# Barrens Topminnow (*Fundulus julisia*) Species Status Assessment

Version 1.1

**Outline**

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# Species Status Assessment Report for the Barrens Topminnow (Fundulus julisia)

## CHAPTER 1. INTRODUCTION

The Barrens Topminnow (*Fundulus julisia* Williams and Etnier 1982) is a small fish endemic (restricted to a locality or region) to streams on the Barrens Plateau in middle Tennessee. The Barrens Topminnow was initially proposed to be listed in 1977 as endangered with critical habitat under the Endangered Species Act of 1973, as amended (Act) (42 FR 65209). Because of comments received on the proposed critical habitat and public opposition to listing, the critical habitat was reproposed in 1979 (44 FR 44418); however, the proposed listing rule was withdrawn in 1980 because it was not finalized within the required 2 years (45 FR 5782). The Barrens Topminnow was designated a Category 2 Candidate species in 1982 (47 FR 58454), and remained such until that list was discontinued in 1996 (61 FR 64481). The Barrens Topminnow was petitioned to be listed under the Act as part of the 2010 Petition to List 404 Aquatic, Riparian and Wetland Species from the Southeastern United States by the Center for Biological Diversity (CBD 2010, p. 520).

The Species Status Assessment (SSA) framework (USFWS 2015, entire) is intended to support an in-depth review of the species' biology and threats, 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, including the cycle from Candidate Assessment to Listing and Recovery, as well as Consultations. As such, the SSA Report will be a living document upon which other decision 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 Barrens Topminnow 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, where to propose designating critical habitat. Importantly, the SSA Report does not result in a decision by the Service on whether this species should be proposed for listing as a threatened or endangered species under the Act. Instead, this SSA Report provides a review of the available information strictly related to the biological status of the Barrens Topminnow. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the Federal Register, with appropriate opportunities for public input. For the purpose of this assessment, we generally define viability as the ability of the Barrens Topminnow to sustain natural populations in natural spring systems over time. Using the SSA framework (Figure 1.1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resilience, redundancy, and representation (Wolf et al. 2015, entire).

- Resilience describes the ability of populations to withstand stochastic events (arising from random factors). We can measure resilience based on metrics of population health; for example, birth versus death rates and population size. Highly 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 anthropogenic activities.

- Representation describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is capable of adapting to environmental changes. 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 habitat characteristics across the geographical range and other factors as appropriate.

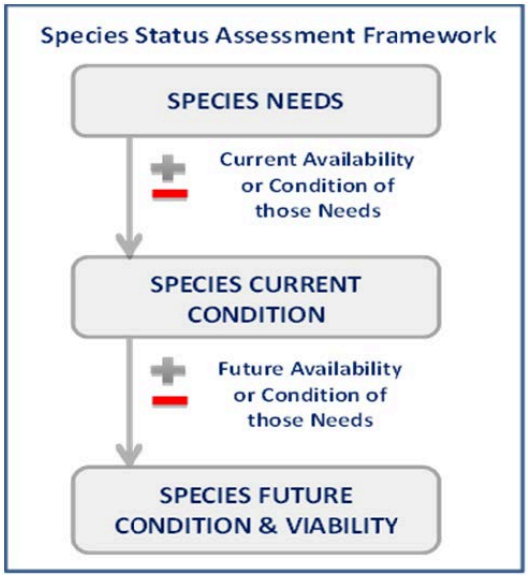


Figure 1.1 Species Status Assessment Framework

- Redundancy describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resilience, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations).

