Species Status Assessment (SSA) Report

for the

Tippecanoe Darter

(*Etheostoma tippecanoe*)

Version 1.0

Tippecanoe darter (Photo credit: Robert Criswell)

March 2018
U.S. Fish and Wildlife Service
Northeast Region
Hadley, MA

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Contents

EXECUTIVE SUMMARY

This report summarizes the results of a species status assessment (SSA) conducted for the Tippecanoe darter (*Etheostoma tippecanoe*). This report is intended to provide the biological support for the decision on whether or not to propose to list the species as threatened or endangered under the Endangered Species Act of 1973, as amended (Act). The process and this SSA report do not represent a decision by the U.S. Fish and Wildlife Service (Service) whether or not to list a species under the Act. Instead, this SSA report provides a review of the best available information strictly related to the biological status of the Tippecanoe darter.

Background

The Tippecanoe darter is a small, freshwater fish endemic to 4th order and larger streams and rivers within the Ohio Region watershed in Pennsylvania, Ohio, Indiana, Kentucky, Tennessee and West Virginia. Tippecanoe darters prefer riffles and runs with cobble-gravel bottom substrates and adequate water flow to keep spaces between and under rocks (where they spend most of their time sheltering) free from sediment. Females completely bury themselves in the substrate under the male to lay their eggs during spawning. Tippecanoe darters are opportunistic benthic insectivores, consuming benthic macroinvertebrates in proportion to their availability in the environment. Tippecanoe darters are sexually mature at 1 year of age and live to a maximum age of 2 years.

Tippecanoe darter populations are widespread but disjunct. Dams currently influence the species' distribution and connectedness over its range, particularly where they have eliminated habitat or led to isolated populations. Stressors to water quality, particularly sediment, have also likely influenced their current distribution. However, the Tippecanoe darter has been increasing in distribution in recent years within multiple watersheds, likely due to improved water quality coupled with improved survey techniques that are more effective at capturing this small (approximately 1-inch) benthic fish.

Methodology

To assess the biological status of the Tippecanoe darter across its range, we used the best available information, including peer reviewed scientific literature and first-hand accounts and survey data provided by State agencies and academic institutions from Pennsylvania, Ohio, Indiana, Kentucky, Tennessee, and West Virginia. Fundamental to our analysis of the Tippecanoe darter was the determination of analytical units (*i.e.*, populations) at a scale useful for assessing the species. We defined Tippecanoe darter populations based primarily on known occurrence locations and continuity, identifying a total of 15 individual Tippecanoe darter populations with which to conduct our assessment.

To qualitatively assess the current condition of populations we considered components describing characteristics about each population's demography (occupancy, occupancy extent, and connectivity between populations) and physical environment (water quality). These metrics were selected because the supporting data were consistent across the range of the species and at a resolution suitable for assessing the species at the population level. The model output was a condition score for each Tippecanoe darter population that was then used to assess the Tippecanoe darter's current condition across its range under the "3Rs," described below:

> **Resiliency** means having sufficiently large populations for the species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size, if that information exists. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of human activities.
>
> **Redundancy** means having a sufficient number of populations for the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk and can be measured through the duplication and distribution of populations across the range of the species. Generally, the greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.
>
> **Representation** means having the breadth of genetic makeup of the species to adapt to changing environmental conditions. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of the species' morphology, habitat characteristics within the geographical range, or both.

The same methodology was used to assess the species' condition and potential viability under three future scenarios. We chose to model these scenarios at 10, 25, and 50 years because we have data to reasonably predict potential habitat and water quality changes within this timeframe. Scenario 1 modeled the continuation of current trends where we assumed similar rates of urban development, maintenance of water quality, and increased occupancy extent and connectivity. Scenario 2 modeled the optimistic scenario where we assumed a decrease in the rate of urban development, an increase in water quality with concomitant increases in occupancy extent and connectivity, and an increase in occupancy from reintroducing Tippecanoe darters into a watershed where they are currently believed to be extirpated. Lastly, Scenario 3 modeled the pessimistic scenario where we assumed decreasing water quality with concomitant decreases in occupancy extent and connectivity.

Conclusions

Current Condition

The Tippecanoe darter is currently distributed in 12 (80 percent) of the historical 15 populations, 2 are unknown, and 1 is extirpated (representing a complete loss of resiliency in that population).

The Tippecanoe darter is present within all three physiographic provinces from which it is historically known (Appalachian Plateaus, Central Lowland, and Interior Low Plateaus), and survey data suggest the species is expanding in some populations. We qualitatively assessed the extant populations, placing them in "low," "moderate," or "high" categories that represent the populations' potential to bounce back after stochastic events. Of the 12 known extant populations, 5 (33 percent) have a current score of high resiliency, 3 (20 percent) have moderate to high resiliency, and 4 (27 percent) have moderate resiliency. Therefore, we conclude Tippecanoe darter populations currently have moderate to high resiliency.

The Tippecanoe darter currently occurs in at least 80 percent of its historical range (12 of 15 known populations). Redundancy for the Tippecanoe darter is evidenced by multiple extant populations distributed across three physiographic provinces (*i.e.*, six populations in the Appalachian Plateaus, three populations in the Central Lowland, and five populations in the Interior Low Plateaus). The current spatial extent of each population is either static or expanding. Because all current known populations of Tippecanoe darter exhibit moderate to high resiliency, as determined under our current resiliency assessment, the species is considered to also have moderate to high redundancy.

The Tippecanoe darter currently maintains representation in multiple watersheds within all three physiographic provinces from which it is historically known. As related to the species' diversity of environmental settings, the Tippecanoe darter is widely distributed, and the spatial extent of each extant population is either static or expanding. Given the Tippecanoe darter retains representation in three physiographic provinces, and maintains the same (with one exception) distribution it had historically, we conclude that the species' representation is moderate to high.

Future Condition

Under Scenario 1 (continuation of current trend), the condition of 12 Tippecanoe darter populations is predicted to remain relatively unchanged from the current condition, and the condition of 3 populations is predicted to have improved within 50 years. Under Scenario 1, the species' redundancy and representation remained unchanged (*e.g.*, all current populations remained extant), and the resiliency of the four improved populations is predicted to increase.

Under Scenario 2 (optimistic scenario), the condition of 11 Tippecanoe darter populations is predicted to remain relatively unchanged from the current condition, and the condition of 4 populations is predicted to have improved within 50 years. Under Scenario 2, the species' redundancy would improve (the addition of a single population), representation would remain unchanged, and the resiliency of the five improved populations is predicted to increase.

Under Scenario 3 (pessimistic scenario), the condition of 12 Tippecanoe darter populations is predicted to remain relatively unchanged from the current condition, and the condition of 3 populations is predicted to decrease within 50 years. Under Scenario 3, the species' redundancy and representation remained unchanged (*e.g.*, all current populations remained extant), although the resiliency of three populations is predicted to decrease.

Summary

We considered what the Tippecanoe darter needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation. For the purpose of this assessment, we generally define viability as the ability of the Tippecanoe darter to sustain populations in natural river ecosystems over time. Based on the Tippecanoe darter's life history and habitat needs, we identified the potential negative and positive influences and the contributing sources of those influences that are likely to affect the species' viability. We evaluated how potential influences may be currently affecting the species and whether, and to what extent, they would affect the species in the future. Dams currently influence the species' distribution and connectedness over its range, particularly where they have eliminated habitat or led to isolated populations. We identified numerous stressors to water quality that have occurred and to some extent continue to occur within the species' range; however, Tippecanoe darters are predicted to persist within all currently extant populations in the future under each of the future scenarios assessed.

CHAPTER 1 – INTRODUCTION

Background

This report summarizes the results of a species status assessment (SSA) conducted for the Tippecanoe darter (*Etheostoma tippecanoe*). We, the U.S. Fish and Wildlife Service (Service), were petitioned to list 404 aquatic, riparian, and wetland species, including the Tippecanoe darter, as endangered or threatened under the Endangered Species Act of 1973, as amended (Act) on April 20, 2010, by the Center for Biological Diversity, Alabama River Alliance, Clinch Coalition, Dogwood Alliance, Gulf Restoration Network, Tennessee Forests Council, West Virginia Highlands Conservancy, Tierra Curry, and Noah Greenwald. In September of 2011, the Service found that the petition presented substantial scientific or commercial information indicating that the listing of 374 species, including the Tippecanoe darter, may be warranted. Thus, we conducted an SSA to compile the best scientific and commercial data available regarding the species' biology and factors that influence the species' viability.

Analytical Framework

The SSA report, the product of conducting an SSA, is intended to be a concise review of the species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA report to be easily updated as new information becomes available, and to support all functions of the Endangered Species Program. As such, the SSA report will be a living document upon which other documents, such as listing rules, recovery plans, and 5-year reviews, would be based if the species warrants listing under the Act.

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

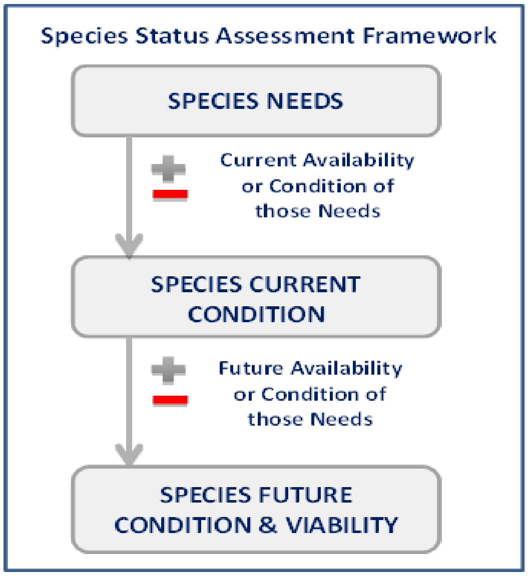


Figure 1. Species Status Assessment Framework

Using the SSA framework (figure 1), we consider what a species needs to maintain viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (Shaffer *et al*., 2002, pp. 139–140; Wolf *et al*. 2015, entire). For the purpose of this assessment, we generally define viability as the ability of the Tippecanoe darter to sustain populations in natural river ecosystems over time. Resiliency, redundancy, and representation are defined as follows:

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

• **Redundancy** means having a sufficient number of populations for the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk and can be measured through the duplication and distribution of populations across the range of the species. Generally, the greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.

• **Representation** means having the breadth of genetic makeup of the species to adapt to changing environmental conditions. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of the species' morphology, habitat characteristics within the geographical range, or both.

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

CHAPTER 2 – SPECIES INFORMATION

Taxonomy and Genetics

The Tippecanoe darter (*Etheostoma tippecanoe*) belongs to the Percidae (true perches) family of fishes and was first described by Jordan and Evermann (1890, entire) from a specimen collected from the Tippecanoe River, Marshland, Indiana. The Tippecanoe darter is recognized as a valid taxon and is listed as such in the American Fisheries Society's *Common and Scientific Names of Fishes from the United States*, *Canada*, *and Mexico* (Page *et al*. 2013, p. 140). We have no information to suggest there is scientific disagreement about the Tippecanoe darter's taxonomy.

The Tippecanoe darter is a member of the subgenus Nothonotus which contains 20 recognized species (Near and Keck 2005, p. 3487). Members of Nothonotus occur east and west of the Mississippi River, within the Ozark Highland physiographic province, a single tributary of the Mississippi River on the coastal plain of Mississippi, the Mobile Basin, and the Eastern Highlands physiographic province (Wood 1996, p. 300). Hybridization has been reported in a few instances for the Tippecanoe darter, all with bluebreast darter (*Etheostoma camurum*) (Mayden and Burr 1980, entire; Trautman 1981, p. 673; Stauffer *et al*. 2016, p. 441; Zimmerman 2018). Given Tippecanoe darter and bluebreast darter occupy similar habitats within the same range and few specimens of this hybrid combination have ever been reported, hybridization between these species is likely minimal (Mayden and Burr 1980, p. 392; Zimmerman 2018).

Kinziger *et al*. (2001, pp. 235–236) generated complete mitochondrial cytochrome b DNA sequences for 2 Tippecanoe darter specimens from 12 rivers across the range of the species and includes specimens from Indiana (Tippecanoe River), Pennsylvania (French Creek), West Virginia (Elk River and Little Kanawha River), Kentucky (Licking River, Barren River, Green River, and Redbird Creek), Ohio (Big Darby Creek), and Tennessee (Big South Fork Cumberland River, Red River, and Harpeth River). Their results illustrated low genetic variation among populations of Tippecanoe darter, with the only notable difference in the Barren and Green Rivers, Kentucky, whereby these populations were found to be moderately divergent from all other populations of this species, but similar enough that they are still considered to be the same species (Kinziger *et al*. 2001, pp. 236–237). Consequently, Kinziger *et al*.'s (2001, entire) analysis was performed to assess taxonomic status (in relation to a newly recognized species, *Etheostoma denoncourti*) and was not intended to address population-genetic structuring. We are unaware of additional genetic studies that analyze Tippecanoe darter population genetics in greater depth.

Species Description

The Tippecanoe darter (figure 2) is one of the smallest darters; the largest specimen reported being only 35 millimeters (mm) (1.38 inches (in)) standard length (SL; the length measured from the tip of the snout to the last vertebra, which excludes the length of the caudal fin (tail)) (Page 1983, p. 109). Fourteen adult female Tippecanoe darters collected from Green River, Kentucky, averaged 25.8 mm (1.02 in) SL (range = 21.2 to 27.2 mm; 0.83 to 1.07 in), and 15 adult males averaged 28.1 mm (1.11 in) SL (range = 22.5 to 30.8 mm; 0.86 to 1.21 in) (Warren *et al*. 1986, p. 216). Males are gold or orange with 4 to 11 blue-black vertical bars on the side and a blue breast. Females are more subdued with yellow-brown sides and olive-brown on the back (Page 1983, p. 109). Breeding males have bright yellow-golden sides, intensely blue vertical bars and a blue-black breast (Trautman 1981, p. 678). Warren *et al*. (1986, p. 216) observed an increase in the intensity of orange on the body of the largest breeding male, so much so that most of the blue vertical bars on the body were completely obscured by orange. We are not aware of any morphological differences across the species' range.

Figure 2. Tippecanoe darter (*Etheostoma tippecanoe*) (photo courtesy of Tim Stecko, Pennsylvania State University).

Life History

***Longevity*—**The maximum ages of Tippecanoe darters collected from the Green River, Kentucky, and from the Tippecanoe River, Indiana, were 1 year and 2 years, respectively, indicating this darter's life expectancy is between 1 and 2 years of age (Simon 2004, p. 11; Warren *et al*. 1986, p. 216). This species is known to have dramatic year-to-year variation in population numbers (Trautman 1981, p. 678).

***Sheltering*—**Tippecanoe darters inhabit warm rivers and large streams, where they occur in clean riffles and runs having significant areas of gravel substrate, and usually with some cobble or rubble (Stauffer *et al*. 2016, p. 453). Tippecanoe darters shelter under and between rocks (Welsh and Perry 1998, p. 416). In Ohio, they are found in riffles having a slow to moderate current and a bottom of clean gravel and sand (Trautman 1981, p. 678); in the Green River, Kentucky, they have been found in deep runs (35 centimeters (cm) (13.8 in)) in the fastest available current and a bottom of gravel and pebbles mixed with cobble (Warren *et al*. 1986, p. 216); and they occur at greater depths (1.4 to 5.9 meters (m) (4.6 to 19.4 feet (ft)) within the lock and dam tailwaters of the Allegheny and Ohio Rivers where abundant gravel and swift currents prevent siltation (Honick *et al*. 2017, pp. 226 and 228). In winter, the species usually retires to waters where the current is sluggish and the depth is between 0.6 and 1.5 m (2 and 5 ft) (Trautman 1981, p. 678). During the spawning season, males were observed guarding territories in water between 7.6 and 46 cm (3 and 18 in) depth at the heads or tails of riffles or along their edges where the current was gentle but strong enough to keep the sandy gravel free from clayey silt (Trautman 1981, p. 678). Juveniles are found in gentle to moderate currents along the margins of riffles (Simon and Wallus 2006, p. 408).

***Feeding*—**Tippecanoe darters are opportunistic benthic insectivores, consuming prey in proportion to the prey's availability in the environment. Van Snik Gray *et al*. (1997, entire) studied the food habits of nine darter species, including the Tippecanoe darter, in French Creek, Pennsylvania, and found that juvenile and adult male Tippecanoe darters fed on benthic macroinvertebrates (small, bottom-dwelling animals lacking a backbone), primarily fly and caddisfly larvae.

***Reproduction*—**Tippecanoe darters are sexually mature in their first year, breeding in the Green River, Kentucky, and the Tippecanoe River, Indiana, in July, and in Pennsylvania from May to early August (Warren *et al*. 1986, p. 216; Page and Simon 1988, p. 208; Stauffer *et al*. 2016, p. 452).

Tippecanoe darters are classified as egg buriers (Warren *et al*. 1986, pp. 216–217). Spawning occurs at depths between 7.6 and 46 cm (3 to 18 in) in slow to moderate current riffles (or along their edges) in Ohio and in runs in the fastest available current over gravel and pebbles mixed with cobble in Kentucky (Trautman 1981, p. 678; Warren *et al*. 1986, p. 216). The male establish a territory in the open or under rocks and excavates a cavity, thus creating a nest area to attract females (Stauffer *et al*. 2016, p. 453). Dominant males defend their territories and chase away other males, but quickly abandon nests after spawning (Warren *et al*. 1986, p. 216). We are not aware of any behavioral differences across the species' range.

One or more females will completely bury themselves in the substrate under the male to lay their eggs. Eggs are attached to stones in small clusters (Warren *et al*. 1986, pp. 216–217). Warren *et al*. (1986, pp. 216–217) observed six eggs laid in a single spawning act during a laboratory study, but concluded that a typical egg clutch under natural conditions was likely higher. Ovarian egg counts of 14 gravid female Tippecanoe darters averaged 30.4 mature ova (range = 1 to 58), indicating the potential number of eggs in a clutch (Warren *et al*. 1986, pp. 216–217). Tippecanoe darters also likely spawn more than once given the observed periodic withdrawal of females from the substrate and subsequent reburial and multiple spawnings by the male (Warren *et al*. 1986, p. 217). Fertilized egg diameter (n = 7) averaged 1.4 mm (0.06 in), and eggs hatched in 6 to 7 days (144 to 168 hours) at 22 degrees Celsius (72 degrees Fahrenheit) in laboratory aquaria (Page and Simon 1988, p. 208). Time to hatching for fertilized eggs likely varies based on water temperature. For most *Etheostoma* species, incubation time lasts approximately 5 to 25 days (Hubbs *et al*. 1969, p. 184; Burr and Page 1979, p. 9). Hatchling lengths (n = 2) averaged 5.09 mm (0.20 in) total length (TL; the length measured from the tip of the snout to the end of the tail).

***Movement/Dispersal*—**We are unaware of any Tippecanoe darter-specific movement/dispersal studies. However, the scientific literature suggests that many other small-bodied, riffle-dwelling fish species complete their lifecycle within single riffles or riffle complexes spanning just a few hundred meters (Hill and Grossman 1987, pp. 377–378; Roberts and Angermeier 2007, p. 422); however, some darter species have been documented moving upstream and downstream between riffles and between riffles and pools, with within-year movements generally ranging from 36 to 420 m (118 to 1,378 ft), but with some movements of up to 4.8 kilometers (km) (3.0 miles (mi)) (May 1969, pp. 86–87, 91; Freeman 1995, p. 363; Roberts and Angermeier 2007, pp. 422, 424–427).

In Ohio, multiple surveys within the same streams using the same methodology over four decades demonstrate Tippecanoe darter population's ability to disperse. For example, Tippecanoe darter populations expanded 60 km (37 mi) downstream between 1984 and 1997; 80 km (50 mi) downstream between 1997 and 2004; 34 km (21 mi) upstream between 1994 and 2005; and 13 km (8 mi) upstream between 1994 and 2005 (OSU 2016, unpublished data). Assuming similar rates of population expansion from year-to-year, Tippecanoe darter populations may expand up to 11.4 km (7.1 mi) downstream and 3.1 km (1.9 mi) upstream, annually.

Tippecanoe darter larval period could be an important life stage for dispersal. The expansion of the known ranges of the Tippecanoe darter and bluebreast darter has been robust in Pennsylvania and Ohio, compared with the expansion of spotted darter (*Etheostoma maculatum*) (Honick *et al*. 2017, p. 225). Honick *et al*. (2017, pp. 228–229) discussed reasons for differences in distribution changes among the three darter species, one of which included potential differences in pelagic larval duration (PLD), or the amount of time an aquatic larva spends in the water column. As water quality has improved, longer PLDs may have aided the Tippecanoe darter and bluebreast darter in re-establishing and expanding their ranges (compared with the spotted darter). We are unaware of any Tippecanoe darter-specific PLD studies, and acknowledge substantial variation in darter PLD has been observed among closely related species (Douglas *et al*. 2013, pp. 2–3).

Table 1 provides a summary of the Tippecanoe darter's life history needs based on the best available information.

Table 1. Summary of Tippecanoe darter life history information by life stage.

Life Stage	Resource and/or circumstance needs and related information
Eggs	• Spawning occurs from May to early August, depending on location. • Eggs are laid beneath gravel substrates and are attached to rocks. • Spawning sites occur in riffles and runs having adequate gravel substrate, usually with some cobble or rubble, and where water velocity is adequate to prevent siltation.
Larvae	• Newly hatched larvae are 3.8 mm (0.15 in) TL. • Larval period could be an important life stage for dispersal.
Juveniles	• Benthic habitat similar to adults except during the spawning season when Tippecanoe darters will segregate by depth, current, and body size. • During prespawning or spawning activities, juveniles are found in shallower and slower riffle areas compared with mature adults; otherwise, homogeneous distribution of size classes.
Adults	• 1- to 2-year life expectancy. • Males and females are sexually mature in their first year. • Found under and between rocks in riffles and runs at wide ranging depths (0.076 to 5.9 m (0.25 to 19.4 ft)) and water velocities (*e.g.*, slow, moderate, fast/swift). • Females bury themselves completely during egg-laying while the male remains directly above. • Males display territorial behavior (*i.e.*, chase other males away) during spawning periods, but quickly abandon nests after spawning.

