 2024a). Acid rain, coupled with other problems such as invasive exotic species, pathogens, and climate change, has decimated Tennessee's high elevation spruce-fir forest. These forests provide important habitat for several rare and endangered species, such as the Spruce-fir Moss Spider (Gunnarsson and Johnson 1989, TWRA 2005).

Southern Appalachian Brook Trout range / National Park Service

The effects of acid deposition in aquatic systems are no less severe. It causes a cascade of effects that harm or kill individual fish, reduce populations, extirpate fish species from a waterbody, and decrease biodiversity. In watersheds where soils do not have a buffering capacity, acid rain also releases aluminum from the ground into lakes and streams. Both increased acidity and aluminum are toxic to fish (EPA 2024a).

TDEC has listed 41 miles of park streams as having a very low pH level (very acidic) and considers them to be impaired, which means the streams are less able to support mayflies, caddisflies and salamanders. Acidic streams are suspected to be the main cause for the decline of the native Brook Trout (*Salvelinus fontinalis* population in the park (NPS 2015a).

The range of the Southern Appalachian Brook Trout is greater than just the Great Smoky Mountains National Park, but the Park has been a pioneer in research related to Brook Trout genetics, population monitoring, restoration, and other Brook Trout studies by local, state, and federal agencies and a myriad of universities (NPS 2015c).

While all streams in the park are more acidic than they were 20 years ago and may still require decades to recover, air quality is improving. From 1995-2022, nationwide annual emissions of sulfur dioxide from power plants fell by 93 percent and annual emissions of nitrogen oxides from power plants fell by 87 percent (EPA 2023a).

From 1995-2022, annual emissions of SO2 from power plants fell by 93 percent and annual emissions of NOX from power plants fell by 87 percent. In 2022, sources in both the Cross-State Air Pollution Rule SO2 annual program and the Acid Rain Program together emitted 0.85 million tons, a reduction of 11 million tons from 1995 levels. In 2022, sources in both the Cross-State Air Pollution Rule NOX annual program and the Acid Rain Program together emitted 0.75 million tons, a reduction of 5.1 million tons from 1995 levels (US EPA 2023a).

Ozone Pollution

Ground level ozone pollution (as opposed to the protective stratospheric layer) is a problem in GSMNP and other regions of the state. It derives from sources similar to those that create acid rain, i.e., from pollutants emitted by cars, power plants, refineries, and other industrial sources. Specifically, chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) create ground level ozone (EPA 2024b). Ozone exposure levels on park ridge tops are up to twice as high as those in Knoxville and Atlanta. These levels are sufficient not only to injure trees and plants, but also to threaten human health. Research has found that the following plants show signs of ozone damage in GSMNP: black cherry (*Prunus serotina*), milkweed (*Asclepius* sp.), tuliptree (*Liriodendron tulipifera*), sassafras (*Sassafras albidum*), winged sumac (*Rhus copallinum)*, blackberry (*Rubus* sp.), and cutleaf coneflower (*Rudbeckia laciniata*) (NPS 2015b).

4.6.2. Mercury

Mercury can cause both air and water pollution and is thus dealt with in its own category. Fish sampling surveys in the US have shown widespread mercury contamination in streams, wetlands, reservoirs, and lakes, with 33 states—including Tennessee—having issued fish consumption advisories due to mercury contamination. Metals, which include mercury, are the most common cause of pollution in Tennessee lakes and reservoirs (TDEC 2024a). As of 2022, Sections of 21 rivers and streams have been posted for elevated levels of mercury in fish tissue (TDEC 2022a).

Smoke stack, a significant source of mercury / Dave Sizer

Levels of mercury measured in air and surface water are low, and in natural waters, inorganic mercury is generally not a health concern. The real issue is methylmercury, an organic form that is highly toxic to the nervous system. Methylmercury is produced from inorganic mercury by methylation, a microbial process. More than 95 percent of all mercury in fish is methylmercury, and this form of mercury biomagnifies to high concentrations at the top of food chains (USGS 2019a).

Bioaccumulation is the process by which organisms (including humans) can take up contaminants more rapidly than their bodies can eliminate them, causing mercury levels in their bodies to accumulate over time. This can contribute to biomagnification, the buildup of contaminants through the food chain.

Mercury contamination is global and affects many waters that have no obvious mercury source, since mercury emissions disperse widely in the atmosphere before being deposited to the earth's surface. Mercury is emitted by natural sources, such as volcanoes and geothermal springs, while human-related sources primarily include coal combustion, waste incineration, industrial uses, and mining. During the last 150 years, human activities have more than doubled natural amounts of mercury in the atmosphere (USGS 2019a).