To evaluate the biological status of the Barrens Topminnow, both currently and into the future, we assessed a range of conditions to allow us to consider the species' resilience, redundancy, and representation (together, the 3Rs). This SSA Report provides a thorough assessment of biology and natural history and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the species. The format for this SSA Report includes: (1) the resource needs of individuals and populations (Chapter 2); (2) the Barrens Topminnow's historical distribution and a framework for determining the distribution of resilient populations across its range for species viability (Chapter 3); (3) reviewing the likely causes of the current and future status of the species and determining which of these risk factors affect the species' viability and to what degree (Chapter 4); and (4) concluding with a description of the viability in terms of resilience, redundancy, and representation (Chapter 5). This document is a compilation of the best available scientific and commercial information and a description of past, present, and likely future risk factors to the Barrens Topminnow.

## CHAPTER 2. SPECIES NEEDS AND DISTRIBUTION

### Biology and Life History

*Taxonomy*

The Barrens Topminnow, *Fundulus julisia*, was first collected during Tennessee Valley Authority (TVA) preimpoundment surveys in the Duck River watershed near Manchester in 1938 (Rakes 1989, p.1). These specimens were cataloged as the closely related Whiteline Topminnow, *F. albolineatus*, though with some recognition that they represented an undescribed species. The species was described from by Williams and Etnier in 1982 and was placed in the subgenus *Xenisma*, and the type locality was designated as a spring on Joseph R. Banks' property (elsewhere referenced as "Summitville Mountain Spring" and Benedict Spring, the name used in this document). The species epithet (specific name), *julisia*, is derived from the Cherokee words for "watercress fish" in reference to the species preferred habitat in watercress and other aquatic vegetation (Williams and Etnier 1982, entire).

The subgenus *Xenisma* contains fishes commonly referred to as studfishes, such as Northern Studfish (*Fundulus catenatus*), Southern Studfish (*F. stellifer*), and Stippled Studfish (*F. bifax*) as well as Barrens Topminnow and Whiteline Topminnow. Members of this group tend to be residents of backwaters and edges of streams. Barrens Topminnow is considered to be sister species to the now extinct Whiteline Topminnow (Rogers and Cashner 1987, entire). This fish was found only in Big Spring in Huntsville, AL until the 1890s and went extinct due to extensive changes in habitat (Boschung and Mayden 2003, p.384).

*Genetic Diversity*

There are currently two distinct genetic stocks of Barrens Topminnows, Elk River drainage and Caney Fork River drainage. It is likely that the populations from the Duck River drainage were also genetically distinct (Strange and Lawrence 2002, entire). Hurt et al (2017, entire) concurred that the Caney Fork and Elk River drainages represent two separate Evolutionarily Significant Units (ESUs, historically isolated groups of populations that are on independent evolutionary trajectories) based on mitochondrial haplotypes and further found that fish sampled from the Duck River drainage grouped with the Caney Fork drainage fish, which makes sense given that the extant (living) Duck River populations were stocked from Caney Fork populations. The Elk River stock is now limited to an ark population (individuals kept in captivity to prevent complete extirpation of a population or species) of fish taken from Pond Spring and held at the Tennessee Aquarium Conservation Institute (TNACI), Conservation Fisheries, Inc. (CFI) and Dale Hollow National Fish Hatchery (Kuhajda 2017).

Within the Caney Fork drainage, Hurt et al. (2017, entire) found that based on analysis of microsatellite data, the extant native populations and the sites stocked from these populations could be divided into 2 Management Units (MU). Management Units are defined as "populations that do not show reciprocal monophyly (descended from a common ancestor) for [mitochondrial DNA (mtDNA)] alleles, yet have diverged in allele frequency and are significant for conservation." These divisions are not the result of recent isolation and small populations, but

separation over a period that extends beyond range reductions. We used these genetically defined MUs from Hurt et al. (2017, entire) for this status assessment because historic stocking efforts have transferred fish across watershed boundaries. The two MUs within the Caney Fork ESU are the Hickory Creek MU and the Witty Creek MU. The Hickory Creek MU represents the populations from the Hickory Creek watershed and sites stocked from this watershed (all from Benedict Spring). The Witty Creek MU is composed of populations within the Witty Creek watershed and sites stocked with fish from Pedigo Spring and McMahan Creek. Short Spring was stocked with fish from both the Witty Creek MU and the Hickory Creek MU and is treated under the Hickory Creek MU in this assessment, though it is of mixed stock.