Environmental Setting

Tippecanoe darters range across six states (Indiana, Kentucky, Ohio, Pennsylvania, Tennessee, and West Virginia) and three physiographic provinces (Appalachian Plateaus, Central Lowland, and Interior Low Plateaus) within the Ohio River hydrologic unit code (HUC) 5 watershed (Ohio Region watershed) (figure 3).

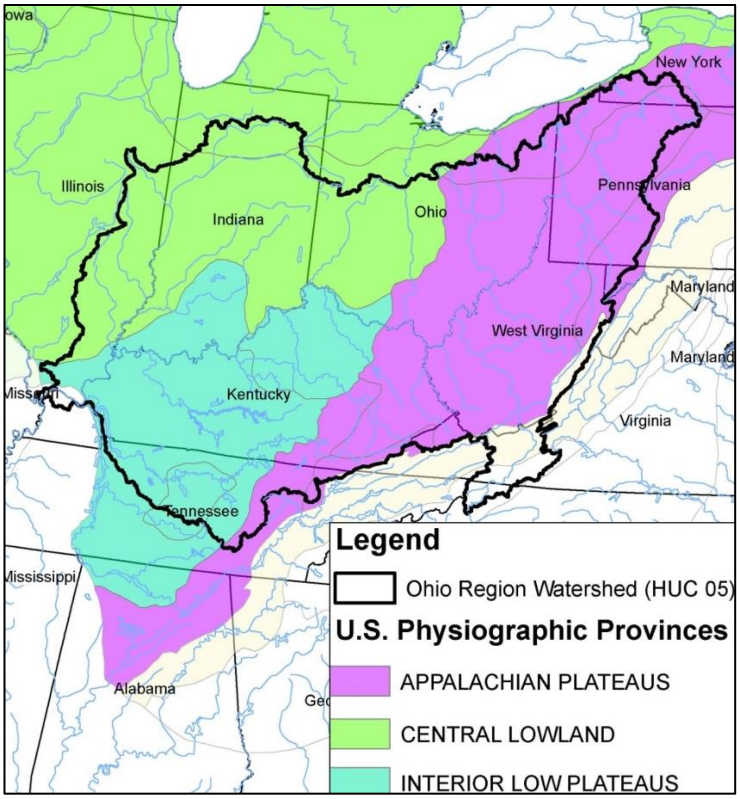


Figure 3. Ohio Region watershed and physiographic provinces within the range of the Tippecanoe darter.

The Appalachian Plateaus physiographic province is composed of sedimentary rocks including sandstones, conglomerates, and shales that exist largely as horizontal beds that have been cut by streams to form mountainous terrain. In addition to these sedimentary rocks, beds of coal are locally significant throughout the Appalachian Plateaus, making this area the heart of the American coal industry. In the recent geologic past, the northern portion of the Appalachian Plateaus has been subject to the effects of glaciation (National Park Service (NPS) 2017a). The rolling hills of the Appalachian Plateaus contain rich and diverse broadleaf forests of oaks, hickories, maples, and poplars in the valleys and birch-maple-hemlock forests at higher elevations (White *et al*. 2005, p. 377).

The Interior Low Plateaus physiographic province is composed almost completely of horizontal beds of sandstone, shale, and limestone. The limestone of the province is marked by well-developed karst topography, including Mammoth Cave National Park, Kentucky. The Interior Low Plateaus are home to widespread but small-scale coal, petroleum, and natural gas mineral resources (NPS 2017b). Soils are primarily red and yellow podzols (*i.e*., forested soils) (White *et al*. 2005, p. 377).

The Central Lowland physiographic province is composed of sandstones, shales, limestones, conglomerates, and coals. Many mineral resources are found throughout the Central Lowlands (NPS 2017c). The topography and surface geology were shaped by glaciation. The landscape varies from gently rolling to extremely flat. Soils are rich neutral to basic loams, resulting in high-alkalinity surface waters (White *et al*. 2005, p. 377).

Rivers within the Ohio Region watershed where the Tippecanoe darter occurs are ecologically diverse. River gradients range from gentle to high slopes, with variable substrate (*e.g*., rocky, sandy with cobble, sandy with glacial till) and variable alkalinity (White *et al*. 2005, p. 378). Climate is temperate with cool moist winters and warm humid summers. Average monthly precipitation is fairly uniform throughout the year, with significant accumulations of snow in the north and Appalachians. The majority (80 percent) of the Ohio Region watershed is forested. The proportion of agricultural land increases from 12 percent to 14 percent in the east to 64 percent to 73 percent in western Ohio and Indiana (White *et al*. 2005, p. 377).

Habitat Needs

The Tippecanoe darter is known from 4th order and larger streams and rivers. Adequate interstitial space (*i.e*., space between and underneath rocks) is a necessary physical feature for the Tippecanoe darter to feed and shelter. In addition, loose gravel or sand is critical for successful spawning. In Indiana, stream habitat is a mix of cobble-gravel that is stable, but loose enough that you can dig your foot down into and is where Tippecanoe darters spend their time buried down in the interstitial spaces (Fisher 2016a). In Ohio, the largest numbers of Tippecanoe darters were found on those portions of riffles having a bottom of clean gravel and sand (Trautman 1981, p. 678). In the Ohio River, Tippecanoe darters were documented in areas with gravel outwashes near tributaries, lock and dam tailwaters, and the cobble-gravel habitat found upstream and downstream of islands (Honick *et al*. 2017, p. 226–227). In Kentucky, young or immature Tippecanoe darters were captured in riffle/pool transitional areas and deep runs with substrates of gravel, cobble, and organic debris (Thomas 2017). Tippecanoe darters occur at wide ranging depths (0.076 to 5.9 m (0.25 to 19.4 ft)) and water velocities (*e.g*., slow, moderate, fast/swift) (Trautman 1981, p. 678; Warren *et al*. 1986, p. 216; Simon and Wallus 2006, p. 408; Honick *et al*. 2017, pp. 226 and 228); hence, water depth does not appear to be a major factor influencing Tippecanoe darter distribution, and water flow likely needs to be just fast enough to keep interstitial spaces free from sediment.

Little is known regarding water quality parameters tolerated or preferred by the Tippecanoe darter; however, based on information for other darter species and Tippecanoe darter occurrence records, we assume the Tippecanoe darter requires waters that have pH levels close to neutral and contaminant levels below those likely to cause toxicity to native aquatic fauna (including prey base, *i.e*., benthic macroinvertebrates). Degraded water quality (including high sediment load) has the potential to induce stress on individuals, reduce spawning success, or cause direct mortality.

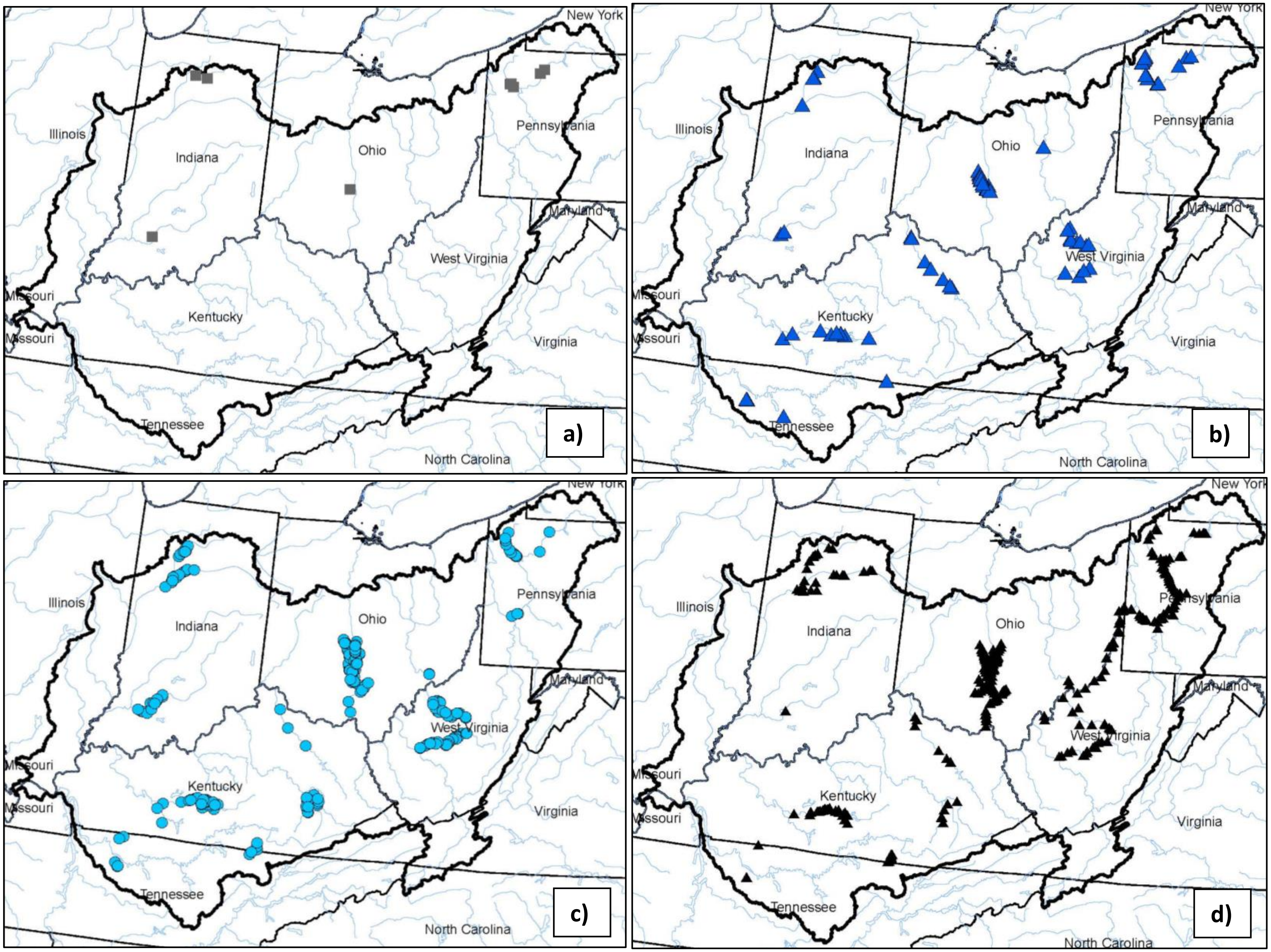
Connectivity, for the purpose of this assessment, refers to a Tippecanoe darter's ability to disperse to and from populations by accounting for the presence of dams, proximity to closest source population, occupancy extent of closest source population, and upstream or downstream movement of immigrants. Although little is known regarding the minimal habitat patch size or degree of habitat connectivity necessary to support persistent Tippecanoe darter populations, it is generally understood in the field of conservation biology that larger and more-connected populations contribute to the long-term viability of a species (*e.g*., higher population resiliency) and that smaller isolated populations are more at risk of decline or extirpation (*e.g*., lower population resiliency) as a result of genetic drift, demographic or environmental stochasticity, and catastrophic events (Gilpin and Soulé 1986, pp. 32–34; Angermeier 1995, entire; Fagan 2002, p. 3248; Wiegand *et al*. 2005, entire; Letcher *et al*. 2007, 5–6; Peterson *et al*. 2014, pp. 564–565).

In summary, Tippecanoe darters occur in 4th order and larger streams and rivers. Tippecanoe darters prefer riffles and runs with rocky bottom substrates and adequate water flow to keep spaces between and under rocks free from sediment. Based on information for other darter species and Tippecanoe darter occurrence records, we assume the Tippecanoe darter requires waters that have pH levels close to neutral and contaminant levels below those likely to cause toxicity to native aquatic fauna. While data are sparse regarding the minimum patch size and degree of genetic connectivity required for Tippecanoe darter population viability, the fundamentals of conservation biology suggest these factors are important to the species.

Range and Distribution

Before 1940, the Tippecanoe darter was known only from the upper Tippecanoe River and East Fork White River, Indiana; upper Scioto watershed, Ohio; and French Creek and upper Allegheny River, Pennsylvania (figure 4a). Surveys between 1940 and 1989 documented Tippecanoe darter in all of the previous watersheds, plus the lower Tippecanoe River, Indiana; Elk River and Little Kanawha River, West Virginia; Licking River and Green River, Kentucky; Walhonding River, Ohio; and Big South Fork, Stones, and Harpeth rivers, Tennessee (figure 4b). Surveys between 1990 and 2005 documented the Tippecanoe darter in all of the previous watersheds (except the Walhonding River, Ohio), plus the addition of the upper Wabash River, Indiana; Lower Muskingum River, Ohio; lower Allegheny River, Pennsylvania; upper Kentucky River drainage, Kentucky; and Red River, Tennessee (figure 4c). Surveys between 2006 and 2017 documented Tippecanoe darter in all of the previous watersheds (except the Walhonding River, Ohio), plus the addition of the Ohio River proper (figure 4d). All HUC 8 watersheds within the three physiographic provinces where the Tippecanoe darter has been located have extant populations (n = 29), except for an apparent extirpation (n = 1) from the Walhonding River, Ohio. Also, there are no additional Tippecanoe darter records from the Stones River, Tennessee, or from above the Green River Lake Dam, Green River, Kentucky, since the original records documented in 1968 and 1978, respectfully. To our knowledge, no additional surveys that could have resulted in capturing the Tippecanoe darter have been conducted at either location; therefore, population status in the Stones River and above the Green River Lake Dam is unknown (figure 5 and table 2).

There has been a marked increase in Tippecanoe darter distribution in recent years (figures 4a, 4b, 4c, and 4d). Improved water quality coupled with improved survey techniques has likely been responsible for this observed increase in distribution (Honick *et al*. 2017, p. 222). Tippecanoe darters were likely under-sampled for years because normal big river sampling methods were inadequate (Fisher 2016a). Because of its diminutive size, species-specific habitat, and its need to bury down into the substrate during key life history stages, it was no doubt easily overlooked (Fisher 2016a). In Ohio, there has been a significant increase in distribution since 1980, some of which is likely due to increased sampling effort, but actual range expansion is also occurring (Zimmerman 2016). Surveys in multiple streams, with historical and contemporary samples using the same methodology, have documented recent expansion for Tippecanoe darter and two other darter species in Ohio and Pennsylvania (Honick *et al*. 2017, p. 224).



Figures 4a, 4b, 4c, and 4d. Tippecanoe darter occurrence records a) pre-1940 (gray squares), b) between 1940 and 1989 (blue triangles), c) between 1990 and 2005 (blue circles), and d) between 2006 and 2017 (black triangles).

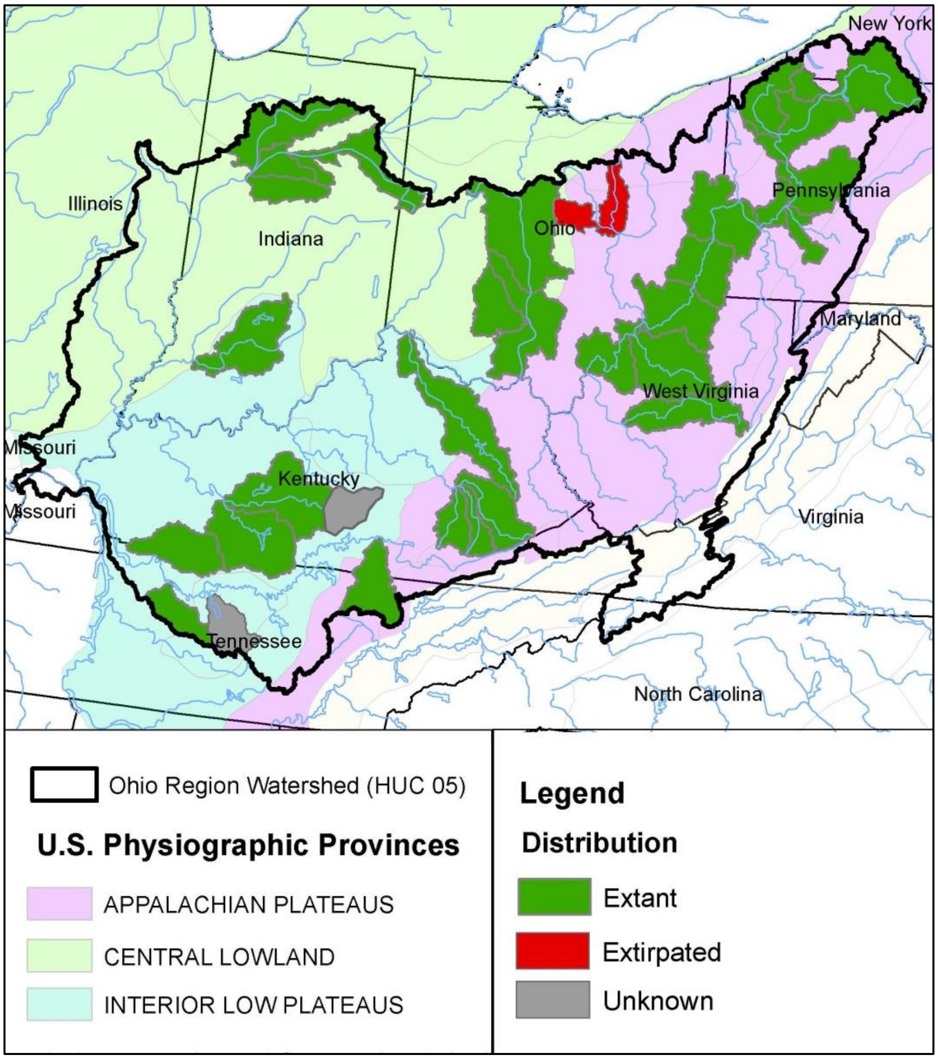


Figure 5. Current Tippecanoe darter distribution illustrated by HUC 8 watersheds. Note, in some cases, HUC 8 watersheds overestimate Tippecanoe darter stream distribution, particularly within watersheds where dams are restricting movement either upstream or downstream.

Table 2. Current Tippecanoe darter status by HUC 8 watershed within the Appalachian Plateaus, Central Lowland, and Interior Low Plateaus physiographic provinces (green = extant, red = extirpated, and gray = unknown). *Note, Lower Scioto, OH, and Licking, KY, watersheds occur within two physiographic provinces.

Physiographic Province	HUC 8 Watershed	
Appalachian Plateaus	French, PA	Upper Allegheny, PA/NY
	Kiskiminetas, PA	Elk, WV
	Little Kanawha, WV	Lower Scioto, OH*
	Little Muskingum-Middle Island, WV/OH	Licking, KY*
	Lower Allegheny, PA	Middle Fork Kentucky, KY
	Middle Allegheny-Redbank, PA	North Fork Kentucky, KY
	Middle Allegheny-Tionesta, PA	South Fork Kentucky, KY
	Upper Ohio, OH	South Fork Cumberland, KY/TN
	Upper Ohio-Shade, WV/OH	Walhonding, OH
	Upper Ohio-Wheeling, PA/WV/OH	
Central Lowland	Middle Wabash-Deer, IN	Lower Scioto, OH*
	Upper Wabash, IN	Paint, OH
	Wildcat, IN	Upper Scioto, OH
	Tippecanoe, IN	
Interior Low Plateaus	Lower East Fork White, IN	Red, TN
	Barren, KY	Harpeth, TN
	Upper Green, KY	Stones, TN
	Licking, KY*	
	Upper Green, KY (above the Green River Lake Dam)	

CHAPTER 3 – FACTORS INFLUENCING VIABILITY

Based on the Tippecanoe darter's life history and habitat needs, we identified the potential negative and positive influences and the contributing sources of those influences that are likely to affect the species' viability.

Water Quality

Sedimentation

Excessive stream sedimentation (or siltation) results from soil erosion associated with upland activities (*e.g*., agriculture, forestry, mining, unpaved roads, road or pipeline construction, and general urbanization) as well as activities that can destabilize stream channels themselves (*e.g*., dredging or channelization, construction of dams, culverts, pipeline crossings, or other instream structures) (West Virginia Department of Environmental Protection (WVDEP) 2012, p.12). The negative effects of increased sedimentation are well understood for aquatic species (Newcombe and MacDonald 1991, p.72; Burkhead *et al*. 1997, p 411; Burkhead and Jelks 2001, p. 964). Excessive sediments can cover the stream bottom and fill the interstitial spaces between bottom substrate particles (*i.e*., sand, gravel, and cobbles) and in severe cases also cause stream bottoms to become "embedded," in which case substrate features including larger cobbles, rocks, and boulders are surrounded by, or buried in, sediment. This can affect fish species directly by limiting sheltering or breeding habitat and/or by causing shifts in the benthic community structure that alter the prey base (Berkman and Rabeni 1987, 291–293; Messinger and Chambers 2001, p. 50–51; Sutherland *et al*. 2002, entire; McGinley *et al*. 2013, pp. 223–226).

Since enactment of various state and Federal regulations (*e.g*., Federal Clean Water Act of 1977 (33 U.S.C. 1251 et seq.), Surface Mining Control and Reclamation Act of 1977 (30 U.S.C. 1234–1328)) and the increased implementation of forestry and construction best management practices designed to reduce erosion and sedimentation, levels of stream sedimentation have generally improved over time. Based on information obtained from the Environmental Protection Agency's (EPA) Clean Water Act (CWA) Section 303(d) and Total Maximum Daily Loads (TMDLs) program (EPA 2017a), impairment from sedimentation is listed within three streams where the Tippecanoe darter occurs: Walnut Creek, North Fork Paint Creek, and Wheeling Creek, Ohio. Trautman (1981, p. 678) observed male Tippecanoe darters deserting their territories when storms caused water to become turbid in Ohio. Sedimentation has likely played a role in the Tippecanoe darter's current distribution, particularly in reservoirs/behind dams where extensive sedimentation can cause stream bottoms to become embedded and where the species is not known to occur.