However, from 2013 to 2022, releases of mercury to air in the US decreased by 57%. An 85% reduction (-41,000 pounds) in mercury air emissions from electric utilities drove the overall decline. EPA's 2012 Mercury and Air Toxics Standards or MATS, set technology-based emissions standards for mercury and other hazardous air pollutants (HAP). MATS—along with a shift from coal to other fuel sources and the installation of pollution control technologies at coal-fired power plants (EPA 2024c)—has achieved significant health and environmental benefits by reducing a broad range of hazardous air pollutants. By 2017 mercury emissions had dropped by 86 percent, down to approximately 4 tons. In 2025, the current US administration plans to reconsider this rule (EPA 2025).

4.6.3. Water Pollution

The Tennessee Water Quality Control Act of 1977 defines pollution as activity that will result or will likely result in harm, potential harm or detriment to the public health, safety, or welfare or will likely result in harm, potential harm, or detriment to the health of animals, birds, fish, or aquatic life.

As TDEC regulates and monitors surface waters in Tennessee, it is unlawful for any person to carry out any activity which results in the alteration of the physical, chemical, radiological, biological, or bacteriological properties of any waters of the state, including wetlands, except in accordance with the conditions of a valid permit.

Tennessee contains 60,447 miles of streams, and 586,985 acres of lakes and reservoirs. Approximately 50% of streams and 98% of lakes and reservoirs are monitored, and this has demonstrated that approximately 60% of streams and rivers and 48% of lakes and reservoirs are impaired largely due to pollution (TDEC 2024b).

Since 2014, the percentage of stream mileage capable of fully supporting aquatic usages has decreased (Fig. 4.6).

Aquatic habitat and life can both be negatively affected by pollutants—often a result of land use impacts related to development, industrial discharge, agricultural runoff, or other activities.