The Barrens Topminnow shows very limited genetic variation within populations and that variation is much lower than that seen in other, wider ranging, *Fundulus* species (Mummichog, *F. heteroclitus*; Blackstripe Topminnow, *F. notatus*) (Hurt et al. 2017, p 9). In the analysis by Hurt et al (2017, entire), only three mitochondrial haplotypes were found, only one of which was in the Caney Fork population. Gene microsatellites (regions of variable repeats in the DNA with a high mutation rate) showed greater variation, but still significantly lower than related species. The genetics of the stocked sites appeared to capture the full variation found in the natural sites. The data suggest that small population numbers contribute to the reduced genetic variation as well as the natural limits to populations associated with specialized headwater and spring habitats. It appears that most of the populations show signs of genetic bottlenecking in the past. This is most clear in fish from Benedict Spring which has dried up significantly several times in recent years, reducing the population to between 100-500 individuals each time. As such, this population and sites stocked from it show the lowest levels of genetic diversity.

Figure 2-1. Nuptial (reproductive) male Barrens Topminnow (Photo courtesy of Conservation Fisheries, Inc.)

*Morphological Description*

The Barrens Topminnow is a small, colorful killifish that grows to 98mm (3.9 in). As is typical of the genus *Fundulus*, Barrens Topminnows have upturned mouths, flattened heads and backs,

and rounded fins with the unpaired fins (i.e. dorsal and anal fins) set far back on the body (Etnier and Starnes 1993, pp. 360-361). The nuptial (reproductive) males are very showy with bright, iridescent background colors of greens, blues, with reddish orange spots and yellow fins as well as tubercles (hardened projections) on the anal fin rays (Figure 2.1). The females, juveniles and non-reproductive males are drabber with pale brown bodies sprinkled with darker spots on the sides (Williams and Etnier 1982; Etnier and Starnes 1993, pp. 365-366). For a detailed description of meristic characteristics and other morphological features, see Williams and Etnier (1982) and Etnier and Starnes (1993, p. 365).


Figure 2-2. Barrens Topminnow Habitat: A, spring pool (Benedict Spring, type locality); B, spring run (McMahan Creek). (Photos curtesy of Tennessee Aquarium Conservation Institute)

*Habitat*

A detailed life history study of the Barrens Topminnow was conducted by Patrick Rakes (1989, entire) as part of his master's thesis. This species is a spring specialist that is found in springhead pools and the slower areas of spring runs. Typical of members of the genus *Fundulus*, Barrens Topminnows prefer areas of slower current. These fish prefer areas with abundant aquatic vegetation such as filamentous algae (e.g. *Clodophora* and *Pithophora*), watercress (*Nasturtium officinale*) rushes (*Juncus*), pondweed (*Potamogeton*), and eelgrass (*Valisneria*) and will even utilize overhanging terrestrial plants and tree roots. Barrens Topminnows have only been found in areas with a large proportion of groundwater influence in the streams. Due to the groundwater influence of these habitats, the temperatures are relatively stable ranging from 15℃ to 25℃ (59-77°F). The karst topography of the Barrens Plateau area allows for a number of spring systems to be present, though not all of these have been inhabited by the topminnow. In times of drought, if the discharge of the springs is severely reduced, Barrens Topminnows likely move downstream into more permanent water if suitable habitat is available.