Water Chemistry

There is little information regarding the Tippecanoe darter's tolerance of specific water quality parameters. We can infer from the available occurrence data and the scientific literature that the species is adapted to waters that have pH levels close to neutral and contaminant levels below those likely to cause toxicity to native aquatic fauna. Based on information obtained from the EPA's CWA Section 303(d) and TMDLs program (EPA 2017a), it appears that the most common water chemistry impairment across the current range of the Tippecanoe darter is contamination with coliform bacteria (likely from sewage or septic releases, or livestock wastes). Although fish are generally not sensitive to coliform bacteria (unless concentrations are significant enough to cause a decrease in dissolved oxygen), the presence may be an indicator of degraded conditions and/or the presence of other pollutants of concern such as ammonia.

Like coliform bacteria, ammonia can enter streams not only via municipal effluent discharges but also via indirect means such as nitrogen fixation, air deposition, and runoff from agricultural lands (EPA 2013a, entire). Ammonia causes direct toxic effects on aquatic life when it is present at levels high enough to make it difficult for aquatic organisms to sufficiently excrete the toxicant, leading to toxic buildup in internal tissues and blood, and potentially death (EPA 2013a, entire). EPA has published national recommended ambient water quality criteria for the protection of aquatic life from the toxic effects of ammonia. EPA's *Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater 2013* is the most recent recommendation from EPA and serves as an update to EPA's previous recommendations from 1999. The 2013 ammonia criteria recommendations take into account the latest freshwater toxicity information for ammonia, including toxicity studies for sensitive unionid mussels and gill-breathing snails. The updated criteria are more stringent than the previously recommended 1999 criteria (EPA 2013a, entire). EPA's recommended water quality criteria are not rules, nor do they automatically become part of a state's water quality standards. Currently, no states within the range of Tippecanoe darter have fully adopted the 2013 ammonia criteria. Ammonia has been recognized as a current impairment in the Scioto River, Ohio. Tippecanoe darters, like most aquatic organisms, have likely been impacted when ammonia has exceeded safe levels (EPA 2013a, entire). However, ammonia concentrations have improved with each revision of the EPA Freshwater Aquatic Life Ambient Water Quality Criteria (EPA 2013b, p. *x*). Tippecanoe darter exposure will likely continue to decrease further if/when states adopt the 2013 criteria, which impose lower limits in warm waters with freshwater mussels (Patnode 2017).

Urbanization refers to a change in land cover and land use from forests or agriculture to increased density of residential and commercial infrastructure. Streams affected by urbanization have been described to exhibit an "urban stream syndrome" (Walsh *et al*. 2005, p. 207; Wenger *et al*. 2009, entire; Matthaei and Lang 2016, p. 180). The urban stream syndrome consistently includes "a flashier hydrograph, elevated concentrations of nutrients and contaminants, altered channel morphology and stability, and reduced biotic richness, with an increased dominance of species tolerant to poor water quality and variably includes reduced baseflow and increased suspended solids" (Paul and Meyer 2001, entire; Walsh *et al*. 2005, p. 207). Large cities within the current range of the Tippecanoe darter include Pittsburgh, Pennsylvania, and Columbus, Ohio. On average, there was little to no change in the amount of development over the range of Tippecanoe darter between 2001 and 2011; however, the amount of development increased between one and three percent within several watersheds (Homer *et al*. 2015); consequently, while development is a potential stressor, we expect impacts from urbanization to be highly localized across the range of the species.

Combined sewer overflows (combined overflows), are remnants of the country's early infrastructure. In the past, communities built sewer systems to collect both stormwater runoff and sanitary sewage in the same pipe. During dry weather, these "combined sewer systems (combined systems)," transport wastewater directly to sewage treatment plants. In periods of rainfall or snowmelt, however, the wastewater volume in a combined system can exceed the capacity of the sewer system or treatment plant. For this reason, combined systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or lakes. Combined overflows contain not only stormwater, but also untreated human and industrial waste and toxic materials that could be hazardous to aquatic systems. This is a major water pollution concern for cities with combined systems (EPA 2017b). The EPA's 1994 Combined Sewer Overflows Control Policy (59 FR 18688) is the national framework for control of combined overflows. The policy provides guidance on how communities with combined systems can meet CWA goals in as flexible and cost-effective a manner as possible including phased implementation. Although some larger cities may have problems with combined overflows, most communities with combined overflow problems have fewer than 10,000 people (EPA 2017c). Although combined overflows are a potential stressor, given the wide distribution of Tippecanoe darters, we assume potential impacts from combined overflows will be highly localized.

Agricultural activities that cause non-point source pollution include poorly located or managed animal feeding operations (*e.g*., concentrated animal feeding operation; CAFO); overgrazing; plowing too often or at the wrong time; and improper, excessive, or poorly timed application of pesticides, irrigation water, and fertilizer. Pollutants that result from farming and ranching include sediment, nutrients, pathogens, pesticides, metals, and salts. Insecticides, herbicides, and fungicides are used to kill agricultural pests. These chemicals can enter and contaminate water through direct application, runoff, and atmospheric deposition (EPA 2005, entire). They can poison fish and wildlife, contaminate food sources, and destroy the habitat that animals use for protective cover. Better agricultural practices have reduced runoff throughout the Ohio Region watershed; however, soil erosion along with fertilizer and pesticide pollution continue to be documented (White *et al*. 2005, p. 378). While impacts from some agricultural activities are comparatively localized within populations, sedimentation from agricultural runoff is one of the most pervasive stressors in agricultural landscapes.

Abandoned coal mines and active strip mining with resultant acid mine drainage continue to be documented throughout the Appalachians (White *et al*. 2005, p. 396), and mountaintop mining is widespread throughout eastern Kentucky and West Virginia (Palmer *et al*. 2010, p. 148). The EPA's CWA Section 303(d) and TMDLs program (EPA 2017a) identified iron as an impairment in several sections of the Little Kanawha River and Elk River, West Virginia, and Ohio River. Iron is likely entering streams via acid mine drainage from coal mining. Although widespread impacts from acid mine drainage continue, the effects of coal mining on water quality have improved since the implementation of the Surface Mining Control and Reclamation Act of 1977 (Office of Surface Mining 2003, entire). Lastly, valley fills from mountaintop mining result in burial of headwater streams which can cause permanent loss of aquatic habitat and decreases in water quality (Palmer *et al*. 2010, p. 148). However, Tippecanoe darters are found in 4th order and larger streams and rivers; therefore, we would not expect direct loss of physical Tippecanoe darter habitat from activities associated with mountaintop mining, although there is some potential for impacts to water quality from upstream activities.

Natural gas extraction increased from 2008 to 2012 in Pennsylvania and West Virginia as a result of technological advances in drilling. In Pennsylvania alone, 12,151 new unconventional (*e.g*., Marcelles Shale gas extraction) drilling permits were issued between 2008 and 2012 compared to only 18 between 2000 and 2004 (Pennsylvania Department of Environmental Protection [PADEP] 2018); however, the number of new unconventional well drilling permits decreased 59 percent in 2016 compared to 2014 (PADEP 2016). Wastewater from Marcellus hydraulic fracturing flowback fluids is characterized by high chloride, bromide, iodide, and ammonium (Harkness *et al*. 2015, pp. 1957-1958). Extraction of natural gas produces high salinity water that flows to the surface in advance of the gas. This solution is more concentrated than seawater and is produced by more than 95 percent of Pennsylvania's oil and gas wells (Dresel and Rose 2010, p. 42). "Water quality impacts can result from inadequate management of water and fracturing chemicals on the surface, both before injection and after as flowback and produced water" (Zammerilli *et al*. 2014, p. 74). "Management and disposal of wastewaters increasingly includes efforts to minimize water use and recycling and re-use of fracturing fluids. [Lastly], drilling and hydraulically fracturing a shale gas well can consume between 2 and 6 million gallons of water and local and seasonal shortages can be an issue, even though water consumption for natural gas production generally represents less than 1 percent of regional water demand" (Zammerilli *et al*. 2014, p. 74). Although natural gas extraction has been rapidly developing in Pennsylvania and West Virginia, we are uncertain how impacts to water quality and/or water consumption may be influencing Tippecanoe darter viability.

Habitat Fragmentation

There are over 700 dams throughout the Ohio Region watershed (White *et al*. 2005, p. 413), including navigational locks and dams, small flood control dams and large hydroelectric power generation dams. Tippecanoe darter populations are widespread but disjunct. The average length of occupied extent of stream is approximately 150 mi (241 km) (range from 22 to 500+ mi; 35 to 805+ km). The average distance between extant populations is over 100 mi (161 km) (range from 14 to 264 mi; 23 to 425 km). Four populations are completely isolated because of large dams precluding movement of fish. In some instances, dams are precluding expansion (upstream or downstream) within populations themselves. In Indiana, the J. Edward Roush Lake Dam and Williams Dam are precluding Tippecanoe darter expansion into the upper reaches of the Wabash River and East Fork White River, respectively (Fisher 2018). Several dams on the lower Muskingum River are likely limiting the potential for Tippecanoe darter to recolonize the upper Muskingum River basin (*e.g*., Walhonding River) which is believed to be extirpated (Zimmerman 2016). The Tippecanoe darter is known to occur within at least four tributaries of the Cumberland River, Tennessee (*e.g*., South Fork Cumberland River, Harpeth River, Red River, and Stones River); however, the Tippecanoe darter has never been documented within the Cumberland River proper. There are five major impoundments within the Cumberland River mainstem, virtually eliminating free-flowing river habitat (White *et al*. 2005, p. 392) and likely isolating the South Fork Cumberland River and Stones River populations (figures 9 and 10). The current disjunct distribution is likely what remains of a formerly more continuous distribution, and dams have likely eliminated populations that were never discovered (Starnes and Etnier undated, p. 82).

Other Factors Considered

The introduction of nonnative species may stress indigenous fish populations via increased predation, competitive interactions, transmission of pathogens, or hybridization (Mills *et al*. 2004, pp. 719–720; Cucherousset and Olden 2011, pp. 216–221). While some of these interactions may be affecting individuals, we have no information to suggest that introduction of nonnative species, disease, or predation are affecting Tippecanoe darter viability now or may in the future.

The Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) found that "continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems" (IPCC 2014, p. 56). According to state climate summaries released by the National Oceanic and Atmospheric Administration National Centers for Environmental Information (Kunkel *et al*. 2017, entire), historically unprecedented warming is projected by the end of the 21st century across the range of the Tippecanoe darter, leading to increases in heat wave intensity, decreases in cold wave intensity, increases in extreme precipitation (with resultant increases in the frequency and intensity of floods), and increases in the intensity of naturally occurring droughts.

The U.S. Army Corps of Engineers and the Ohio River Basin Alliance prepared a pilot study to address the effects of climate change within the Ohio River Basin (*i.e*., Ohio River HUC 5 watershed) (Drum *et al*. 2017, entire). Modeling results indicate a gradual increase in annual mean temperatures over time but substantial variability in hydrologic flow. Subwatersheds located northeast, east, and south of the Ohio River are expected to experience greater precipitation and thus higher stream flows (Drum *et al*. 2017, p. 1). Conversely, those subwatersheds located north and west of the Ohio River are expected to experience ever-decreasing precipitation resulting in decreased in-stream flows. Reduced streamflow coupled with the prospect of rising air temperatures that can result in higher water temperatures may lead to some aquatic species being at risk of extirpation in impacted watersheds; however, seasonal management of reservoir discharge volumes and water temperature may offset some of these anticipated impacts (Drum *et al*. 2017, p. 2).

"The key stressors to aquatic ecosystems that arise from climate change are changes in water temperature and changes in precipitation patterns and flow regimes. Higher temperature will decrease dissolved oxygen and will increase the uptake of toxins by some fish. With these changes, the biotic communities will change as limits of tolerance for some species are exceeded, and the changed conditions become acceptable to invading species (Drum *et al*. 2017, p. 54)." Although we do not know the upper thermal limits of Tippecanoe darter tolerance given the species' broad range and occurrence in 4th order or greater streams and rivers, we assume Tippecanoe darters are relatively tolerant of warmer water conditions. For similar reasons, we also assume they will be less vulnerable to droughts, compared to species occurring in lower order or headwater streams. Consequently, the effects of climate change on species' viability are largely unknown, but limited information suggests the species may not be particularly vulnerable. A "Climate Change Vulnerability Assessment" of more than 700 species in the Appalachian region ranked the bluebreast darter as "presumed stable" to the effects of climate change (Appalachian Landscape Conservation Cooperative 2017). Because the Tippecanoe darter is taxonomically similar with and occupies similar habitats across the same range as the bluebreast darter (Honick *et al*. 2017, entire), we conclude that the Tippecanoe darter is also presumed stable to the effects of climate change.

Summary

Current Tippecanoe darter populations are widespread but disjunct. Water pollution, including sedimentation, and dams have likely influenced the current distribution and species' viability. Dams have eliminated habitat and led to isolated populations. We identified numerous stressors to water quality that have occurred and to some extent continue to occur within the species' range; however, water quality has improved in some areas, and Tippecanoe darters have responded favorably.

CHAPTER 4 – CURRENT CONDITIONS

Methodology

To assess the biological status of the Tippecanoe darter across its range, we used the best available information, including peer reviewed scientific literature, academic reports, and survey data provided by State agencies and academic institutions. Fundamental to our analysis of the Tippecanoe darter was the determination of analytical units (*i.e.*, populations) at a scale useful for assessing the species. In this report, we defined Tippecanoe darter populations based primarily on known occurrence locations and continuity. Current resiliency is assessed for each population, followed by a summary of rangewide redundancy and representation.

To qualitatively assess the current condition of populations we considered components describing characteristics about each population's demography and physical environment. Three components describing population demography include occupancy, occupancy extent, and connectivity between populations. The population's physical environment is assessed by water quality. Using the parameters defined in table 3, we categorize each population as being in "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UNK), or "presumed extirpated" (0). The "Connectivity" component is further defined using multiple subcomponents, the parameters for which are defined in tables 4 and 5. To aid in the comparison of populations (with each other and under the future scenarios outlined in chapter 5) and assessment of the species' current viability using the 3Rs, we weighted each parameter equally and determined the average score to describe each population's current condition (table 6).

Table 3. Parameters used to define categories for each component used to assess population condition.

	High	**Moderate**	**Low**	**Unknown**	**0**
Occupancy	Currently occupied (*i.e.*, documented between 2006 and present).	N/A	N/A	Unknown occupancy (*i.e.*, documented in the 1960s or 1970s and not documented since).	Presumed extirpated.
Occupancy Extent	100 or more river/stream miles of occupied **or** known suitable habitat.	50 to 99 river/stream miles of occupied **or** known suitable habitat.	Less than 50 river/stream miles of occupied **or** known suitable habitat.	N/A	Presumed extirpated.
Connectivity[1]	High immigration potential between populations.	Moderate immigration potential between populations.	Low immigration potential between populations.	N/A	No immigration potential between populations.
Water Quality	Minimal or no water quality impairments **or** impairments present but low aquatic toxicity **or** impairments present but highly localized.	Water quality impairments present with moderate aquatic toxicity.	Extensive water quality impairments known to impact populations.	N/A	N/A

[1] Connectivity metric accounts for dams, proximity to closest source population, occupancy extent of closest source population, and upstream or downstream movement of immigrants.

Occupancy

To assess population occupancy, occurrence records provided by State agencies and academic institutions were evaluated. Tippecanoe darter occurrence records came from multiple sources and represented a diversity of sampling techniques and methods, and therefore did not exhibit standardization. The number of individuals collected was inconsistently recorded, and sampling methods varied among records. Although assessing abundance and growth rate would be preferred, the data were not sufficient for this type of analysis; therefore, we used occupancy as a surrogate. A population was considered "occupied" if it included an occurrence record within the last 11 years (2006 or more recent).

Occupancy extent

Occupancy extent is an estimate of the occupied (or historically occupied) stream habitat within each Tippecanoe darter population. Occupancy extent for the Tippecanoe darter was evaluated by measuring the distance between the furthest upstream record and the furthest downstream record using the measuring tool in ArcMap 10.3.1. We acknowledge that this may overestimate the amount of habitat actually used by Tippecanoe darters given suitable habitat is likely patchily distributed (*i.e.*, not continuous) within stream reaches (see Chapter 6).

Connectivity

Connectivity for the purposes of this SSA is a measure of immigration potential in the event of a catastrophic event causing extirpation. Tippecanoe darter populations are often referred to as disjunct; therefore, connectivity is considered a fundamental component for assessing Tippecanoe darter viability. Our measure of connectivity between populations accounts for the presence of dams, proximity to closest source population, occupancy extent of closest source population, and upstream or downstream movement of immigrants (the latter is captured in both the dam and distance to source components). We further defined how each of these subcomponents varies in terms of qualitative condition (table 4). We categorized the final connectivity scores as "high" (H; high immigration potential between populations), "moderate" (M; moderate immigration potential between populations), "low" (L; low immigration potential between populations) or "0" (no immigration potential between populations). We weighted each subcomponent equally and determined the average score to describe each population's current connectivity (table 5).

Table 4. Definitions of subcomponents used to assess current connectivity.

	High	**Moderate**	**Low**	**0**
Dams between closest source population	No dams; **or**, 1 or more locks & dams with downstream movement of immigrants.	1 lock & dam with upstream movement of immigrants.	1 or more small dams with upstream movement of immigrants; **or**, 1 or more large dams with downstream movement of immigrants; **or**, 2 or more locks & dams with upstream movement of immigrants.	Dams precluding movement of immigrants.
Distance to closest source population	Less than 100 mi with downstream movement of immigrants.	101 to 199 mi with downstream movement of immigrants; **or**, less than 100 mi with upstream movement of immigrants.	200 mi or more; **or**, 101 to 199 mi with upstream movement of immigrants.	N/A
Occupancy extent of closest source population	Greater than 100 stream miles of occupied or potential habitat.	50 to 99 mi of occupied or potential habitat.	Less than 50 mi of occupied or potential habitat.	N/A

Table 5. Current connectivity of Tippecanoe darter populations. Connectivity condition scores are categorized as “high” (H; high immigration potential between populations.), “moderate” (M; moderate immigration potential between populations), “low” (L; low immigration potential between populations) or “0” (no immigration potential between populations).

No.	Population	Dams	Distance to source	Occupancy extent of source		Connectivity condition score
1	Middle-Upper Wabash, IN	L	H	M		M
2	Tippecanoe River, IN	0	N/A	N/A		0
3	Lower East Fork White, IN	H	L	H		M
4	Upper Green, KY	L	H	L		L
5	Licking River, KY	H	M	H		H
6	N, S, Middle Fork Kentucky, KY	L	L	H		L
7	South Fork Cumberland, KY/TN	0	N/A	N/A		0
8	Scioto, OH	H	M	H		H
9	Walhonding, OH	L	L	H		L
10	Ohio, PA/WV/OH	H	H	M		H
11	Red River, TN	H	H	L		M
12	Stones River, TN	0	N/A	N/A		0
13	Harpeth River, TN	M	M	L		L
14	Elk River, WV	M	M	H		M
15	Upper Green-1978, KY	0	N/A	N/A		0

Water quality

Water quality is a component used to describe the relative health of a stream and its presumed habitability for Tippecanoe darters. Water quality conditions within populations of the Tippecanoe darter were determined by assessing known and reported water quality issues from the EPA’s CWA Section 303(d) and Total Maximum Daily Loads (TMDLs) program (EPA 2017a) and by assessing the National Land Cover Database 2011 (NLCD) land cover data within HUC 8 watersheds (Homer *et al*. 2015).

Current Condition—3Rs

The results of the Tippecanoe darter population condition model provide the basis for our analyses of the species’ current status using the 3Rs. The population condition score is a measure of each population’s resiliency (table 6, figure 6), and these scores form the basis of our analyses of the species’ redundancy (among the various populations) and representation (across its environmental settings).

Table 6. Current condition of Tippecanoe darter populations. Population condition scores are categorized as "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UKN), or "presumed extirpated" (0).