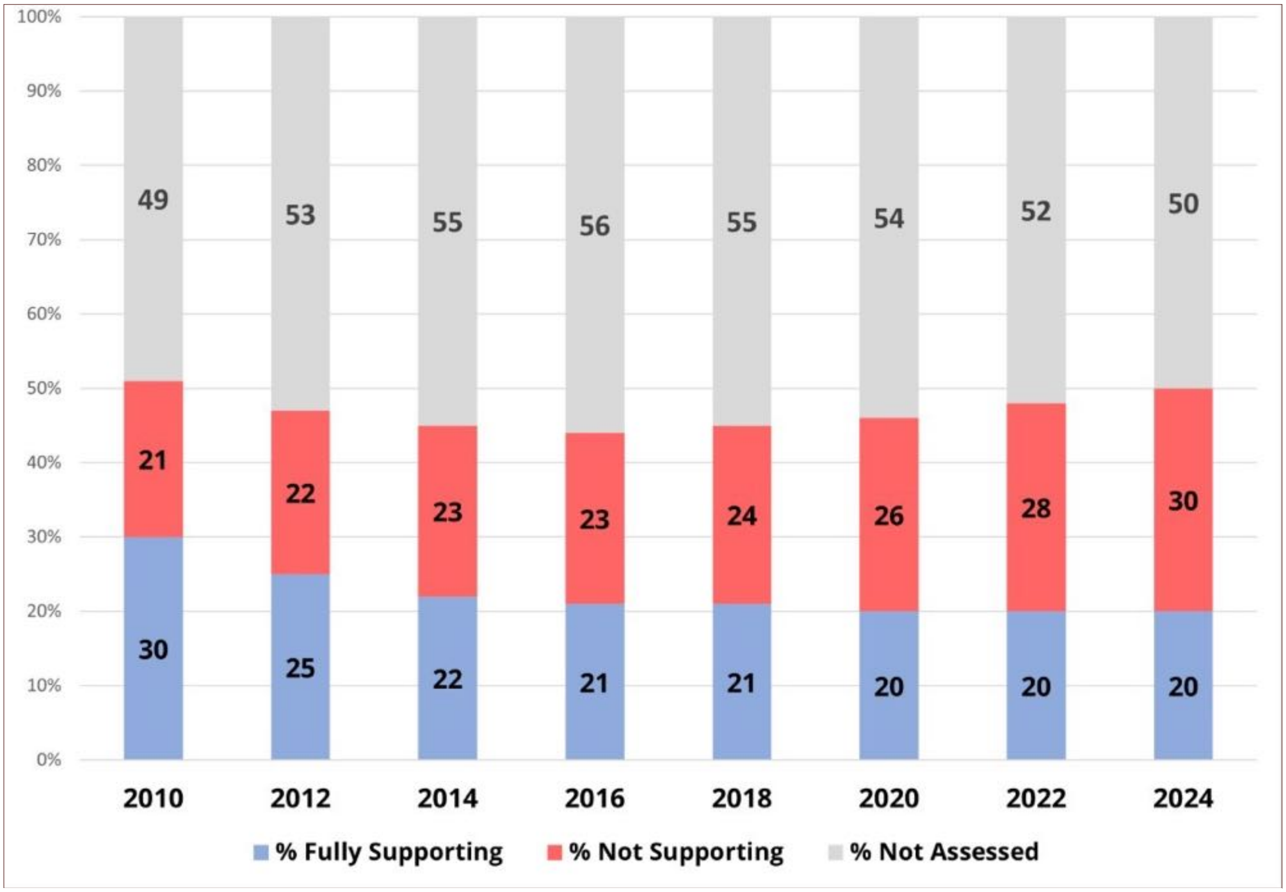


Figure 4.6 Overall use support status for streams in Tennessee

Pollutants are often carried in sediments, and sedimentation can lead to embeddedness of stream substrates (wherein fine sediments like sand and silt cover or surround larger rocks and gravel), which in turn degrades aquatic habitats.

Sources of pollution from developed areas commonly include fertilizers, pesticides, animal waste, septic tanks, sewage, trash, erosion from construction, vehicular fluids, and industrial and commercial site runoff. These sources contribute in-stream contaminants, including nitrogen, chloride, insecticides, and polycyclic aromatic hydrocarbons (PAHs). A USGS study found that aquatic invertebrate communities begin to degrade from the onset of urban development, which indicates that some species are highly sensitive to physical and chemical changes associated with urban development (USGS 2009). In 2018, a German chemist floated the length of the Tennessee River collecting samples and found alarmingly high levels of microplastics, ranging from 16,000 to 18,000 particles per cubic meter, compared to 200 particles per cubic meter in Germany's Rhine

Single use plastic along the banks of the Tennessee River / Tennessee Aquarium

River (Gibbens 2018). Dumping of garbage into Tennessee rivers has also been identified as an issue in several COAs.

Tennessee's Clean Water Act Monitoring & Assessment Report (TDEC 2024b) provides a comprehensive summary of water quality assessments (see Tables 4.2. and 4.3.). Agriculture, hydrologic modification, and municipal and non-point dischargers are identified as the top three sources of pollutants to impaired Tennessee streams. The most common causes of pollution in lakes and reservoirs have been found to be metals and toxic organics such as PCBs and dioxins, and the sources are atmospheric deposition (e.g., mercury in the air) and legacy/historical sources (e.g., abandoned mines) (TDEC 2024a).

4.7. Climate and Resilience

The primary emphasis of Tennessee's 2015 SWAP companion report, Climate Change Vulnerability Assessment for Tennessee Wildlife and Habitats (Glick et al. 2015) was to use a multi-faceted approach and examine three major aspects of climate change impacts: species vulnerabilities, terrestrial and aquatic habitat changes, and landscape resiliency. Fig. 4.7 summarizes these three major elements: assessment of species vulnerability using NatureServe's Climate Change Vulnerability Index (CCVI) (Young et al. 2011); assessment of terrestrial habitat vulnerability to climate stress including vegetation change; and evaluation of relative landscape resilience based on geophysical settings (Anderson et al. 2014.) The focus on these elements together was intended to provide managers with a more comprehensive picture of climate change vulnerability by incorporating factors relevant to both species and habitats. The three-element approach is adapted from ideas piloted by the North Atlantic Landscape Conservation Cooperative for the Connecticut River watershed (NALCC [date unknown]).