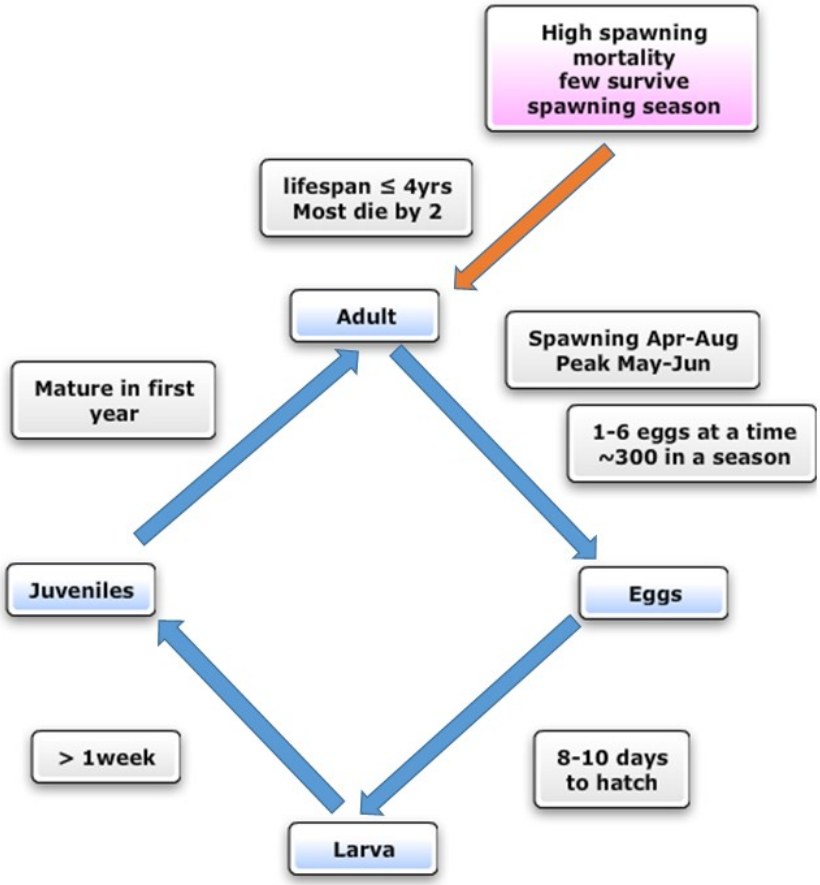


Figure 2-3. Barrens Topminnow Lifecycle

*Lifecycle*

The Barrens Topminnow is a protracted, fractional spawner (a few eggs at a time over a long period) that spawns over the course of the warm months (April to August), peaking from May to June (Figure 2-3). The colorful males perform an elaborate mating display, flaring their fins and chasing females in the clear water of the spring. The female will lay 1-6 eggs on filamentous algae or other submerged vegetation where they look like small air bubbles. Over the course of the breeding season, a female may lay more than 300 eggs over multiple spawning events. The adults typically live only 2 years due to high spawning mortality, though some survive to 4 years. The eggs hatch 8-10 days after spawning and the larvae stay close to vegetative cover. The young fish develop rapidly and within a few days, the larvae have transformed into juveniles (J.R. Shute, pers. comm.). Most fish mature and are ready to spawn within the first year, though some of the later spawned fish are in year 2 before they spawn (Rakes 1989, entire).

| Life Stage | Resources Needed | Information Source |
|---|---|---|
| Fertilized Eggs | • **Filamentous algae or other submerged vegetation for egg adhesion**<br>• Sufficient water levels<br>• Sufficient water temp >15°C (59°F)<br>• 8-10 days<br>• Sufficient DO | Rakes 1989 |
| Larval | • Submerged vegetation for cover<br>• **Low Predation**<br>• Consistent, cool water<br>• 60-85 days to transform | Rakes 1989 |
| Juveniles | • Consistent, cool water<br>• Microcrustaceans for feeding<br>• **Low predation and competition**<br>• Submerged vegetation for cover | Rakes 1989<br>Laha and Mattingly 2005 |
| Adults | • Consistent, cool water<br>• Microcrustaceans and aquatic insects<br>• **Low competition environment**<br>• Clear water for mating display<br>• Filamentous algae or other submerged vegetation for spawning substrate | Rakes 1989 |

Table 2-1. Barrens Topminnow individual needs.