<table>
<tr><th>No.</th><th>Population</th><th>Occupancy</th><th>Occupancy Extent</th><th>Connectivity</th><th>Water Quality</th><th></th><th colspan="2">Population Condition Score</th></tr>
<tr><td>1</td><td>Middle-Upper Wabash, IN</td><td>H</td><td>H</td><td>M</td><td>M</td><td></td><td>M</td><td>H</td></tr>
<tr><td>2</td><td>Tippecanoe River, IN</td><td>H</td><td>M</td><td>0</td><td>M</td><td></td><td colspan="2">M</td></tr>
<tr><td>3</td><td>Lower East Fork White, IN</td><td>H</td><td>M</td><td>M</td><td>H</td><td></td><td>M</td><td>H</td></tr>
<tr><td>4</td><td>Upper Green, KY</td><td>H</td><td>H</td><td>L</td><td>H</td><td></td><td colspan="2">H</td></tr>
<tr><td>5</td><td>Licking River, KY</td><td>H</td><td>H</td><td>H</td><td>H</td><td></td><td colspan="2">H</td></tr>
<tr><td>6</td><td>N, S, Middle Fork Kentucky, KY</td><td>H</td><td>H</td><td>L</td><td>H</td><td></td><td colspan="2">H</td></tr>
<tr><td>7</td><td>South Fork Cumberland, KY/TN</td><td>H</td><td>L</td><td>0</td><td>H</td><td></td><td colspan="2">M</td></tr>
<tr><td>8</td><td>Scioto, OH</td><td>H</td><td>H</td><td>H</td><td>M</td><td></td><td colspan="2">H</td></tr>
<tr><td>9</td><td>Walhonding, OH</td><td>0</td><td>0</td><td>L</td><td>H</td><td></td><td colspan="2">0</td></tr>
<tr><td>10</td><td>Ohio, PA/WV/OH</td><td>H</td><td>H</td><td>H</td><td>M</td><td></td><td colspan="2">H</td></tr>
<tr><td>11</td><td>Red River, TN</td><td>H</td><td>L</td><td>M</td><td>H</td><td></td><td colspan="2">M</td></tr>
<tr><td>12</td><td>Stones River, TN</td><td>UKN</td><td>L</td><td>0</td><td>H</td><td></td><td colspan="2">UKN</td></tr>
<tr><td>13</td><td>Harpeth River, TN</td><td>H</td><td>L</td><td>L</td><td>H</td><td></td><td colspan="2">M</td></tr>
<tr><td>14</td><td>Elk River, WV</td><td>H</td><td>M</td><td>M</td><td>H</td><td></td><td>M</td><td>H</td></tr>
<tr><td>15</td><td>Upper Green-1978, KY</td><td>UKN</td><td>L</td><td>0</td><td>H</td><td></td><td colspan="2">UKN</td></tr>
</table>

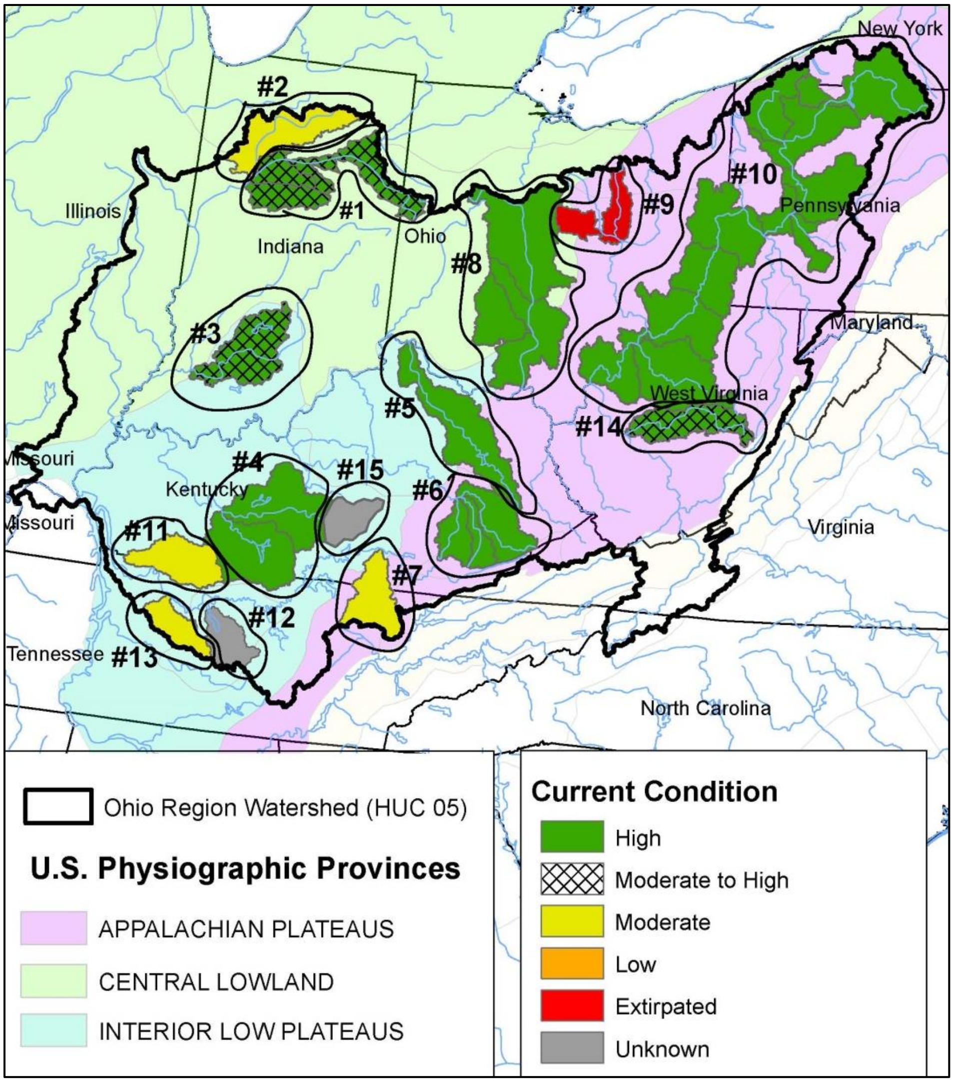


Figure 6. Current condition of Tippecanoe darter populations illustrated by HUC 8 watersheds.

Resiliency—Resiliency describes the ability of a population to withstand environmental or demographic stochastic disturbance and is positively related to population size and growth rate, patch size, and connectivity to other populations. The population characteristic components from the Tippecanoe darter model, which incorporate estimates of occupancy, occupancy extent, and connectivity, are used in conjunction with water quality to assess Tippecanoe darter population resiliency.

#1 Middle-Upper Wabash, Indiana

The Middle-Upper Wabash population is located in northern Indiana and includes Deer Creek, the lower Tippecanoe River, Wabash River, Mississinewa River and Wildcat Creek. Land cover is dominated by agriculture (80 percent) with little forest and development, 8 percent and 4 percent, respectively, within the HUC 8 watersheds. "Other" land cover types (*e.g.*, open water, wetlands, and grasslands) account for the remaining 8 percent of land cover. The first record of the Tippecanoe darter within this population was documented in 1985 in the lower reaches of the Tippecanoe River (Fisher 2008; Carney *et al*. 1993; Indiana Department of Natural Resources (IDNR) 2016, unpublished data). The most recent records documenting the Tippecanoe darter within the Middle-Upper Wabash are from 2017 (below the Norway Dam in the lower Tippecanoe River) (IDNR 2017, unpublished data). Tippecanoe darter occupancy extent (*i.e.*, occupied or known potential habitat) is approximately 131 mi (211 km) of stream habitat. The furthest upstream records within the Wabash River are just below the J. Edward Roush Lake Dam (figure 7), which would be impassable by Tippecanoe darter (Fisher 2018). Surveys suggest that the range of this Tippecanoe darter population is expanding (Fisher 2016a). Connectivity (*i.e.*, immigration potential from the nearest neighboring population) is ranked as moderate given two large dams (Oakdale and Norway dams) and associated reservoirs (Lake Freeman and Lake Shafer) currently separating the population from its nearest upstream neighbor (figure 7). Middle-Upper Wabash is relatively free of major pollutants, but agricultural runoff has been noted (White *et al*. 2005, p. 416); therefore, water quality is ranked as moderate. Overall, we conclude the Middle-Upper Wabash population currently has moderate to high resiliency (figures 6 and 7).

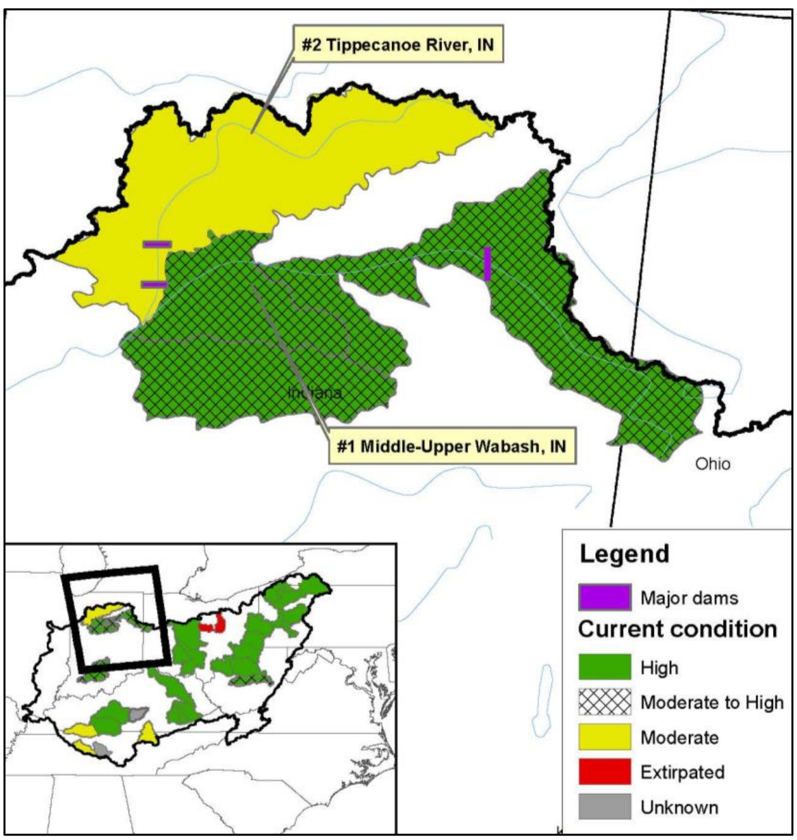


Figure 7. Current condition of the Tippecanoe darter in the #1 Middle-Upper Wabash, Indiana, and #2 Tippecanoe River, Indiana, populations (illustrated by HUC 8 watersheds).

#2 Tippecanoe River, Indiana

The Tippecanoe River population is located in northern Indiana. Land cover is dominated by agriculture (79 percent) with little forest and development, 11 percent and 3 percent, respectively, within the HUC 8 watershed. "Other" land cover types account for the remaining 7 percent of land cover. The first record of the Tippecanoe darter within this population was documented in 1888, and it has been documented as recently as 2017 (Fisher 2008; Carney *et al*. 1993; IDNR 2016, unpublished data; IDNR 2017, unpublished data). Tippecanoe darter occupancy extent is approximately 55 mi (89 km) of stream on the Tippecanoe River. Recent survey data suggest that the Tippecanoe darter is expanding into its historical range where it had been missing during surveys conducted by the IDNR in the early 2000s (Fisher 2017). In 2017, the first survey attempt in the historical upstream reaches yielded several Tippecanoe darters, and surveyors concluded that the species seemed to be abundant. Connectivity is ranked as zero, meaning the population is believed to be isolated. Connectivity is believed to be zero because immigrants from the only neighboring population would have to travel upstream and pass through either the Oakdale and/or Norway dams, which is considered unlikely given the size of these large hydroelectric dams (figure 7). Water quality is ranked as moderate given the predominantly agricultural land cover and potential agricultural runoff. Overall, we conclude that the Tippecanoe River population currently has moderate resiliency (figures 6 and 7).

#3 Lower East Fork White, Indiana

The Lower East Fork White population is located in southern Indiana. Land cover is 58 percent forest, 32 percent agriculture, 1 percent development, and 9 percent "other" within the HUC 8 watershed. The first record of the Tippecanoe darter within this population was documented in 1936, and it has been documented as recently as 2006 (Fisher 2008; IDNR 2016, unpublished data). During the late 1990s and early 2000s, species-specific surveys for Tippecanoe darters were conducted by the IDNR (Fisher 2016a). Surveys have documented Tippecanoe darters occupying approximately 60 mi (97 km) of stream habitat in the East Fork White River. The furthest upstream record is just below the Williams Dam (figure 8), which has been in place since the 1920s, and which would be impassable by Tippecanoe darter (Fisher 2016b; Fisher 2018). Connectivity is ranked as moderate given the closest known population is over 200 mi north. Water quality is ranked as high given the notable improvements and favorable response from fish communities (Crawford *et al*. 1996, p. 1). Overall, we conclude that the Lower East Fork White population currently has moderate to high resiliency (figures 6 and 8).

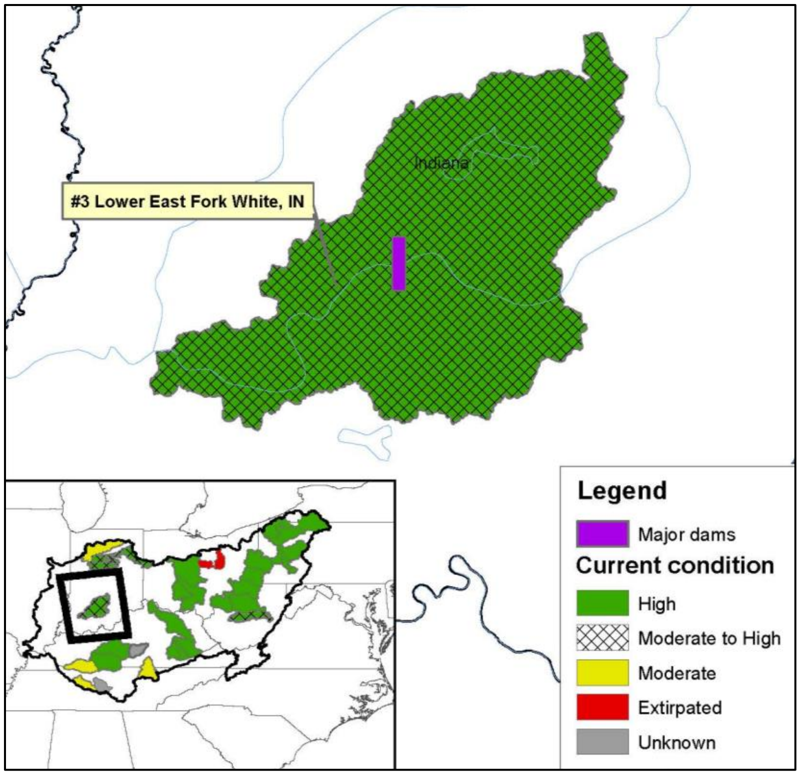


Figure 8. Current condition of the Tippecanoe darter in the #3 Lower East Fork White, Indiana, population (illustrated by HUC 8 watersheds).

#4 Upper Green, Kentucky

The Upper Green population is located in Kentucky and includes the Green River, Little Barren River, Barren River, Trammel Creek, and Russell Creek. Land cover is 51 percent forest, 39 percent agriculture, 1 percent developed, and 9 percent "other" within the HUC 8 watersheds. The first record of the Tippecanoe darter within this population was documented in 1958, and it has been documented as recently as 2015 (Kentucky Department of Fish and Wildlife Resources (KDFWR) 2017, unpublished data). Occupancy extent is approximately 258 mi (415 km) of stream habitat in the Upper Green population. The furthest upstream record is just below the Green River Lake Dam, which stands 144 ft (44 m) high and was completed in 1969. Between 2012 and 2015, the Kentucky Department of Fish and Wildlife Resources collected the Tippecanoe darter at 18 of 41 sites distributed throughout a 95-mi (153 km) reach of the mainstem Green River between Mammoth Cave National Park and the Green River Lake Dam (*i.e*., unoccupied critical habitat unit designated for the diamond darter) using a benthic trawl. It was frequently captured (mostly young-of-year or immature) in riffle/pool transitional areas and deep runs with substrates of gravel, cobble, and organic debris (Thomas 2017). Thomas and Brandt (2016, p. 58) concluded that Tippecanoe darters were "generally" distributed in the 95-mi (153 km) reach of the mainstem Green River. This reach of the Green River supports robust populations of the Tippecanoe darter (Thomas 2017). Connectivity is ranked low given the large dam separating this population from its closest neighbor and the unknown status of its closest neighbor (figure 9). Water quality is ranked as high. Overall, we conclude that the Upper Green population currently has high resiliency (figures 6 and 9).

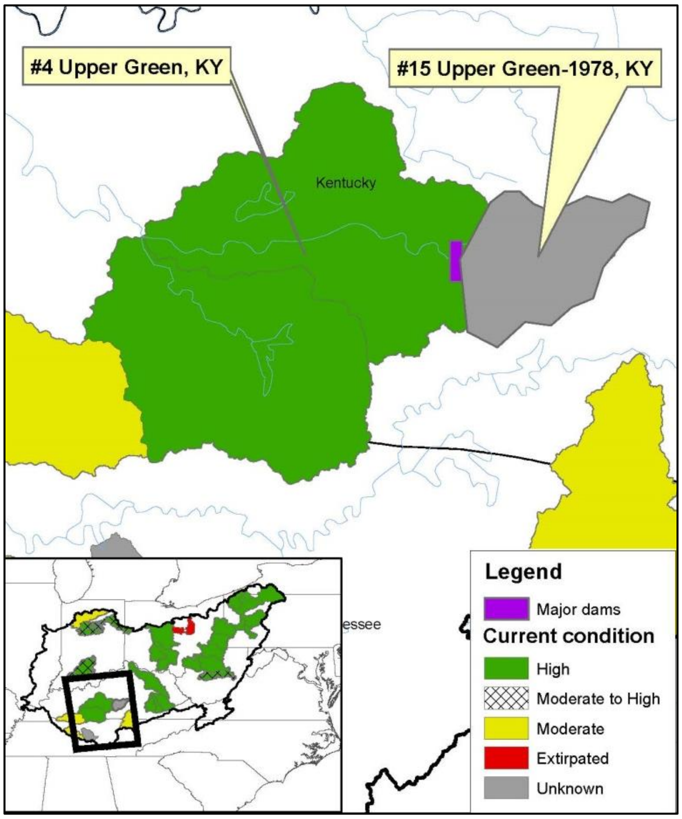


Figure 9. Current condition of the Tippecanoe darter in the #4 Upper Green, Kentucky, and #15 Upper Green-1978, Kentucky, populations (illustrated by HUC 8 watershed).

<u>#15 Upper Green-1978, Kentucky</u>

The Upper Green-1978 population is composed of a single record from 1978 from the Green River (KDFWR 2017, unpublished data). The Upper Green-1978 population is separated from the Green River population by the Green River Lake Dam and Green River Lake (figure 9). The Green River Lake Dam stands 144 ft (44 km) high and was completed in 1969. To our knowledge, no surveys have been completed since 1978 to verify Tippecanoe darter presence or absence in the Green River above the Green River Lake; therefore, occupancy is unknown. Connectivity is expected to be zero given the dam is serving as a barrier to upstream migration. Overall, we conclude that the Upper Green-1978 population currently has unknown resiliency (figures 6 and 9).

<u>#5 Licking River, Kentucky</u>

The Licking River is located in northern Kentucky and flows in a northwest direction eventually joining the Ohio River. Land cover is 54 percent forest, 34 percent agriculture, 3 percent developed, and 9 percent "other" within the HUC 8 watershed. The first record of the

Tippecanoe darter within this population was documented in 1955, and it has been documented as recently as 2012 (KDFWR 2017, unpublished data). Occupancy extent is approximately 144 mi of stream habitat in the Licking River. The furthest upstream records are just below Cave Run Lake Dam. Connectivity and water quality are ranked as high for this population. Overall, we conclude that the Licking River population currently has high resiliency (figure 6).

#6 North, South and Middle Fork Kentucky River, Kentucky

The North, South and Middle Fork Kentucky River population is located in Kentucky and includes the Middle Fork Kentucky River, Red Bird River, Goose Creek, South Fork Kentucky River, and North Fork Kentucky River. The watersheds are predominantly forested (75 to 84 percent) within the HUC 8 watersheds. The three major forks discharge to form the Kentucky River. The first record of the Tippecanoe darter within this population was documented in 1992, and it has been documented as recently as 2013 (KDFWR 2017, unpublished data). Occupancy extent is approximately 110 mi (177 km) of stream habitat. Connectivity is ranked as low given the closest known population is over 300 mi (483 km) away, plus immigrants would have to swim upstream through 14 locks and dams on the Kentucky River (this is assuming Tippecanoe darters are missing from the Kentucky River). Water quality is ranked as high for this population. Overall, we conclude that the North, South and Middle Fork Kentucky River population currently has high resiliency (figure 6).

#7 South Fork Cumberland, Kentucky/Tennessee

The South Fork Cumberland River population is located on the boarder of Kentucky and Tennessee and includes Rock Creek, Big South Fork, and Station Camp Creek. Much of this population falls within the federally owned lands of the U.S. Forest Service's Daniel Boone National Forest and the NPS' Big South Fork National River and Recreation Area. The watershed is 80 percent forested within the HUC 8 watershed. This area was historically impacted by coal mining (Stiles 2017). The first record of the Tippecanoe darter within this population was documented in 1979, and it has been documented as recently as 2015 (KDFWR 2017, unpublished data; Tennessee Wildlife Resources Agency (TWRA) 2017, unpublished data). Occupancy extent is approximately 23 mi (37 km) of stream habitat. Connectivity is ranked as zero because of Wolf Creek Dam, a 258-ft (79-m) high earthen and concrete dam that forms a 100-mi (160-km) reservoir, Lake Cumberland, along the Cumberland River; consequently, the population is believed to be isolated (figure 10). Water quality is ranked as high for this population. Overall, we conclude that the South Fork Cumberland River population currently has moderate resiliency (figures 6 and 10).

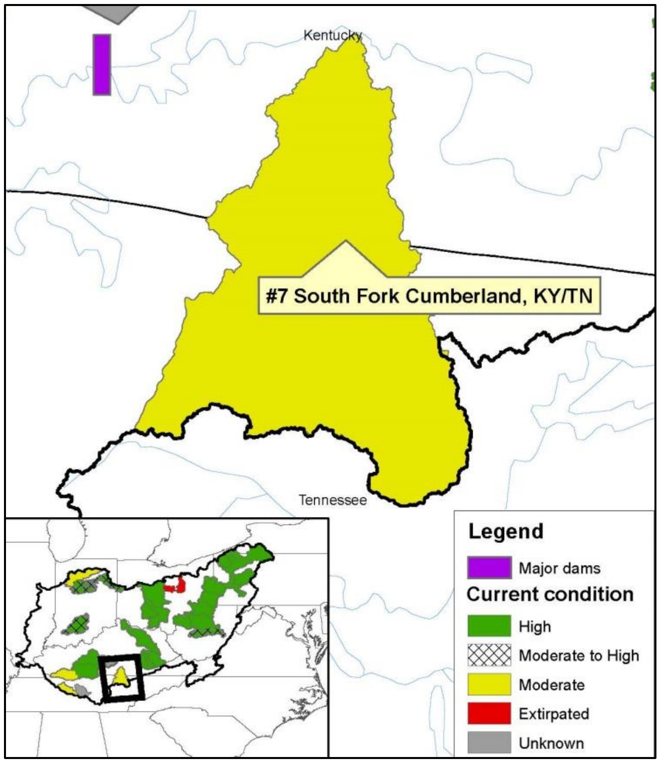


Figure 10. Current condition of the Tippecanoe darter in the #7 South Fork Cumberland, Kentucky/Tennessee, population (illustrated by HUC 8 watershed).