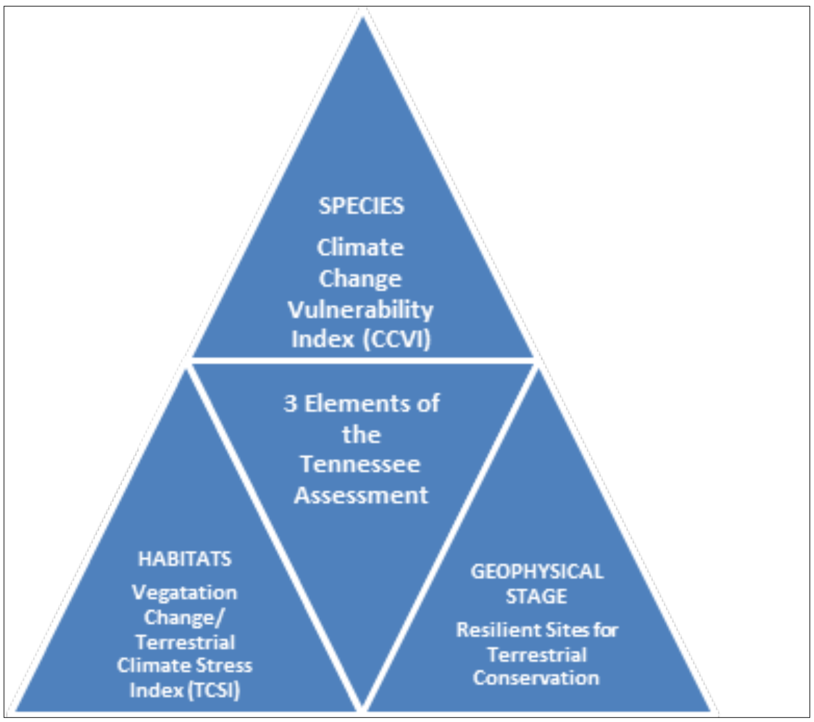


Figure 4.7 Three elements of the Tennessee Assessment

The text and maps in the following sections are excerpted from the Tennessee Climate Change Vulnerability Assessment companion report to serve as a general overview of the results and application of the assessment work for informing further prioritization and strategy development during the SWAP updates. A more exhaustive and systematic analysis of climate change and severe weather impacts as well as adaptation measures and the importance of resilience in landscapes is provided in Chapter 5.

4.7.1. Species and Habitat Vulnerability Summaries

State fish and wildlife experts used NatureServe's Climate Change Vulnerability Index (CCVI) (Young et al. 2011) to assess a total of 189 plant and animal SGCN, including 15 mammals, 51 birds, 17 reptiles, 26 amphibians, 19 fish, 27 freshwater mussels, 8 crayfish, and 26 plants. Sixty-three percent (119) of the 189 species assessed scored as "Presumed Stable" or "Increase Likely," and 37 percent (70 species) were considered at least Moderately Vulnerable (see Glick et al. 2015 for detailed species scores).

Mammals, birds, and reptiles comprised most of the species ranked as Presumed Stable or Increase Likely due, in part, to their mobility and other factors that enhance their adaptive capacity. Plants, fish, and mussels comprised the greatest number of species that ranked as Moderately, Highly, or Extremely Vulnerable for a variety of reasons, including the presence of natural and anthropogenic barriers to dispersal, restricted habitat range, and high levels of sensitivity to changes in temperature and moisture. Fig. 4.8 provides a comparison of the CCVI vulnerability scores summarized across taxonomic groups. For more specific information on the scoring process and results, see Glick et al. (2015).