**Population Needs**

Each population of the Barrens Topminnows needs to be able to withstand, or be *resilient* to, stochastic events or disturbances. These are events that are reasonably likely to occur, however, occur infrequently enough that they can drastically alter the ecosystem where they happen. Classic examples of stochastic events include drought, major storms (hurricanes), fire, and landslides (Chapin et al. 2002, p. 285 - 288). To be resilient to stochastic events, populations of Barrens Topminnows need to have a large number of individuals (several hundred)(abundance), and occupy multiple sites in multiple subwatersheds (spatial extent). Additionally, populations need to exist in locations where environmental conditions provide suitable habitat and water quality such that adequate numbers of individuals can be supported. Without all of these factors, a population has an increased likelihood for localized extirpation.

**Species Needs**

For a species to persist and thrive over time, it must exhibit attributes across its range that relate to either representation or redundancy (Figure 2-4). *Representation* describes the ability of a species to adapt to changing environmental conditions over time and encompasses the "ecological and evolutionary patterns and processes that not only maintain but also generate species" (Shaffer and Stein, p. 308). It is characterized by the breadth of genetic and environmental diversity within and among populations. For the Barrens Topminnow to exhibit adequate representation, resilient populations should occur in the ecoregion to which it is native (Eastern Highland Rim); these populations should occur at the widest extent possible across the historic range of the species; and they should occupy multiple tributaries in drainages where they are native. The breadth of morphological, genetic, and behavioral variation should be preserved to maintain the evolutionary variation of the species. Finally, natural levels of connectivity should be maintained between representative populations because it allows for the exchange of novel and beneficial adaptations where connectivity is high or is the mechanism for localized adaption and variation where connectivity is lower and the species is naturally more isolated (Figure 2-4).

*Redundancy* describes the ability of a species to withstand catastrophic events. It "guards against irreplaceable loss of representation" (Redford et al. 2011, p. 42; Tear et al. 2005, p. 841) and minimizes the effect of localized extirpation on the range-wide persistence of a species (Shaffer and Stein, p. 308). Redundancy for the Barrens Topminnow is characterized by having multiple, resilient and representative populations distributed each of the watersheds (i.e., Caney Fork, Elk, and Duck rivers) historically occupied by the species. For this species to exhibit redundancy, it must have multiple resilient populations with connectivity maintained among them. Connectivity allows for immigration and emigration between populations and increases the likelihood of recolonization should a population become extirpated. It is likely that in the past, local extirpations occurred during drought years and were countered by