#8 Scioto, Ohio

The Scioto River population is located in southcentral Ohio and includes Big Darby Creek, Big Walnut Creek, Deer Creek, Little Darby Creek, North Fork Paint Creek, Paint Creek, Salt Creek, Scioto River, Walnut Creek, and Alum Creek. Land cover within the three HUC 8 watersheds encompassing this population range from 40 to 70 percent agriculture, 11 to 50 percent forest, and 2 to 12 percent developed. The first record of the Tippecanoe darter within this population was documented in 1939, and the most recent records are from 2017 (Ohio State University (OSU) 2016, unpublished data; Zimmerman 2018). Tippecanoe darter occupancy extent is approximately 283 mi (455 km) of stream habitat originating near Columbus, Ohio, and flowing south to the Ohio River proper. Surveys suggest that the range of this population is expanding and "robust healthy populations" occur in the Scioto River (Zimmerman 2017). Connectivity is ranked as high. Water quality is ranked as moderate because of reported water quality issues including ammonia and sedimentation; however, water quality impairments are not believed to be impacting Tippecanoe darters at the population level given the exponential increase in occurrences and range expansion over the last several decades. Overall, we conclude that the Scioto population currently has high resiliency (figure 6).

#9 Walhonding, Ohio

A single occurrence of the Tippecanoe darter was documented in the upper Muskingum basin in 1962 in the Walhonding River (OSU 2016, unpublished data). Successive surveys have not documented Tippecanoe darters in the Walhonding or upper Muskingum basin since 1962 (Zimmerman 2016). Other darters that often associate with Tippecanoe darters have naturally repopulated the Muskingum basin, but it appears the Tippecanoe darter was eliminated from this river sometime in the past (Zimmerman 2016). A significant number of dams on the mainstem Muskingum River prevent Tippecanoe darters from returning to this area on their own. We conclude that the Walhonding population is extirpated (figure 6).

#10 Ohio, Pennsylvania/West Virginia/Ohio

Of all the populations, the Ohio population is the largest and most contiguous. This unit includes French Creek, Allegheny River, Bull Creek, Deer Creek, Pine Creek, Mahoning Creek, Kiskiminetas River, and Oil Creek in Pennsylvania; lower Muskingum River, Wheeling Creek, Little Beaver Creek and Cross Creek in Ohio; Little Kanawha River, Hughes River, and West Fork Little Kanawha River in West Virginia; and the Ohio River proper. Land cover within the HUC 8 watersheds encompassing this population ranges from 50 to 86 percent forest, 7 to 33 percent agriculture, and 1 to 17 percent developed, and includes the major city of Pittsburgh, Pennsylvania. Water quality has improved since the 1970s, but cities (*e.g*., Pittsburgh) remain point sources for nutrients and industrial waste. Agricultural runoff dominates most tributary inputs, and abandoned mines still exude acid (White *et al*. 2005, p. 381). This unit includes free-flowing rivers (*e.g*., French Creek, Little Kanawha River, and upper Allegheny River) and navigation locks and dams systems (*e.g*., lower Allegheny River and Ohio River). Prior to European contact, the river was clear and constantly flowing and contained clean beds of gravel, rock, and sand. Today, the entire river is impounded with deep navigation channels. To maintain the navigational channels, the U.S. Army Corps of Engineers dredges an average of 500,000 cubic meters of silt, sand, and gravel each year (White *et al*. 2005, p. 384). Locks and dams systems provide habitat preferred by Tippecanoe darter downstream of dam plunge pools, but only in conjunction with gravel substrate (Criswell *et al*. 2014, p. 3). Koryak *et al*. (2011, p. 511) easily captured hundreds of Tippecanoe darters at a rocky riffle downstream of a lock and dam within the Allegheny River. A disabled lock and dam in the lower reaches of the Little Kanawha River, West Virginia (below the town of Elizabeth), is likely blocking upstream movement of Tippecanoe darters from the Ohio River proper; however, Tippecanoe darters from the upper reaches of the Kanawha River can still migrate downstream (Cincotta 2018). Occurrence data suggest that the species is persisting and expanding. The first record of the Tippecanoe darter in this unit is from 1935, and the most recent records are from 2017 (Pennsylvania Fish and Boat Commission (PAFBC) 2016, unpublished data; OSUMB 2016, unpublished data; West Virginia Division of Natural Resources (WVDNR) 2017, unpublished data; Zimmerman 2018). Tippecanoe darter occupancy extent is over 500 mi (805 km) of stream. Surveys suggest that the range of this population is expanding and “robust healthy populations” occur in the upper Ohio River proper and its larger tributaries (Zimmerman 2017). Connectivity is ranked as high and water quality is ranked as moderate. Overall, we conclude that the Ohio population currently has high resiliency (figure 6).

#11 Red River, Tennessee

The Red River is a tributary to the Cumberland River in Tennessee. Land cover is 63 percent agriculture, 25 percent forested, 3 percent developed, and 9 percent “other” within the HUC 8 watershed. The first record of Tippecanoe darter within this population was documented in 1991, and it has been documented as recently as 2014 (KDFWR 2017, unpublished data; TWRA 2017, unpublished data). Tippecanoe darter occupancy extent is approximately 22 mi (35 km) of stream. Connectivity is ranked as moderate, and water quality is ranked as high. Overall, we conclude that the Red River population currently has moderate resiliency (figures 6 and 11).

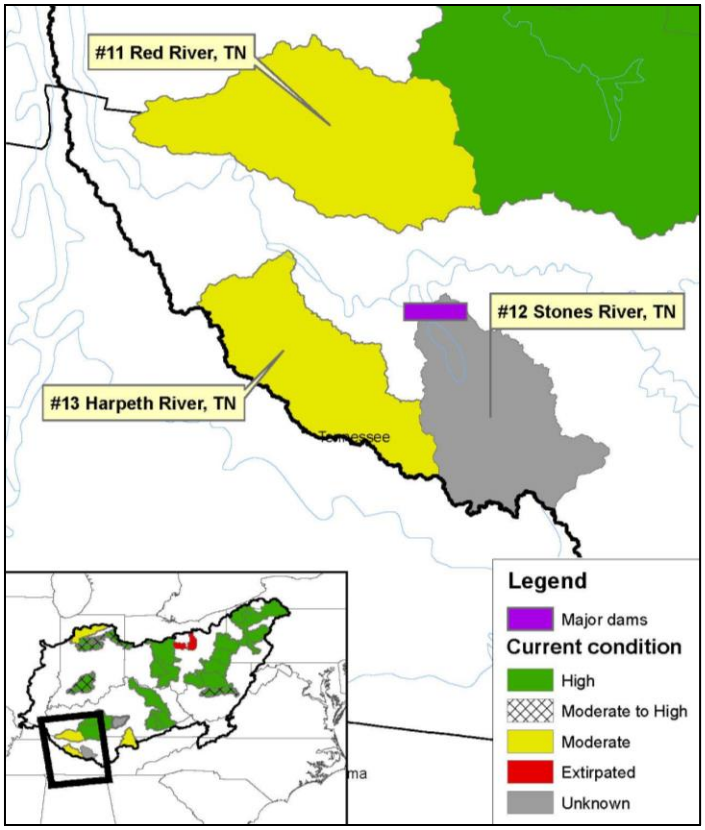


Figure 11. Current condition of the #11 Red River, #12 Stones River, and #13 Harpeth River, Tennessee, populations (illustrated by HUC 8 watersheds).

<u>#12 Stones River, Tennessee</u>

The Stones River is a tributary to the Cumberland River in Tennessee. Within the HUC 8 watershed, land cover is 43 percent forest, 32 percent agriculture, 10 percent development, and 15 percent "other." A single Tippecanoe darter record was collected from the Stones River in 1968 (TWRA 2017, unpublished data). In the same year, the J. Percy Priest Dam, a 130-ft (40-m) high earth and concrete-gravity dam, was completed. To our knowledge, no surveys have been completed since 1968 to verify Tippecanoe darter presence or absence in the Stones River; therefore, occupancy is unknown. Furthermore, connectivity is expected to be zero given the J. Percy Priest Dam serves as a barrier to upstream migration (figure 11). Overall, we conclude that the Stones River population currently has unknown resiliency (figures 6 and 11).

#13 Harpeth River, Tennessee

The Harpeth River is a tributary to the Cumberland River in Tennessee. Land cover is 57 percent forest, 27 percent agriculture, 5 percent development, and 11 percent "other" within the HUC 8 watershed. The first record of the Tippecanoe darter within this population was documented in 1991, and it has been documented as recently as 2014 (TWRA 2017, unpublished data). Tippecanoe darter occupancy extent is approximately 26 mi (42 km) of stream. Connectivity is ranked as low, and water quality is ranked as high. Overall, we conclude that the Harpeth River population currently has moderate resiliency (figures 6 and 11).

#14 Elk River, West Virginia

The Elk River population is located in West Virginia and includes the Elk River and the lower Birch River. Land cover is 91 percent forest, 2 percent agriculture, 1 percent development, and 6 percent "other" within the HUC 8 watershed. The Elk River is one of the most ecologically diverse in the state of West Virginia, supporting over 100 fish species and 30 mussel species, and is home to the only extant population of the federally endangered diamond darter. The Elk River has had a long history of coal mining, timbering, oil and gas activities, and high coliform counts due to a lack of municipal sewage treatment; however, many of these issues have been mitigated in recent years (Cincotta 2017). The first record of the Tippecanoe darter within this population was documented in 1966, and it has been documented as recently as 2015 (WVDNR 2017, unpublished data). Tippecanoe darter occupancy extent is approximately 98 mi (158 km) of stream. Connectivity is ranked as moderate, and water quality is ranked as high. Overall, we conclude that the Elk River population currently has moderate to high resiliency (figure 6).

Summary of resiliency—The Tippecanoe darter is persisting and in some cases expanding in most (80 percent) of its historical range. We are aware of a single extirpation representing a complete loss of resiliency in that population. The resiliency of two populations is unknown. Of the 12 known extant populations, 5 (33 percent) have a current score of high resiliency, 3 (20 percent) have moderate to high resiliency, and 4 (27 percent) have moderate resiliency. Therefore, we conclude that Tippecanoe darter populations currently have moderate to high resiliency.

Redundancy—Redundancy describes the ability of a species to withstand catastrophic events by maintaining multiple, resilient populations distributed within the species' ecological settings and across the species' range.

Tippecanoe darter currently occurs in at least 80 percent of its historical range (12 of 15 known populations). Redundancy for the Tippecanoe darter is evidenced by multiple extant populations distributed across three physiographic provinces within the Ohio Region watershed (*i.e.*, six populations in the Appalachian Plateaus, three populations in the Central Lowland, and five populations in the Interior Low Plateaus[2]). The current spatial extent of each population is either

[2] Note, the Scioto, Ohio, population is distributed across both the Appalachian Plateaus and Central Lowland physiographic provinces, and the Licking River, Kentucky, population is distributed across both the Appalachian Plateaus and Interior Low Plateaus physiographic provinces (table 2 and figure 6).

static or expanding. Because all currently known populations of the Tippecanoe darter exhibit moderate to high resiliency, as determined under our current resiliency assessment, the species is considered to also have moderate to high redundancy.

Representation—Representation describes the ability of a species to adapt to changing environmental conditions over time and is characterized by the breadth of genetic and environmental diversity within and among populations.

As discussed in Chapter 2, we are aware of a single Tippecanoe darter genetic study (Kinziger *et al*. 2001, entire) that was not intended to address population-genetic structuring. Because we know of only this one study and are not aware of any morphological or behavioral differences with which to characterize the Tippecanoe darter's representation rangewide, we discuss the environmental diversity of Tippecanoe darter habitats to assess its current representation.

As discussed in Chapter 2, Tippecanoe darters are known from a variety of different environmental settings in three distinct physiographic provinces: Appalachian Plateaus, Central Lowland, and Interior Low Plateaus. Populations have been documented in rivers with varying physical and chemical characteristics (*e.g*., gradient, substrate, flow, and alkalinity). The Tippecanoe darter is widely distributed and currently maintains representation in 18, 7, and 6 HUC 8 watersheds in the Appalachian Plateaus, Central Lowland, and Interior Low Plateaus physiographic provinces, respectively (table 2). In the Appalachian Plateaus province, the Tippecanoe darter is represented by six populations with moderate (n=1), moderate to high (n=1), and high (n=4) resiliency. In the Central Lowland province, the species is represented by three populations with moderate (n=1), moderate to high (n=1), and high (n=1) resiliency. In the Interior Low Plateaus, the species is represented by five populations with moderate (n=2), moderate to high (n=1), and high (n=2) resiliency. Given the Tippecanoe darter retains representation in three physiographic provinces and maintains the same (with one exception) distribution it had historically, we conclude that the species' representation is moderate to high.

Summary of Current Condition

The Tippecanoe darter is currently distributed in 12 of the historical 15 populations, 2 are unknown, and 1 is extirpated. The extant populations have moderate to high resiliency and redundancy scores. The Tippecanoe darter is present within all three physiographic provinces from which it is historically known, and survey data suggest that the species is expanding in some populations (figure 12). This leads us to conclude that the Tippecanoe darter's representation is also moderate to high. Therefore, our analysis under the 3Rs leads us to conclude that the condition of the Tippecanoe darter is currently moderate to high.

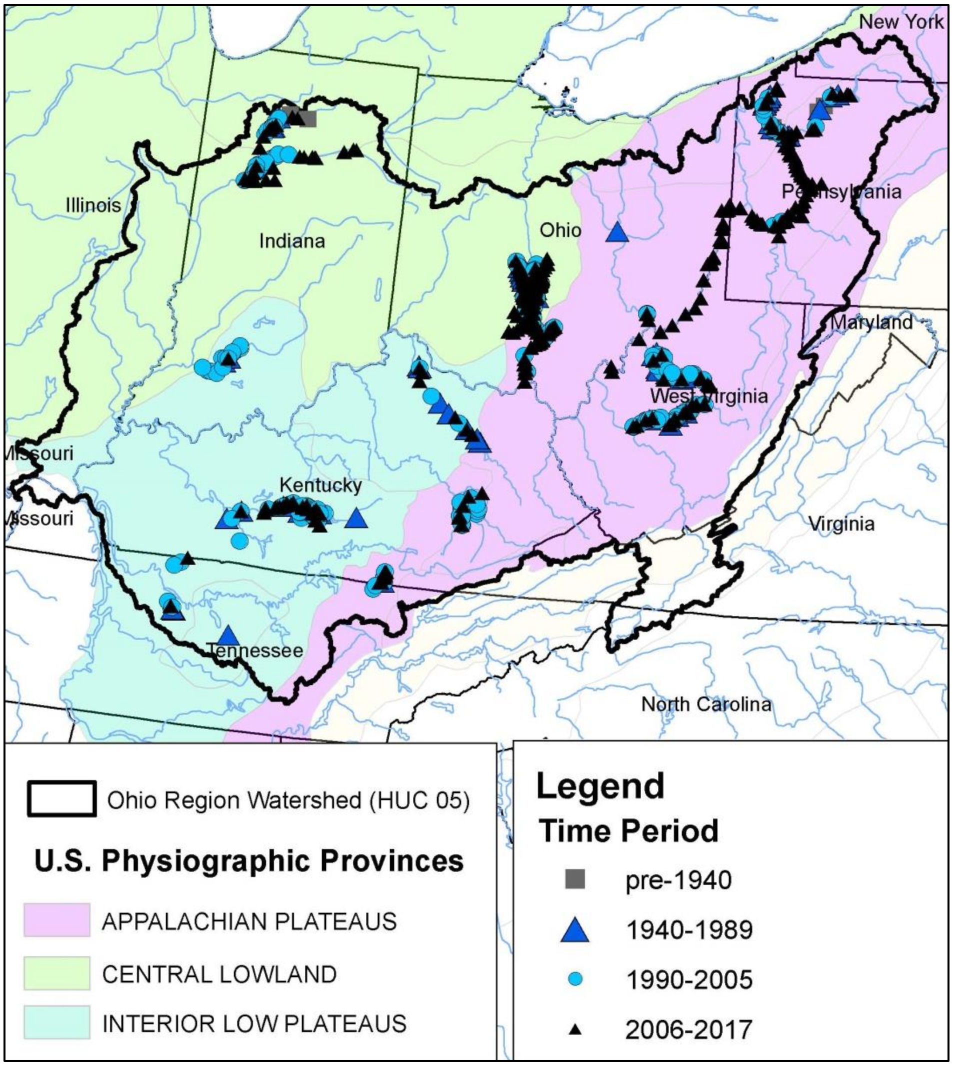


Figure 12. Tippecanoe darter occurrence records.

CHAPTER 5—SPECIES' FUTURE VIABILITY

Methodology

Using the same methodology and criteria described above for assessing current condition, we modeled three scenarios to assess the potential viability of the Tippecanoe darter at 10, 25, and 50 years in the future. Here we describe three plausible future scenarios and whether there will be a change from current conditions to any of the 3Rs under each scenario. Our future scenarios differ by considering variations that are predicted in land cover, water quality, and occupancy. These scenarios capture the range of likely viability outcomes that the Tippecanoe darter could exhibit within 50 years. We chose 10 years for our future scenarios because the species is short lived (1 to 2 years); therefore, we anticipate that changes in demographics (*e.g.*, decreased spawning success) from potential stressors will be measurable within a minimum of 10 years. Also, 25 and 50 years were chosen to account for changes (for the better or worse) in factors influencing the species in the future (*e.g.*, water quality and habitat fragmentation) that we would expect to occur only gradually; consequently, we assume these timeframes are reasonable for assessing potential changes to the viability of the Tippecanoe darter. Tables summarizing the future conditions under each scenario at 10, 25, and 50 years are provided below. Tables summarizing individual components used to characterize future conditions are detailed in appendix A.

To assess changes in land cover, we determined the rate of land cover change between the 2001 and 2011 NLCD data (Homer *et al*. 2015, entire). We determined the rate of land cover change for each HUC 8 watershed encompassing Tippecanoe darter populations. Total percent forest cover across all watersheds decreased one percent between 2001 and 2011. On average, the total percent of agriculture and development across all watersheds did not change between 2001 and 2011. However, the watersheds of five populations (*i.e*., Scioto, Ohio; Ohio, Pennsylvania/West Virginia/Ohio; Red River, Tennessee; Stones River, Tennessee; and Harpeth River, Tennessee) had an increase in development of between 1 and 3 percent between 2001 and 2011. For our future scenarios, we assumed the same rate of development for Scenario 1 (continuation of current trend), a decrease in the rate of development for Scenario 2 (optimistic scenario), and an increase in the rate of development for Scenario 3 (pessimistic scenario).

Scenario 1: Continuation of Current Trend

Current trends suggest that darters are expanding within populations (we assume as a result of improved survey techniques and/or increased abundance); therefore, under Scenario 1 we predict an **increase in occupancy extent**[3] at all extant populations where additional suitable habitat is

[3] Survey data from Ohio were used to approximate the rate of Tippecanoe darter expansion (*i.e*., increase in occupancy extent). The Ohio dataset was chosen because we considered it the most complete (*i.e*., multiple surveys within the same streams using the same methodology over four decades). Tippecanoe darters expanded 37 mi (60 km) downstream between 1984 and 1997; 50 mi (80 km) downstream between 1997 and 2004; 21 mi (34 km) upstream between 1994 and 2005; and 8 mi (13 km) upstream between 1994 and 2005 (OSU 2016,

present. We do not predict an increase in occupancy extent within the Tippecanoe River or Lower East Fork White, Indiana, populations, because of dams and/or lack of suitable habitat for expansion (Fisher 2018). For those populations with increasing occupancy extent, we predict a decrease in distance to source populations, ultimately leading to an **increase in connectivity**[4], except for those populations where dams will continue to prevent fish passage (*i.e.*, Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (*i.e.*, Middle-Upper Wabash and East Fork White River, Indiana; Fisher 2018).

In the continuation of current trend scenario, we predict **maintaining water quality:**

- Assumes similar rate of urban development as the rate observed between 2001 and 2011.
- Assume same rate of improvement of waste water discharge controls.
- Assume same rate of combined sewer overflow separation (*i.e.*, 30 percent or more).
- Assume little change in water volume within developing watersheds from water withdrawals.
- Assume maintenance of existing riparian forested buffers.
- Assume no change in CAFO regulations.

Results - Scenario 1 (Continuation of Current Trend): Based on assumptions for continuing trends, the conditions of 12 Tippecanoe darter populations are predicted to remain relatively unchanged from the current condition, and the conditions of 3 populations are predicted to have improved within 50 years (table 7, figure 13). Under Scenario 1, the species' redundancy and representation remained unchanged (*e.g.*, all current populations remained extant), and the resiliencies of the three improved populations are predicted to increase.

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unpublished data). We conservatively estimate that Tippecanoe darters will expand approximately 20 mi (32 km) per decade based on continuation of current trend.

[4] We conservatively estimate that Tippecanoe darters will decrease distance to closest source population by approximately 20 mi (32 km) per decade based on continuation of current trend.

Table 7. Scenario 1 summary: Tippecanoe darter population conditions at 10, 25, and 50 years. Assumes a continuation of the current trend with corresponding increases in occupancy extent (for those populations where additional suitable habitat is present) and connectivity.[5] Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UKN), or "presumed extirpated" (0).