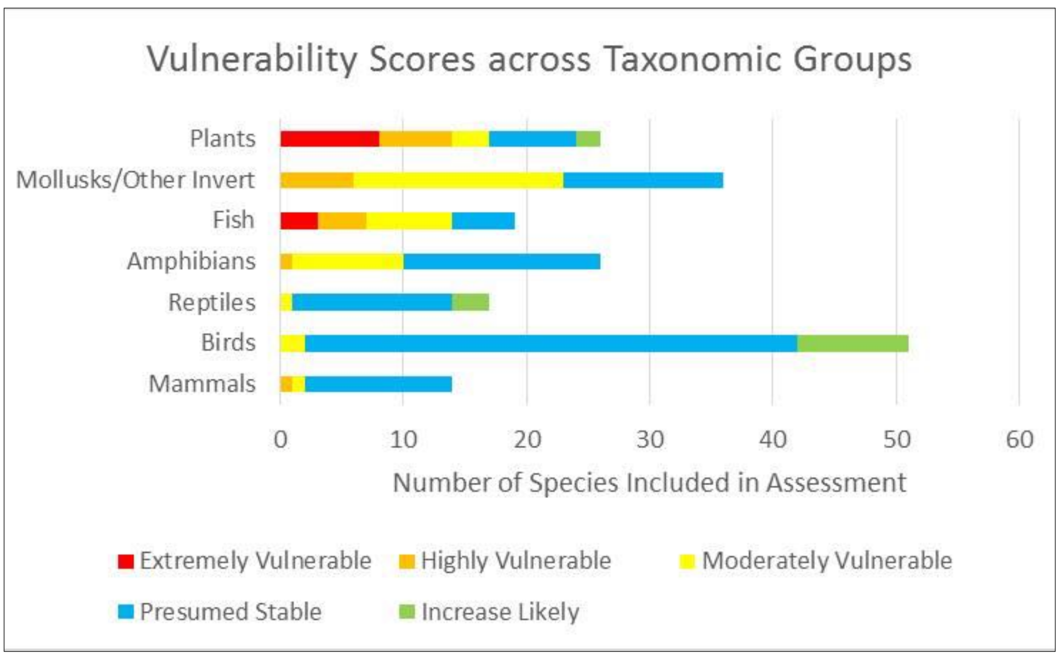


Figure 4.8 Comparison of CCVI vulnerability scores across taxonomic groups (For more specifics on the scoring process and results, see Glick et al. 2015.)

Some of the most significant impacts of climate change on Tennessee's fish and wildlife species will be associated with potential changes to their habitats. Notable impacts include the following:

- Changes in the composition of plant communities in both forest and grassland systems, particularly in the western portion of the state

- An increase in the frequency and severity of disturbances such as wildfires and outbreaks of already-problematic species such as Southern Pine Beetle (*Dendroctonus frontalis*) and Hemlock Wooly Adelgid (*Adelges tsugae*)
- Shifts in the location and extent of suitable habitat for fish and other aquatic species due to higher water temperatures and altered water quality, with areas of coldwater habitat in mountain streams likely to decline and warmwater habitat projected to expand
- Changes in the timing and magnitude of stream flows and other hydrological conditions, including increased drying of ephemeral pools important to amphibians and other wildlife.

Given the complexities and uncertainties in climate projections and associated impacts, the general challenge for managers may be to consider how to transition Tennessee from its current mix of terrestrial habitats to a different mix without losing biodiversity (Joyce et al. 2008). The state's upland forest systems, for instance, support a great diversity of wildlife due in part to the variety of different habitats and niches found within a structurally diverse forest system (TWRA 2014). A study conducted at the Tennessee Aquarium Conservation Institute (Hoffacker 2018) demonstrated the vulnerability of salamander communities rises in stream water temperatures. Warmer stream temperatures mean salamander communities will not be structured the same way, which could have broader ripple effects through their communities. Managing for a diversity of habitat types, even if the composition of associated vegetation changes, may still support desired conditions for valued fish and wildlife.

With many of Tennessee's highly diverse aquatic species already considered at-risk for a variety of reasons, the additional threat from climate change is likely to exacerbate conservation concerns (TWRA 2009). Indeed, it is the combination of climate change and other stressors such as polluted runoff and barriers to stream connectivity that will have the greatest impact on aquatic habitats and the species that depend on them (Sun et al. 2008). An integrated approach to managing aquatic species and habitats that takes into account multiple stressors, including climate change, will be important to help the state meet its short- and long-term wildlife conservation goals.

4.7.2. Spatial Vulnerability Assessment Maps

Tennessee's 2015 vulnerability assessment also included a spatial analysis of climate change vulnerability across terrestrial habitats to help inform a landscape level understanding of potential issues across the state. The landscape vulnerability assessment drew from the approaches used by Joyce et al. (2008), Kershner and Mielbrecht (2012), and Anderson et al. (2014), with a focus on terrestrial habitat priorities updated by the 2015 SWAP (Glick et al. 2015). Several existing datasets and maps from these approaches were synthesized in the assessment, including:

- Terrestrial SGCN Habitat Priority areas in Tennessee
- Potential vegetation change using a Terrestrial Climate Stress Index
- Resilient Sites for Terrestrial Conservation in Tennessee.

Since 2015, the science of landscape-level climate resilience has grown, and much of the accumulated knowledge and tools for measuring climate impacts, mapping resiliency, and prioritizing sites for conservation have been collected into the **Center for Resilient Conservation Science** (CRCS), a project of The Nature Conservancy. The site includes interactive maps and conservation datasets that showcase the results of CRCS projects, as well as the **Resilient and Connected Network Tool**. This topic, as well as resilient landscape mapping is discussed in more detail in Ch. 6 Conservation Actions.

Seal Salamander (*Desmognathus monticola*), one species that could be affected by rises in stream water temperatures / Peter Paplanus