No.	Population	Current Population Condition Score		Scenario 1: Cont. of Current Trend		
				10 Years	25 Years	50 Years
1	Middle-Upper Wabash, IN	M H		M H	M H	M H
2	Tippecanoe River, IN	M		M	M	M
3	Lower East Fork White, IN	M H		M H	M H	M H
4	Upper Green, KY	H		H	H	H
5	Licking River, KY	H		H	H	H
6	N, S, Middle Fork Kentucky, KY	H		H	H	H
7	South Fork Cumberland, KY/TN	M		M	M	M
8	Scioto, OH	H		H	H	H
9	Walhonding, OH	0		0	0	0
10	Ohio, PA/WV/OH	H		H	H	H
11	Red River, TN	M		M	H	H
12	Stones River, TN	UKN		UKN	UNK	UNK
13	Harpeth River, TN	M		M	M H	H
14	Elk River, WV	M H		H	H	H
15	Upper Green-1978, KY	UKN		UNK	UNK	UNK

[5] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana).

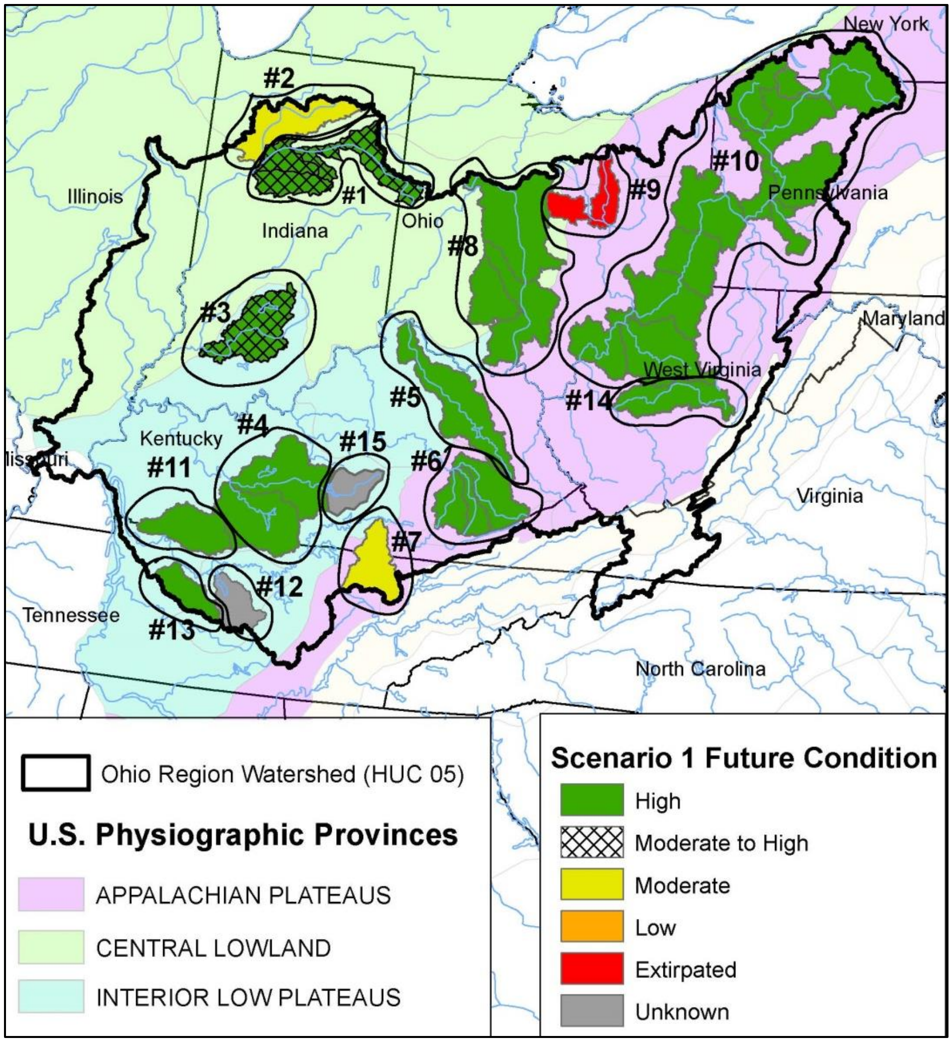

Figure 13. Summary of predicted condition of Tippecanoe darter populations under Scenario 1 within 50 years of continuation of current trend (illustrated by HUC 8 watersheds).

Scenario 2: Optimistic Scenario

Similar to Scenario 1, Scenario 2 assumes current trends will continue (we assume as a result of improved survey techniques and/or increased abundance) and there will be **increases in occupancy extent**[6] at all extant populations where additional suitable habitat is present. We do not predict an increase in occupancy extent within the Tippecanoe River or Lower East Fork White, Indiana, populations, because of dams and/or lack of suitable habitat for expansion (Fisher 2018). Increasing occupancy extent will lead to a decrease in distance to source populations, ultimately leading to an **increase in connectivity**[7] except for those populations where dams currently prevent fish passage (*i.e.*, Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (*i.e.*, Middle-Upper Wabash and East Fork White River, Indiana; Fisher 2018). In addition, in Pennsylvania, PAFBC is currently evaluating water quality and habitat suitability in waters with barriers with the goal of reestablishing populations within currently unoccupied (and inaccessible) stream reaches (Fischer 2018), which would ultimately increase occupancy extent and/or connectivity. Also, Scenario 2 assumes there will be increasing water quality within all populations except Middle-Upper Wabash and Tippecanoe River, Indiana, populations, where we do not expect significant changes in water quality given the static agricultural land cover.

In the optimistic scenario, we predict **improving water quality**.

- Assumes reduced rate of development from the rate observed between 2001 and 2011.
- Assumes increased rate of improvement of waste water discharge controls, including adoption of EPA's 2013 ammonia criteria (*i.e.*, assumes all States within the range of Tippecanoe darter will adopt within 10 to 25 years).
- Assumes increased rate of combined sewer overflow separation (*i.e.*, 60 percent or more).
- Assumes little change in water volume within developing watersheds from water withdrawals.
- Assumes maintenance or some increase in riparian forested buffers (*e.g.*, Natural Resources Conservation Service private landowner agreements).
- Assume better CAFO regulations.

In addition to improving water quality, we anticipate that Tippecanoe darters will be reintroduced into the Upper Muskingum basin (*e.g.*, Walhonding River, Ohio) where they are currently absent but known to have occurred previously. Other darters that often associate with Tippecanoe darters have naturally repopulated the Muskingum basin, but it appears the

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[6] Survey data from Ohio were used to approximate the rate of Tippecanoe darter expansion (*i.e.*, increase in occupancy extent). The Ohio dataset was chosen because we considered it the most complete (*i.e.*, multiple surveys within the same streams using the same methodology over four decades). Tippecanoe darters expanded 37 mi (60 km) downstream between 1984 and 1997; 50 mi (80 km) downstream between 1997 and 2004; 21 mi (34 km) upstream between 1994 and 2005; and 8 mi (13 km) upstream between 1994 and 2005 (OSU 2016, unpublished data). We conservatively estimate that Tippecanoe darters will expand approximately 20 mi (32 km) per decade based on continuation of current trend.

[7] We conservatively estimate that Tippecanoe darters will decrease distance to closest source population by approximately 20 mi (32 km) per decade based on the optimistic scenario.

Tippecanoe darter was eliminated from this river sometime in the past (Zimmerman 2016). A significant number of dams on the mainstem Muskingum River prevent Tippecanoe darters from returning to this area on their own. Plans for reintroducing Tippecanoe darters to this area are in progress (Zimmerman 2018). Ohio State University and Ohio Division of Wildlife personnel may begin reintroductions as early as June 2018 (Zimmerman 2018). Successful reintroduction would result in an **increase in occupancy** within the Walhonding population. Reintroductions within the Stones River, Tennessee, and Upper Green-1978, Kentucky, populations were not considered under this scenario because current occupancy is unknown and we have no information to suggest reintroductions are or would be considered in the next 50 years.

Results - Scenario 2 (Optimistic Scenario): Based on assumptions for the optimistic scenario, the conditions of 11 Tippecanoe darter populations are predicted to remain relatively unchanged from their current conditions, and the conditions of 4 populations are predicted to have improved within 50 years (table 8, figure 14). Under Scenario 1, the species' redundancy would improve (the addition of a single population), representation would remain unchanged, and the resiliencies of the four improved populations are predicted to increase.

Table 8. Scenario 2 summary: Tippecanoe darter population conditions at 10, 25, and 50 years. Assumes improving water quality with corresponding increases in occupancy extent (for those populations where additional suitable habitat is present) and connectivity[8], and assumes reintroduction of Tippecanoe darters within Walhonding, Ohio, population, within the next 10 years. Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as “high” condition (H), “moderate” condition (M), “low” condition (L), “unknown” condition (UKN), or “presumed extirpated” (0).

No.	Population	Current Population Condition Score		Scenario 2: Optimistic		
				10 Years	25 Years	50 Years
1	Middle-Upper Wabash, IN	M H		M H	M H	M H
2	Tippecanoe River, IN	M		M	M	M
3	Lower East Fork White, IN	M H		M H	M H	M H
4	Upper Green, KY	H		H	H	H
5	Licking River, KY	H		H	H	H
6	N, S, Middle Fork Kentucky, KY	H		H	H	H
7	South Fork Cumberland, KY/TN	M		M	M	M
8	Scioto, OH	H		H	H	H
9	Walhonding, OH	0		M	H	H
10	Ohio, PA/WV/OH	H		H	H	H
11	Red River, TN	M		M	H	H
12	Stones River, TN	UKN		UKN	UNK	UNK
13	Harpeth River, TN	M		M	M H	H
14	Elk River, WV	M H		H	H	H
15	Upper Green-1978, KY	UKN		UNK	UNK	UNK

[8] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana).

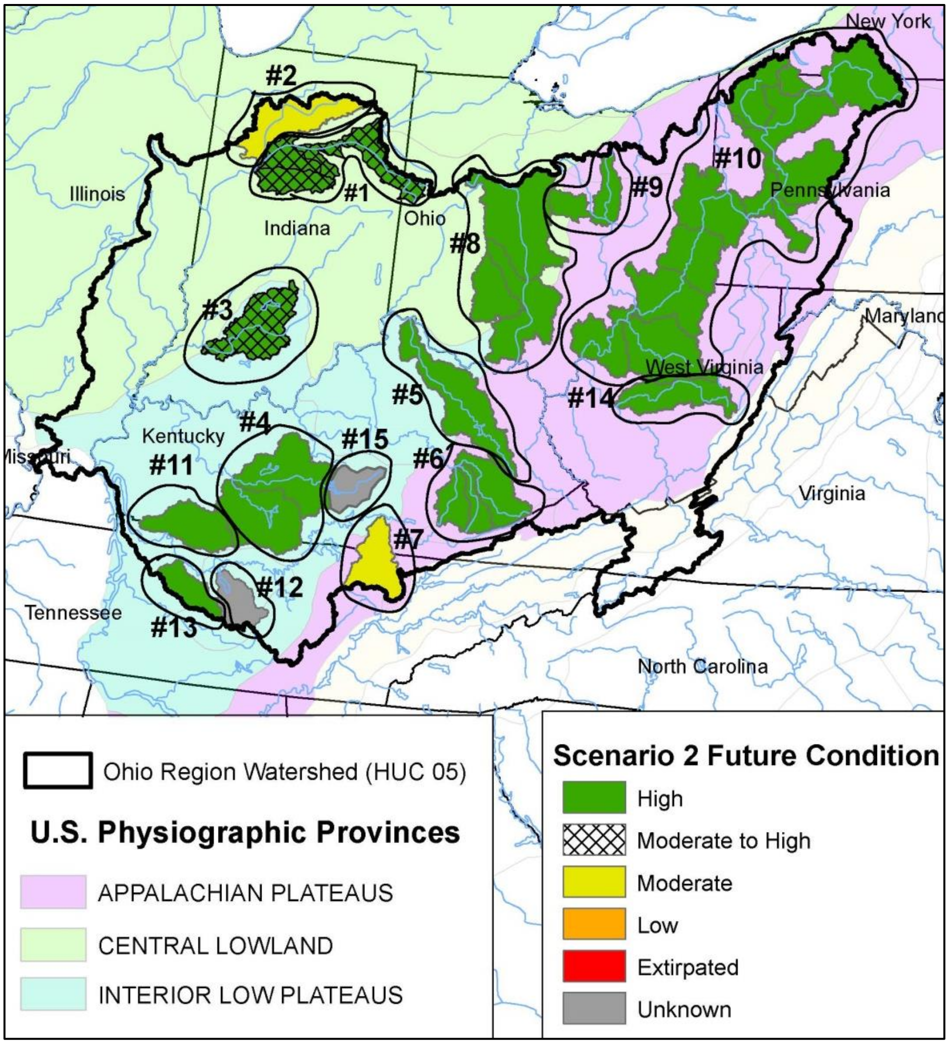

Figure 14: Summary of predicted condition of Tippecanoe darter populations under Scenario 2 within 50 years of optimistic scenario (illustrated by HUC 8 watersheds).

Scenario 3: Pessimistic Scenario

Scenario 3 predicts decreasing water quality within populations with measurable (*i.e*., one percent or more) rates of growth in development observed between 2001 and 2011: Scioto, Ohio; Ohio, Pennsylvania/West Virginia/Ohio; Red River, Tennessee; Stones River, Tennessee; and Harpeth River, Tennessee. Under this scenario, Tippecanoe darters will **decrease occupancy extent** (assume this equates to decreased abundance) **and connectivity** when water quality reaches "Low" conditions (*i.e*., extensive water quality impairments known to impact populations). We assume no change in water quality at the remaining populations because there was little to no measurable change in land cover between 2001 and 2011 and we have no information to suggest land use will change substantially within the next 50 years. Although occupancy extent may be reduced within populations, we expect impacts to be localized and not lead to a complete loss of occupancy (*i.e*., no extirpations are anticipated under this scenario within the next 50 years).

In the pessimistic scenario, we predict **decreasing water quality**.

- Assumes higher rate of development from the rate observed between 2001 and 2011.
- Assume same rate of improvement of waste water discharge controls; however, increase in the number of sewage treatment plants; therefore, increased ammonia.
- Assumes reduced rate of combined sewer overflow separation (*i.e*., 30 percent or less).
- Assumes lower water volume within developing watersheds due to increased water withdrawals.
- Assumes decrease in forested riparian buffers.
- Assume increase in CAFOs, with no changes in regulations.

Results - Scenario 3 (Pessimistic Scenario): Based on assumptions for the pessimistic scenario, the conditions of 12 Tippecanoe darter populations are predicted to remain relatively unchanged from their current conditions, and the conditions of 3 populations are predicted to decrease within 50 years (table 9, figure 15). Under Scenario 3, the species' redundancy and representation remained unchanged (*e.g*., all current populations remained extant), although the resiliencies of three populations are predicted to decrease.

Table 9. Scenario 3 summary: Tippecanoe darter population conditions at 10, 25, and 50 years. Assumes decreasing water quality[9] with a corresponding decrease in occupancy extent and connectivity[10] when water quality reaches "Low" conditions (*i.e.*, extensive water quality impairments known to impact populations). Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UKN), or "presumed extirpated" (0).

No.	**Population**	**Current Population Condition Score**	**Scenario 3: Pessimistic**		
			10 Years	**25 Years**	**50 Years**
1	Middle-Upper Wabash, IN	M H	M H	M H	M H
2	Tippecanoe River, IN	M	M	M	M
3	Lower East Fork White, IN	M H	M H	M H	M H
4	Upper Green, KY	H	H	H	H
5	Licking River, KY	H	H	H	H
6	N, S, Middle Fork Kentucky, KY	H	H	H	H
7	South Fork Cumberland, KY/TN	M	M	M	M
8	Scioto, OH	H	H	M	M
9	Walhonding, OH	0	0	0	0
10	Ohio, PA/WV/OH	H	H	H	M
11	Red River, TN	M	M	M	M
12	Stones River, TN	UKN	UKN	UNK	UNK
13	Harpeth River, TN	M	M	M	L
14	Elk River, WV	M H	M H	M H	M H
15	Upper Green-1978, KY	UKN	UNK	UNK	UNK

[9] Predicts decreasing water quality within populations with measurable (*i.e.*, 1-percent or more) rates of growth in development observed between 2001 and 2011: Scioto, Ohio; Ohio, Pennsylvania/West Virginia/Ohio; Red River, Tennessee; Stones River, Tennessee; and Harpeth River, Tennessee.

[10] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana).

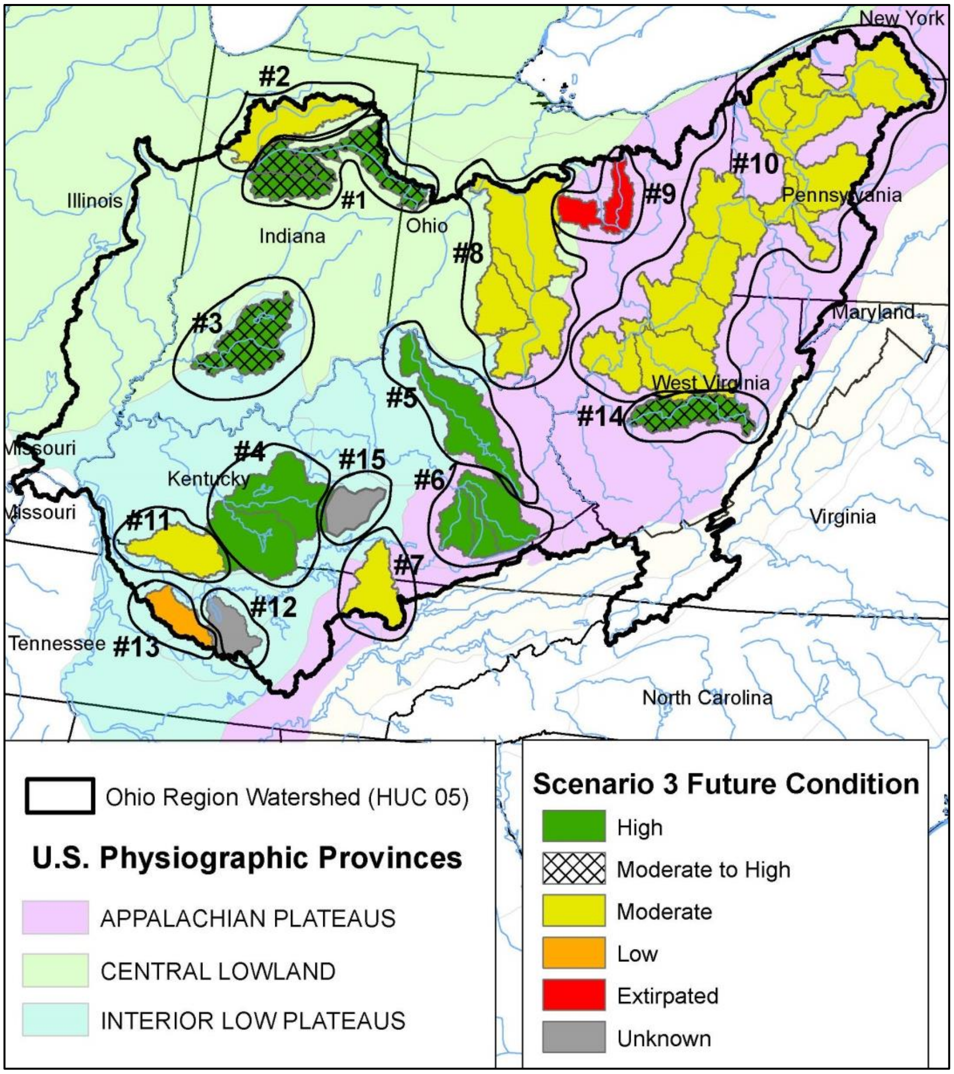

Figure 15. Summary of predicted condition of Tippecanoe darter populations under Scenario 3 within 50 years of pessimistic scenario (illustrated by HUC 8 watersheds).

Summary of Species' Future Viability

The best available data indicate that, of the 15 known Tippecanoe darter populations, 12 are extant, 2 are unknown, and 1 is extirpated. Tippecanoe darter occurrence data suggest that the species is persisting and in some cases expanding in 80 percent (12 of 15) of the known populations. Although we do not have information to assess abundance, we assume Tippecanoe darter abundance is increasing within some populations based on range expansion.
We considered what the Tippecanoe darter needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation. For the purpose of this assessment, we generally define viability as the ability of the Tippecanoe darter to sustain populations in natural river ecosystems over time.

Based on the Tippecanoe darter's life history and habitat needs, we identified the potential negative and positive influences and the contributing sources of those influences that are likely to affect the species' current condition and viability. We evaluated how these stressors may be currently affecting the species and whether, and to what extent, they would affect the species in the future. While impairments to water quality (*e.g.*, sedimentation, agricultural and urban runoff) and dams have likely influenced the species' current condition, Tippecanoe darters are predicted to persist within all currently extant populations in the future under each of the future scenarios assessed.

Under the three plausible scenarios, the Tippecanoe darter will occur in a minimum of 12 populations while maintaining moderate to high resiliency (with the exception of a single population having low resiliency under Scenario 3), redundancy, and representation. Based on our analysis, we conclude that the risk of extirpation of any known extant population is very low.

CHAPTER 6 – UNCERTAINTY

Predicting the future condition requires us to make plausible assumptions. Our analyses are predicated on multiple assumptions, which could lead to over- and underestimates of viability. In table 10, we identify the key sources of uncertainty and indicate the likely effect of our assumptions on the viability assessment.

Table 10. Assumptions made in the analysis and the impact on our viability assessment if such assumptions are incorrect. "Overestimates" means the viability of the species is optimistic. "Underestimates" means the viability of the species is pessimistic. "Either" means the impact could lead to over- or underestimates if our assumption is incorrect.

Assumption	**Impact on Viability Assessment**
Each component used to assess population condition is weighted equally.	Either
Two populations lacking recent surveys are considered unknown status (*i.e.*, not extant).	Underestimates
The current known range accurately represents the number of stream miles occupied by Tippecanoe darter.	Underestimates
The extent and magnitude of future influences are accurately predicted.	Either
The amount of occupied (or potential) habitat (*i.e.*, "occupancy extent") is important to Tippecanoe darter resiliency.	Either
"Occupancy extent" equals the distance between the furthest upstream record and the furthest downstream record.	Overestimates
Survey data from Ohio were used to extrapolate the rate of Tippecanoe darter expansion within other populations under Scenarios 1 and 2.	Either
Subcomponents used in the "connectivity" metric accurately describe Tippecanoe darter population connectivity.	Either
Tippecanoe darters will increase occupancy extent 20 mi (32 km) per decade at all extant populations where additional suitable habitat is present under Scenarios 1 and 2 (except for populations with zero connectivity).	Overestimates
Tippecanoe darters will decrease distance to closest source population (*i.e.*, increased connectivity) by 20 mi (32 km) per decade at all extant populations under Scenarios 1 and 2 (except for populations with zero connectivity or where suitable habitat between populations is lacking).	Overestimates
Water quality remains unchanged under Scenario 3 for populations with no measurable (*i.e.*, less than one percent) change in urban development between 2001 and 2011.	Overestimates

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APPENDIX A

SCENARIO 1. Continuation of Current Trend

Scenario 1 (10-years). Assumes a continuation of the current trend with corresponding increases in occupancy extent (for those populations where additional suitable habitat is present) and connectivity.[11] Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as “high” condition (H), “moderate” condition (M), “low” condition (L), “unknown” condition (UKN), or “presumed extirpated” (0).

No.	Population	Occupancy	Occupancy Extent	Connectivity	Water Quality	Population Condition Score	
1	Middle-Upper Wabash, IN	H	H	M	M	M	H
2	Tippecanoe River, IN	H	M	0	M	M	
3	Lower East Fork White, IN	H	M	M	H	M	H
4	Upper Green, KY	H	H	L	H	H	
5	Licking River, KY	H	H	H	H	H	
6	N, S, Middle Fork Kentucky, KY	H	H	L	H	H	
7	South Fork Cumberland, KY/TN	H	L	0	H	M	
8	Scioto, OH	H	H	H	M	H	
9	Walhonding, OH	0	0	M	H	0	
10	Ohio, PA/WV/OH	H	H	H	M	H	
11	Red River, TN	H	L	M	H	M	
12	Stones River, TN	UKN	L	0	H	UKN	
13	Harpeth River, TN	H	L	L	H	M	
14	Elk River, WV	H	H	M	H	H	
15	Upper Green-1978, KY	UKN	L	0	H	UKN	

[11] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana).

Scenario 1 (10-years). Tippecanoe darter connectivity between populations. Connectivity condition scores are categorized as "high" (H; high immigration potential between populations.), "moderate" (M; moderate immigration potential between populations), "low" (L; low immigration potential between populations) or "0" (no immigration potential between populations). Horizontal hatching indicates a change from the current condition.

No.	Population	Dams (assumes no change from current condition)	Distance to source (assume decreasing)	Occupancy extent of source (assume increasing)		Connectivity condition score
1	Middle-Upper Wabash, IN	L	H	M		M
2	Tippecanoe River, IN	0	N/A	N/A		0
3	Lower East Fork White, IN	H	L	H		M
4	Upper Green, KY	L	H	L		L
5	Licking River, KY	H	M	H		H
6	N, S, Middle Fork Kentucky, KY	L	L	H		L
7	South Fork Cumberland, KY/TN	0	N/A	N/A		0
8	Scioto, OH	H	H	H		H
9	Walhonding, OH	L	M	H		M
10	Ohio, PA/WV/OH	H	H	H		H
11	Red River, TN	H	H	L		M
12	Stones River, TN	0	N/A	N/A		0
13	Harpeth River, TN	M	M	L		L
14	Elk River, WV	M	M	H		M
15	Upper Green-1978, KY	0	N/A	N/A		0

Scenario 1 (10-years). Current and predicted occupancy extent in 10 years. [12]

No.	Population	Current Occupancy Extent (miles)	Occupancy Extent in 10 years (assume increase of 20 miles)
1	Middle-Upper Wabash, IN	131	151
2	Tippecanoe River, IN	55	55*
3	Lower East Fork White, IN	60	60*
4	Upper Green, KY	258	278
5	Licking River, KY	144	164
6	N, S, Middle Fork Kentucky, KY	110	130
7	South Fork Cumberland, KY/TN	23	43
8	Scioto, OH	283	303
9	Walhonding, OH	0 (extirpated)	N/A
10	Ohio, PA/WV/OH	500+	520+
11	Red River, TN	22	42
12	Stones River, TN	0 (single record)	Low
13	Harpeth River, TN	26	46
14	Elk River, WV	98	118
15	Upper Green-1978, KY	0 (single record)	Low

* Occupancy extent will not increase from current condition (Fisher 2018).

[12] Survey data from Ohio were used to approximate the rate of Tippecanoe darter expansion (*i.e.*, increase in occupancy extent). The Ohio dataset was chosen because we considered it the most complete (*i.e.*, multiple surveys within the same streams using the same methodology over four decades). Tippecanoe darters expanded 37 mi (60 km) downstream between 1984 and 1997; 50 mi (80 km) downstream between 1997 and 2004; 21 mi (34 km) upstream between 1994 and 2005; and 8 mi (13 km) upstream between 1994 and 2005 (OSU 2016, unpublished data). We conservatively estimate that Tippecanoe darters will expand approximately 20 mi (32 km) per decade based on continuation of current trend.

Scenario 1 (10-years). Current and predicted distance to source populations. We conservatively estimate Tippecanoe darters will decrease distance to closest source population by approximately 20 mi (32 km) per decade based on continuation of current trend.

No.	Population	Current distance to closest source population (miles)	Source Population	Distance to source in 10 years (miles)
1	Middle-Upper Wabash, IN	14	Tippecanoe River, IN	0
2	Tippecanoe River, IN	N/A	N/A	N/A
3	Lower East Fork White, IN	264	Middle-Upper Wabash, IN	264*
4	Upper Green, KY	40	Upper Green-1978, KY	20
5	Licking River, KY	142	Scioto, OH	122
6	N, S, Middle Fork Kentucky, KY	341	Licking River, KY	321
7	South Fork Cumberland, KY/TN	N/A	N/A	N/A
8	Scioto, OH	115	Ohio, PA/WV/OH	95
9	Walhonding, OH	104	Ohio, PA/WV/OH	84
10	Ohio, PA/WV/OH	84	Elk River, WV	64
11	Red River, TN	65	Harpeth River, TN	45
12	Stones River, TN	N/A	N/A	N/A
13	Harpeth River, TN	65	Red River, TN	45
14	Elk River, WV	84	Ohio, PA/WV/OH	64
15	Upper Green-1978, KY	N/A	N/A	N/A

* Distance to closest source does not decrease from current condition (Fisher 2018).

Scenario 1 (25-years). Assumes a continuation of the current trend with corresponding increases in occupancy extent (for those populations where additional suitable habitat is present) and connectivity.[13] Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UKN), or "presumed extirpated" (0).

No.	Population	Occupancy	Occupancy Extent	Connectivity	Water Quality	Population Condition Score
1	Middle-Upper Wabash, IN	H	H	M	M	M / H
2	Tippecanoe River, IN	H	M	0	M	M
3	Lower East Fork White, IN	H	M	M	H	M / H
4	Upper Green, KY	H	H	L	H	H
5	Licking River, KY	H	H	H	H	H
6	N, S, Middle Fork Kentucky, KY	H	H	L	H	H
7	South Fork Cumberland, KY/TN	H	M	0	H	M
8	Scioto, OH	H	H	H	M	H
9	Walhonding, OH	0	0	M	H	0
10	Ohio, PA/WV/OH	H	H	H	M	H
11	Red River, TN	H	M	H	H	H
12	Stones River, TN	UKN	L	0	H	UKN
13	Harpeth River, TN	H	M	M	H	M / H
14	Elk River, WV	H	H	M	H	H
15	Upper Green-1978, KY	UKN	L	0	H	UKN

[13] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana).

Scenario 1 (25 years). Tippecanoe darter connectivity between populations. Connectivity condition scores are categorized as "high" (H; high immigration potential between populations.), "moderate" (M; moderate immigration potential between populations), "low" (L; low immigration potential between populations) or "0" (no immigration potential between populations). Horizontal hatching indicates a change from the current condition.

No.	Population	Dams	Distance to source	Occupancy extent of source		Connectivity condition score
1	Middle-Upper Wabash, IN	L	H	M		M
2	Tippecanoe River, IN	0	N/A	N/A		0
3	Lower East Fork White, IN	H	L	H		M
4	Upper Green, KY	L	H	L		L
5	Licking River, KY	H	H	H		H
6	N, S, Middle Fork Kentucky, KY	L	L	H		L
7	South Fork Cumberland, KY/TN	0	N/A	N/A		0
8	Scioto, OH	H	H	H		H
9	Walhonding, OH	L	M	H		M
10	Ohio, PA/WV/OH	H	H	H		H
11	Red River, TN	H	H	M		H
12	Stones River, TN	0	N/A	N/A		0
13	Harpeth River, TN	M	M	M		M
14	Elk River, WV	M	M	H		M
15	Upper Green-1978, KY	0	N/A	N/A		0

Scenario 1 (25-years). Current and predicted occupancy extent in 25 years. [14]

No.	Population	Current Occupancy Extent (miles)	Occupancy Extent in 25 years (assume increase of 50 miles)
1	Middle-Upper Wabash, IN	131	181
2	Tippecanoe River, IN	55	55*
3	Lower East Fork White, IN	60	60*
4	Upper Green, KY	258	308
5	Licking River, KY	144	194
6	N, S, Middle Fork Kentucky, KY	110	160
7	South Fork Cumberland, KY/TN	23	73
8	Scioto, OH	283	333
9	Walhonding, OH	0 (extirpated)	N/A
10	Ohio, PA/WV/OH	500+	550+
11	Red River, TN	22	72
12	Stones River, TN	0 (single record)	Low
13	Harpeth River, TN	26	76
14	Elk River, WV	98	148
15	Upper Green-1978, KY	0 (single record)	Low

* Occupancy extent will not increase from current condition (Fisher 2018).

[14] Survey data from Ohio were used to approximate the rate of Tippecanoe darter expansion (*i.e.*, increase in occupancy extent). The Ohio dataset was chosen because we considered it the most complete (*i.e.*, multiple surveys within the same streams using the same methodology over four decades). Tippecanoe darters expanded 37 mi (60 km) downstream between 1984 and 1997; 50 mi (80 km) downstream between 1997 and 2004; 21 mi (34 km) upstream between 1994 and 2005; and 8 mi (13 km) upstream between 1994 and 2005 (OSU 2016, unpublished data). We conservatively estimate that Tippecanoe darters will expand approximately 20 mi (32 km) per decade based on continuation of current trend.

Scenario 1 (25-years). Current and predicted distance to source populations. We conservatively estimate Tippecanoe darters will decrease distance to closest source population by approximately 20 mi (32 km) per decade based on continuation of current trend.

No.	Population	Current distance to closest source population (miles)	Source Population	Distance to source in 25 years (miles)
1	Middle-Upper Wabash, IN	14	Tippecanoe River, IN	0
2	Tippecanoe River, IN	N/A	N/A	N/A
3	Lower East Fork White, IN	264	Middle-Upper Wabash, IN	264*
4	Upper Green, KY	40	Upper Green-1978, KY	0
5	Licking River, KY	142	Scioto, OH	92
6	N, S, Middle Fork Kentucky, KY	341	Licking River, KY	291
7	South Fork Cumberland, KY/TN	N/A	N/A	N/A
8	Scioto, OH	115	Ohio, PA/WV/OH	65
9	Walhonding, OH	104	Ohio, PA/WV/OH	54
10	Ohio, PA/WV/OH	84	Elk River, WV	34
11	Red River, TN	65	Harpeth River, TN	15
12	Stones River, TN	N/A	N/A	N/A
13	Harpeth River, TN	65	Red River, TN	15
14	Elk River, WV	84	Ohio, PA/WV/OH	34
15	Upper Green-1978, KY	N/A	N/A	N/A

* Distance to closest source does not decrease from current condition (Fisher 2018).

Scenario 1 (50-year). Assumes a continuation of the current trend with corresponding increases in occupancy extent (for those populations where additional suitable habitat is present) and connectivity.[15] Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UKN), or "presumed extirpated" (0).

No.	Population	Occupancy	Occupancy Extent	Connectivity	Water Quality		Population Condition Score	
1	Middle-Upper Wabash, IN	H	H	M	M		M	H
2	Tippecanoe River, IN	H	M	0	M		M	
3	Lower East Fork White, IN	H	M	M	H		M	H
4	Upper Green, KY	H	H	L	H		H	
5	Licking River, KY	H	H	H	H		H	
6	N, S, Middle Fork Kentucky, KY	H	H	L	H		H	
7	South Fork Cumberland, KY/TN	H	H	0	H		M	
8	Scioto, OH	H	H	H	M		H	
9	Walhonding, OH	0	0	M	H		0	
10	Ohio, PA/WV/OH	H	H	H	M		H	
11	Red River, TN	H	H	H	H		H	
12	Stones River, TN	UKN	L	0	H		UKN	
13	Harpeth River, TN	H	H	H	H		H	
14	Elk River, WV	H	H	H	H		H	
15	Upper Green-1978, KY	UKN	L	0	H		UKN	

[15] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana).

Scenario 1 (50 years). Tippecanoe darter connectivity between populations. Connectivity condition scores are categorized as "high" (H; high immigration potential between populations.), "moderate" (M; moderate immigration potential between populations), "low" (L; low immigration potential between populations) or "0" (no immigration potential between populations). Horizontal hatching indicates a change from the current condition.

No.	Population	Dams	Distance to source	Occupancy extent of source		Connectivity condition score
1	Middle-Upper Wabash, IN	L	H	M		M
2	Tippecanoe River, IN	0	N/A	N/A		0
3	Lower East Fork White, IN	H	L	H		M
4	Upper Green, KY	L	H	L		L
5	Licking River, KY	H	H	H		H
6	N, S, Middle Fork Kentucky, KY	L	L	H		L
7	South Fork Cumberland, KY/TN	0	N/A	N/A		0
8	Scioto, OH	H	H	H		H
9	Walhonding, OH	L	M	H		M
10	Ohio, PA/WV/OH	H	H	H		H
11	Red River, TN	H	H	H		H
12	Stones River, TN	0	N/A	N/A		0
13	Harpeth River, TN	M	H	H		H
14	Elk River, WV	M	H	H		H
15	Upper Green-1978, KY	0	N/A	N/A		0

Scenario 1 (50-years). Current and predicted occupancy extent in 50 years. [16]

No.	Population	Current Occupancy Extent (miles)	Occupancy Extent in 50 years (assume increase of 100 miles)
1	Middle-Upper Wabash, IN	131	231
2	Tippecanoe River, IN	55	55*
3	Lower East Fork White, IN	60	60*
4	Upper Green, KY	258	358
5	Licking River, KY	144	244
6	N, S, Middle Fork Kentucky, KY	110	210
7	South Fork Cumberland, KY/TN	23	123
8	Scioto, OH	283	383
9	Walhonding, OH	0 (extirpated)	N/A
10	Ohio, PA/WV/OH	500+	600+
11	Red River, TN	22	122
12	Stones River, TN	0 (single record)	Low
13	Harpeth River, TN	26	126
14	Elk River, WV	98	198
15	Upper Green-1978, KY	0 (single record)	Low

* Occupancy extent will not increase from current condition (Fisher 2018).

[16] Survey data from Ohio were used to approximate the rate of Tippecanoe darter expansion (*i.e.*, increase in occupancy extent). The Ohio dataset was chosen because we considered it the most complete (*i.e.*, multiple surveys within the same streams using the same methodology over four decades). Tippecanoe darters expanded 37 mi (60 km) downstream between 1984 and 1997; 50 mi (80 km) downstream between 1997 and 2004; 21 mi (34 km) upstream between 1994 and 2005; and 8 mi (13 km) upstream between 1994 and 2005 (OSU 2016, unpublished data). We conservatively estimate that Tippecanoe darters will expand approximately 20 mi (32 km) per decade based on continuation of current trend.

Scenario 1 (50-years). Current and predicted distance to source populations. We conservatively estimate Tippecanoe darters will decrease distance to closest source population by approximately 20 mi (32 km) per decade based on continuation of current trend.

No.	**Population**	**Current distance to closest source population (miles)**	**Source Population**	**50 years (assumes at least 100 mile expansion toward source)**
1	Middle-Upper Wabash, IN	14	Tippecanoe River, IN	0
2	Tippecanoe River, IN	N/A	N/A	N/A
3	Lower East Fork White, IN	264	Middle-Upper Wabash, IN	264*
4	Upper Green, KY	40	Upper Green-1978, KY	0
5	Licking River, KY	142	Scioto, OH	42
6	N, S, Middle Fork Kentucky, KY	341	Licking River, KY	241
7	South Fork Cumberland, KY/TN	N/A	N/A	N/A
8	Scioto, OH	115	Ohio, PA/WV/OH	15
9	Walhonding, OH	104	Ohio, PA/WV/OH	4
10	Ohio, PA/WV/OH	84	Elk River, WV	0
11	Red River, TN	65	Harpeth River, TN	0
12	Stones River, TN	N/A	N/A	N/A
13	Harpeth River, TN	65	Red River, TN	0
14	Elk River, WV	84	Ohio, PA/WV/OH	0
15	Upper Green-1978, KY	N/A	N/A	N/A

* Distance to closest source does not decrease from current condition (Fisher 2018).

SCENARIO 2. Optimistic Scenario.

Scenario 2 (10-year). Assumes improving water quality with corresponding increases in occupancy extent (for those populations where additional suitable habitat is present) and connectivity[17], and assumes reintroduction of Tippecanoe darters within Walhonding, Ohio, population, within the next 10 years. Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UKN), or "presumed extirpated" (0).

No.	Population	Occupancy	Occupancy Extent	Connectivity	Water Quality		Population Condition Score	
1	Middle-Upper Wabash, IN	H	H	M	M		M	H
2	Tippecanoe River, IN	H	M	0	M		M	
3	Lower East Fork White, IN	H	M	M	H		M	H
4	Upper Green, KY	H	H	L	H		H	
5	Licking River, KY	H	H	H	H		H	
6	N, S, Middle Fork Kentucky, KY	H	H	L	H		H	
7	South Fork Cumberland, KY/TN	H	L	0	H		M	
8	Scioto, OH	H	H	H	M		H	
9	Walhonding, OH	H	L	M	H		M	
10	Ohio, PA/WV/OH	H	H	H	M		H	
11	Red River, TN	H	L	M	H		M	
12	Stones River, TN	UKN	L	0	H		UKN	
13	Harpeth River, TN	H	L	L	H		M	
14	Elk River, WV	H	H	M	H		H	
15	Upper Green-1978, KY	UKN	L	0	H		UKN	

[17] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana).

Scenario 2 (10-years). Tippecanoe darter connectivity between populations. Connectivity condition scores are categorized as "high" (H; high immigration potential between populations.), "moderate" (M; moderate immigration potential between populations), "low" (L; low immigration potential between populations) or "0" (no immigration potential between populations). Horizontal hatching indicates a change from the current condition.

No.	**Population**	**Dams (assumes no change from current condition)**	**Distance to source (assume decreasing)**	**Occupancy extent of source (assume increasing)**		**Connectivity condition score**
1	Middle-Upper Wabash, IN	L	H	M		M
2	Tippecanoe River, IN	0	N/A	N/A		0
3	Lower East Fork White, IN	H	L	H		M
4	Upper Green, KY	L	H	L		L
5	Licking River, KY	H	M	H		H
6	N, S, Middle Fork Kentucky, KY	L	L	H		L
7	South Fork Cumberland, KY/TN	0	N/A	N/A		0
8	Scioto, OH	H	H	H		H
9	Walhonding, OH	L	M	H		M
10	Ohio, PA/WV/OH	H	H	H		H
11	Red River, TN	H	H	L		M
12	Stones River, TN	0	N/A	N/A		0
13	Harpeth River, TN	M	M	L		L
14	Elk River, WV	M	M	H		M
15	Upper Green-1978, KY	0	N/A	N/A		0

Scenario 2 (10-years). Current and predicted occupancy extent in 10 years. [18]

No.	Population	Current Occupancy Extent (miles)	Occupancy Extent in 10 years (assume increase of 20 miles)
1	Middle-Upper Wabash, IN	131	151
2	Tippecanoe River, IN	55	55*
3	Lower East Fork White, IN	60	60*
4	Upper Green, KY	258	278
5	Licking River, KY	144	164
6	N, S, Middle Fork Kentucky, KY	110	130
7	South Fork Cumberland, KY/TN	23	43
8	Scioto, OH	283	303
9	Walhonding, OH	0 (extirpated)	N/A
10	Ohio, PA/WV/OH	500+	520+
11	Red River, TN	22	42
12	Stones River, TN	0 (single record)	Low
13	Harpeth River, TN	26	46
14	Elk River, WV	98	118
15	Upper Green-1978, KY	0 (single record)	Low

* Occupancy extent will not increase from current condition (Fisher 2018).

[18] Survey data from Ohio were used to approximate the rate of Tippecanoe darter expansion (*i.e.*, increase in occupancy extent). The Ohio dataset was chosen because we considered it the most complete (*i.e.*, multiple surveys within the same streams using the same methodology over four decades). Tippecanoe darters expanded 37 mi (60 km) downstream between 1984 and 1997; 50 mi (80 km) downstream between 1997 and 2004; 21 mi (34 km) upstream between 1994 and 2005; and 8 mi (13 km) upstream between 1994 and 2005 (OSU 2016, unpublished data). We conservatively estimate that Tippecanoe darters will expand approximately 20 mi (32 km) per decade based on continuation of current trend.

Scenario 2 (10-years). Current and predicted distance to source populations. We conservatively estimate Tippecanoe darters will decrease distance to closest source population by approximately 20 mi (32 km) per decade based on the optimistic scenario.

No.	Population	Current distance to closest source population (miles)	Source Population	Distance to source in 10 years (miles)
1	Middle-Upper Wabash, IN	14	Tippecanoe River, IN	0
2	Tippecanoe River, IN	N/A	N/A	N/A
3	Lower East Fork White, IN	264	Middle-Upper Wabash, IN	264*
4	Upper Green, KY	40	Upper Green-1978, KY	20
5	Licking River, KY	142	Scioto, OH	122
6	N, S, Middle Fork Kentucky, KY	341	Licking River, KY	321
7	South Fork Cumberland, KY/TN	N/A	N/A	N/A
8	Scioto, OH	115	Ohio, PA/WV/OH	95
9	Walhonding, OH	104	Ohio, PA/WV/OH	84
10	Ohio, PA/WV/OH	84	Elk River, WV	64
11	Red River, TN	65	Harpeth River, TN	45
12	Stones River, TN	N/A	N/A	N/A
13	Harpeth River, TN	65	Red River, TN	45
14	Elk River, WV	84	Ohio, PA/WV/OH	64
15	Upper Green-1978, KY	N/A	N/A	N/A

* Distance to closest source does not decrease from current condition (Fisher 2018).

Scenario 2 (25-years). Assumes improving water quality with corresponding increases in occupancy extent (for those populations where additional suitable habitat is present) and connectivity[19], and assumes reintroduction of Tippecanoe darters within Walhonding, Ohio, population, within the next 10 years. Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UKN), or "presumed extirpated" (0).

No.	Population	Occupancy	Occupancy Extent	Connectivity	Water Quality	Population Condition Score	
1	Middle-Upper Wabash, IN	H	H	M	M	M	H
2	Tippecanoe River, IN	H	M	0	M	M	
3	Lower East Fork White, IN	H	M	M	H	M	H
4	Upper Green, KY	H	H	L	H	H	
5	Licking River, KY	H	H	H	H	H	
6	N, S, Middle Fork Kentucky, KY	H	H	L	H	H	
7	South Fork Cumberland, KY/TN	H	M	0	H	M	
8	Scioto, OH	H	H	H	H	H	
9	Walhonding, OH	H	M	M	H	H	
10	Ohio, PA/WV/OH	H	H	H	H	H	
11	Red River, TN	H	M	H	H	H	
12	Stones River, TN	UKN	L	0	H	UKN	
13	Harpeth River, TN	H	M	M	H	M	H
14	Elk River, WV	H	H	M	H	H	
15	Upper Green-1978, KY	UKN	L	0	H	UKN	

[19] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana).

Scenario 2 (25 years). Tippecanoe darter connectivity between populations. Connectivity condition scores are categorized as "high" (H; high immigration potential between populations.), "moderate" (M; moderate immigration potential between populations), "low" (L; low immigration potential between populations) or "0" (no immigration potential between populations). Horizontal hatching indicates a change from the current condition.

No.	Population	Dams	Distance to source	Occupancy extent of source		Connectivity condition score
1	Middle-Upper Wabash, IN	L	H	M		M
2	Tippecanoe River, IN	0	N/A	N/A		0
3	Lower East Fork White, IN	H	L	H		M
4	Upper Green, KY	L	H	L		L
5	Licking River, KY	H	H	H		H
6	N, S, Middle Fork Kentucky, KY	L	L	H		L
7	South Fork Cumberland, KY/TN	0	N/A	N/A		0
8	Scioto, OH	H	H	H		H
9	Walhonding, OH	L	M	H		M
10	Ohio, PA/WV/OH	H	H	H		H
11	Red River, TN	H	H	M		H
12	Stones River, TN	0	N/A	N/A		0
13	Harpeth River, TN	M	M	M		M
14	Elk River, WV	M	M	H		M
15	Upper Green-1978, KY	0	N/A	N/A		0

Scenario 2 (25-years). Current and predicted occupancy extent in 25 years. [20]

No.	Population	Current Occupancy Extent (miles)	Occupancy Extent in 25 years (assume increase of 50 miles)
1	Middle-Upper Wabash, IN	131	181
2	Tippecanoe River, IN	55	55*
3	Lower East Fork White, IN	60	60*
4	Upper Green, KY	258	308
5	Licking River, KY	144	194
6	N, S, Middle Fork Kentucky, KY	110	160
7	South Fork Cumberland, KY/TN	23	73
8	Scioto, OH	283	333
9	Walhonding, OH	0 (extirpated)	N/A
10	Ohio, PA/WV/OH	500+	550+
11	Red River, TN	22	72
12	Stones River, TN	0 (single record)	Low
13	Harpeth River, TN	26	76
14	Elk River, WV	98	148
15	Upper Green-1978, KY	0 (single record)	Low

* Occupancy extent will not increase from current condition (Fisher 2018).

[20] Survey data from Ohio were used to approximate the rate of Tippecanoe darter expansion (*i.e.*, increase in occupancy extent). The Ohio dataset was chosen because we considered it the most complete (*i.e.*, multiple surveys within the same streams using the same methodology over four decades). Tippecanoe darters expanded 37 mi (60 km) downstream between 1984 and 1997; 50 mi (80 km) downstream between 1997 and 2004; 21 mi (34 km) upstream between 1994 and 2005; and 8 mi (13 km) upstream between 1994 and 2005 (OSU 2016, unpublished data). We conservatively estimate that Tippecanoe darters will expand approximately 20 mi (32 km) per decade based on continuation of current trend.

Scenario 2 (25-years). Current and predicted distance to source populations. We conservatively estimate Tippecanoe darters will decrease distance to closest source population by approximately 20 mi (32 km) per decade based on the optimistic scenario.

No.	Population	Current distance to closest source population (miles)	Source Population	Distance to source in 25 years (miles)
1	Middle-Upper Wabash, IN	14	Tippecanoe River, IN	0
2	Tippecanoe River, IN	N/A	N/A	N/A
3	Lower East Fork White, IN	264	Middle-Upper Wabash, IN	264*
4	Upper Green, KY	40	Upper Green-1978, KY	0
5	Licking River, KY	142	Scioto, OH	92
6	N, S, Middle Fork Kentucky, KY	341	Licking River, KY	291
7	South Fork Cumberland, KY/TN	N/A	N/A	N/A
8	Scioto, OH	115	Ohio, PA/WV/OH	65
9	Walhonding, OH	104	Ohio, PA/WV/OH	54
10	Ohio, PA/WV/OH	84	Elk River, WV	34
11	Red River, TN	65	Harpeth River, TN	15
12	Stones River, TN	N/A	N/A	N/A
13	Harpeth River, TN	65	Red River, TN	15
14	Elk River, WV	84	Ohio, PA/WV/OH	34
15	Upper Green-1978, KY	N/A	N/A	N/A

* Distance to closest source does not decrease from current condition (Fisher 2018).

Scenario 2 (50-year). Assumes improving water quality with corresponding increases in occupancy extent (for those populations where additional suitable habitat is present) and connectivity[21], and assumes reintroduction of Tippecanoe darters within Walhonding, Ohio, population, within the next 10 years. Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UKN), or "presumed extirpated" (0).

No.	Population	Occupancy	Occupancy Extent	Connectivity	Water Quality		Population Condition Score	
1	Middle-Upper Wabash, IN	H	H	M	M		M	H
2	Tippecanoe River, IN	H	M	0	M		M	
3	Lower East Fork White, IN	H	M	M	H		M	H
4	Upper Green, KY	H	H	L	H		H	
5	Licking River, KY	H	H	H	H		H	
6	N, S, Middle Fork Kentucky, KY	H	H	L	H		H	
7	South Fork Cumberland, KY/TN	H	H	0	H		M	
8	Scioto, OH	H	H	H	H		H	
9	Walhonding, OH	H	H	M	H		H	
10	Ohio, PA/WV/OH	H	H	H	H		H	
11	Red River, TN	H	H	H	H		H	
12	Stones River, TN	UKN	L	0	H		UKN	
13	Harpeth River, TN	H	H	H	H		H	
14	Elk River, WV	H	H	H	H		H	
15	Upper Green-1978, KY	UKN	L	0	H		UKN	

[21] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana).

Scenario 2 (50 years). Tippecanoe darter connectivity between populations. Connectivity condition scores are categorized as "high" (H; high immigration potential between populations.), "moderate" (M; moderate immigration potential between populations), "low" (L; low immigration potential between populations) or "0" (no immigration potential between populations). Horizontal hatching indicates a change from the current condition.

No.	Population	Dams	Distance to source	Occupancy extent of source		Connectivity condition score
1	Middle-Upper Wabash, IN	L	H	M		M
2	Tippecanoe River, IN	0	N/A	N/A		0
3	Lower East Fork White, IN	H	L	H		M
4	Upper Green, KY	L	H	L		L
5	Licking River, KY	H	H	H		H
6	N, S, Middle Fork Kentucky, KY	L	L	H		L
7	South Fork Cumberland, KY/TN	0	N/A	N/A		0
8	Scioto, OH	H	H	H		H
9	Walhonding, OH	L	M	H		M
10	Ohio, PA/WV/OH	H	H	H		H
11	Red River, TN	H	H	H		H
12	Stones River, TN	0	N/A	N/A		0
13	Harpeth River, TN	M	H	H		H
14	Elk River, WV	M	H	H		H
15	Upper Green-1978, KY	0	N/A	N/A		0

Scenario 2 (50-years). Current and predicted occupancy extent in 50 years. [22]

No.	Population	Current Occupancy Extent (miles)	Occupancy Extent in 50 years (assume increase of 100 miles)
1	Middle-Upper Wabash, IN	131	231
2	Tippecanoe River, IN	55	55*
3	Lower East Fork White, IN	60	60*
4	Upper Green, KY	258	358
5	Licking River, KY	144	244
6	N, S, Middle Fork Kentucky, KY	110	210
7	South Fork Cumberland, KY/TN	23	123
8	Scioto, OH	283	383
9	Walhonding, OH	0 (extirpated)	N/A
10	Ohio, PA/WV/OH	500+	600+
11	Red River, TN	22	122
12	Stones River, TN	0 (single record)	Low
13	Harpeth River, TN	26	126
14	Elk River, WV	98	198
15	Upper Green-1978, KY	0 (single record)	Low

* Occupancy extent will not increase from current condition (Fisher 2018).

[22] Survey data from Ohio were used to approximate the rate of Tippecanoe darter expansion (*i.e.*, increase in occupancy extent). The Ohio dataset was chosen because we considered it the most complete (*i.e.*, multiple surveys within the same streams using the same methodology over four decades). Tippecanoe darters expanded 37 mi (60 km) downstream between 1984 and 1997; 50 mi (80 km) downstream between 1997 and 2004; 21 mi (34 km) upstream between 1994 and 2005; and 8 mi (13 km) upstream between 1994 and 2005 (OSU 2016, unpublished data). We conservatively estimate that Tippecanoe darters will expand approximately 20 mi (32 km) per decade based on continuation of current trend.

Scenario 2 (50-years). Current and predicted distance to source populations. We conservatively estimate Tippecanoe darters will decrease distance to closest source population by approximately 20 mi (32 km) per decade based on the optimistic scenario.

No.	Population	Current distance to closest source population (miles)	Source Population	50 years (assumes at least 100 mile expansion toward source)
1	Middle-Upper Wabash, IN	14	Tippecanoe River, IN	0
2	Tippecanoe River, IN	N/A	N/A	N/A
3	Lower East Fork White, IN	264	Middle-Upper Wabash, IN	264*
4	Upper Green, KY	40	Upper Green-1978, KY	0
5	Licking River, KY	142	Scioto, OH	42
6	N, S, Middle Fork Kentucky, KY	341	Licking River, KY	241
7	South Fork Cumberland, KY/TN	N/A	N/A	N/A
8	Scioto, OH	115	Ohio, PA/WV/OH	15
9	Walhonding, OH	104	Ohio, PA/WV/OH	4
10	Ohio, PA/WV/OH	84	Elk River, WV	0
11	Red River, TN	65	Harpeth River, TN	0
12	Stones River, TN	N/A	N/A	N/A
13	Harpeth River, TN	65	Red River, TN	0
14	Elk River, WV	84	Ohio, PA/WV/OH	0
15	Upper Green-1978, KY	N/A	N/A	N/A

* Distance to closest source does not decrease from current condition (Fisher 2018).

SCENARIO 3. Pessimistic Scenario.

Scenario 3 (10-year). Assumes decreasing water quality[23] with a corresponding decrease in occupancy extent and connectivity[24] when water quality reaches "Low" conditions (*i.e.*, extensive water quality impairments known to impact populations). Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UKN), or "presumed extirpated" (0).

No.	Population	Occupancy	Occupancy Extent	Connectivity	Water Quality		Population Condition Score	
1	Middle-Upper Wabash, IN	H	H	M	M		M	H
2	Tippecanoe River, IN	H	M	0	M		M	
3	Lower East Fork White, IN	H	M	M	H		M	H
4	Upper Green, KY	H	H	L	H		H	
5	Licking River, KY	H	H	H	H		H	
6	N, S, Middle Fork Kentucky, KY	H	H	L	H		H	
7	South Fork Cumberland, KY/TN	H	L	0	H		M	
8	Scioto, OH	H	H	H	M		H	
9	Walhonding, OH	0	0	L	H		0	
10	Ohio, PA/WV/OH	H	H	H	M		H	
11	Red River, TN	H	L	M	H		M	
12	Stones River, TN	UKN	L	0	H		UKN	
13	Harpeth River, TN	H	L	L	H		M	
14	Elk River, WV	H	M	M	H		M	H
15	Upper Green-1978, KY	UKN	L	0	H		UNK	

[23] Predicts decreasing water quality within populations with measurable (*i.e*., one percent or more) rates of growth in development observed between 2001 and 2011: Scioto, Ohio; Ohio, Pennsylvania/West Virginia/Ohio; Red River, Tennessee; Stones River, Tennessee; and Harpeth River, Tennessee.

[24] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana)..

Scenario 3 (10-year). Tippecanoe darter connectivity between populations. Connectivity condition scores are categorized as "high" (H; high immigration potential between populations.), "moderate" (M; moderate immigration potential between populations), "low" (L; low immigration potential between populations) or "0" (no immigration potential between populations). Horizontal hatching indicates a change from the current condition.

No.	Population	Dams	Distance to source	Occupancy extent of source		Connectivity condition score
1	Middle-Upper Wabash, IN	L	H	M		M
2	Tippecanoe River, IN	0	N/A	N/A		0
3	Lower East Fork White, IN	H	L	H		M
4	Upper Green, KY	L	H	L		L
5	Licking River, KY	H	M	H		H
6	N, S, Middle Fork Kentucky, KY	L	L	H		L
7	South Fork Cumberland, KY/TN	0	N/A	N/A		0
8	Scioto, OH	H	M	H		H
9	Walhonding, OH	L	L	H		L
10	Ohio, PA/WV/OH	H	H	M		H
11	Red River, TN	H	H	L		M
12	Stones River, TN	0	N/A	N/A		0
13	Harpeth River, TN	M	M	L		L
14	Elk River, WV	M	M	H		M
15	Upper Green-1978, KY	0	N/A	N/A		0

Scenario 3 (25-year). Assumes decreasing water quality[25] with a corresponding decrease in occupancy extent and connectivity[26] when water quality reaches "Low" conditions (*i.e.*, extensive water quality impairments known to impact populations). Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UKN), or "presumed extirpated" (0).

No.	Population	Occupancy	Occupancy Extent	Connectivity	Water Quality	Population Condition Score
1	Middle-Upper Wabash, IN	H	H	M	M	M / H
2	Tippecanoe River, IN	H	M	0	M	M
3	Lower East Fork White, IN	H	M	M	H	M / H
4	Upper Green, KY	H	H	L	H	H
5	Licking River, KY	H	H	M	H	H
6	N, S, Middle Fork Kentucky, KY	H	H	L	H	H
7	South Fork Cumberland, KY/TN	H	L	0	H	M
8	Scioto, OH	H	M	M	L	M
9	Walhonding, OH	0	0	L	H	0
10	Ohio, PA/WV/OH	H	H	H	M	H
11	Red River, TN	H	L	M	M	M
12	Stones River, TN	UKN	L	0	M	UNK
13	Harpeth River, TN	H	L	L	M	M
14	Elk River, WV	H	M	M	H	M / H
15	Upper Green-1978, KY	UKN	L	0	H	UNK

[25] Predicts decreasing water quality within populations with measurable (*i.e.*, one percent or more) rates of growth in development observed between 2001 and 2011: Scioto, Ohio; Ohio, Pennsylvania/West Virginia/Ohio; Red River, Tennessee; Stones River, Tennessee; and Harpeth River, Tennessee.

[26] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana)..

Scenario 3 (25-year). Tippecanoe darter connectivity between populations. Connectivity condition scores are categorized as "high" (H; high immigration potential between populations.), "moderate" (M; moderate immigration potential between populations), "low" (L; low immigration potential between populations) or "0" (no immigration potential between populations). Horizontal hatching indicates a change from the current condition.

No.	Population	Dams	Distance to source	Occupancy extent of source	Connectivity condition score
1	Middle-Upper Wabash, IN	L	H	M	M
2	Tippecanoe River, IN	0	N/A	N/A	0
3	Lower East Fork White, IN	H	L	H	M
4	Upper Green, KY	L	H	L	L
5	Licking River, KY	H	L	M	M
6	N, S, Middle Fork Kentucky, KY	L	L	H	L
7	South Fork Cumberland, KY/TN	0	N/A	N/A	0
8	Scioto, OH	H	L	H	M
9	Walhonding, OH	L	L	H	L
10	Ohio, PA/WV/OH	H	H	M	H
11	Red River, TN	H	H	L	M
12	Stones River, TN	0	N/A	N/A	0
13	Harpeth River, TN	M	M	L	L
14	Elk River, WV	M	M	H	M
15	Upper Green-1978, KY	0	N/A	N/A	0

Scenario 3 (50-year). Assumes decreasing water quality[27] with a corresponding decrease in occupancy extent and connectivity[28] when water quality reaches "Low" conditions (*i.e.*, extensive water quality impairments known to impact populations). Horizontal hatching indicates a change from the current condition. Population condition scores are categorized as "high" condition (H), "moderate" condition (M), "low" condition (L), "unknown" condition (UKN), or "presumed extirpated" (0).

No.	Population	Occupancy	Occupancy Extent	Connectivity	Water Quality	Population Condition Score	
1	Middle-Upper Wabash, IN	H	H	M	M	M	H
2	Tippecanoe River, IN	H	M	0	M	M	
3	Lower East Fork White, IN	H	M	M	H	M	H
4	Upper Green, KY	H	H	L	H	H	
5	Licking River, KY	H	H	L	H	H	
6	N, S, Middle Fork Kentucky, KY	H	H	L	H	H	
7	South Fork Cumberland, KY/TN	H	L	0	H	M	
8	Scioto, OH	H	L	M	L	M	
9	Walhonding, OH	0	0	L	H	0	
10	Ohio, PA/WV/OH	H	M	M	L	M	
11	Red River, TN	H	L	M	L	M	
12	Stones River, TN	UKN	L	0	L	UKN	
13	Harpeth River, TN	H	L	L	L	L	
14	Elk River, WV	H	M	M	H	M	H
15	Upper Green-1978, KY	UKN	L	0	H	UKN	

[27] Predicts decreasing water quality within populations with measurable (*i.e.*, one percent or more) rates of growth in development observed between 2001 and 2011: Scioto, Ohio; Ohio, Pennsylvania/West Virginia/Ohio; Red River, Tennessee; Stones River, Tennessee; and Harpeth River, Tennessee.

[28] Connectivity does not change for those populations where dams currently prevent fish passage and that are otherwise isolated (i.e., Tippecanoe River, Indiana; South Fork Cumberland, Kentucky/Tennessee; Stones River, Tennessee; and Upper Green-1978, Kentucky) or where suitable habitat between populations is lacking (i.e., Middle-Upper Wabash and East Fork White River, Indiana).

Scenario 3 (50-year). Tippecanoe darter connectivity between populations. Connectivity condition scores are categorized as “high” (H; high immigration potential between populations.), “moderate” (M; moderate immigration potential between populations), “low” (L; low immigration potential between populations) or “0” (no immigration potential between populations). Horizontal hatching indicates a change from the current condition.

No.	Population	Dams	Distance to source	Occupancy extent of source	Connectivity condition score
1	Middle-Upper Wabash, IN	L	H	M	M
2	Tippecanoe River, IN	0	N/A	N/A	0
3	Lower East Fork White, IN	H	L	H	M
4	Upper Green, KY	L	H	L	L
5	Licking River, KY	H	L	L	L
6	N, S, Middle Fork Kentucky, KY	L	L	H	L
7	South Fork Cumberland, KY/TN	0	N/A	N/A	0
8	Scioto, OH	H	L	M	M
9	Walhonding, OH	L	L	M	L
10	Ohio, PA/WV/OH	H	M	M	M
11	Red River, TN	H	M	L	M
12	Stones River, TN	0	N/A	N/A	0
13	Harpeth River, TN	M	L	L	L
14	Elk River, WV	M	L	M	M
15	Upper Green-1978, KY	0	N/A	N/A	0