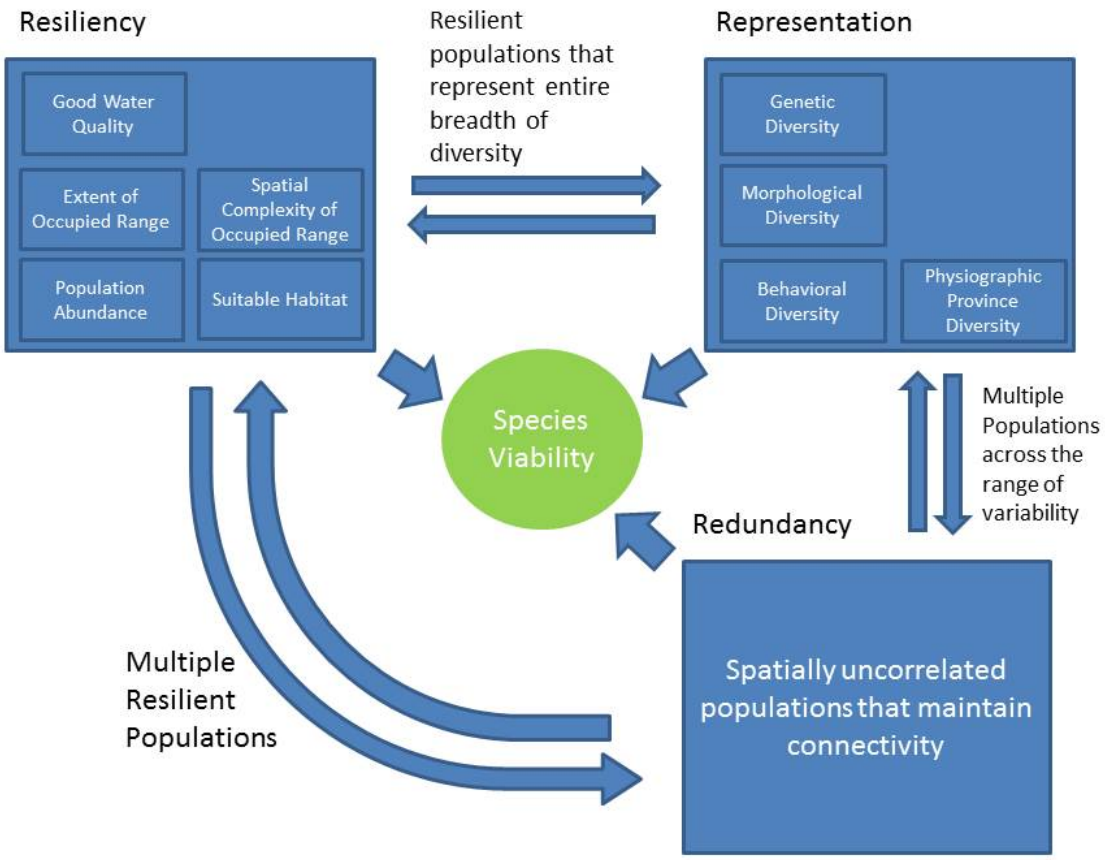


Figure 2-4. How resiliency, representation, and redundancy are related to species viability

## Historical Range and Distribution

The Barrens Topminnow is historically known from the Barrens Plateau which is part of the Eastern Highland Rim in Middle Tennessee. Specimens of the species were originally found by L. F. Miller in 1937 during preimpoundment surveys for the TVA in the Duck River drainage (tributary to the Tennessee River) near Manchester and Tullahoma, Tennessee (Etnier and Dinkins 1983, entire; Etnier 1983, entire). Later surveys found the species at additional sites in the Elk River (tributary to the Tennessee River) drainage and the Caney Fork (tributary of the Cumberland River) drainage. Williams and Etnier formally described the species in 1982 from the type locality, Benedict Spring (Banks Spring) in the Hickory Creek watershed, part of the Caney Fork drainage. Sites were also found in the Duke Creek, Witty Creek, and Bullpen Creek watersheds within the Caney Fork drainage. Within the Elk River drainage, Pond Spring was identified as a robust population, but the only population in the drainage (Etnier 1983, p.3). From the first discovery in 1937 until the 1960s, sites were found in the Little Duck River watershed around Manchester, and in the Carroll Creek watershed around Tullahoma, both in the Duck River drainage.

*Stocked sites*

In an effort to maintain the species, Barrens Topminnows have been stocked into sites where the population had been extirpated, as well as into springs within the native watersheds where they were not known historically, but appeared to have appropriate habitats. Many of these sites were stocked unsuccessfully, but others were more successful.

Because the populations of the Duck River drainage had been extirpated, extant sites in that drainage are stocked with Caney Fork genetic stock. Within the Elk River drainage, sites have been stocked with Pond Spring fish. In the Caney Fork drainage, sites were stocked with fish from either the Witty Creek MU or the Type Locality/Hickory Creek MU. Since the MUs were only recently delineated, stocking of fish did closely follow a geographic pattern within the Caney Fork drainage.

*Current Range*

The most recent range-wide status survey for this species was conducted between 2013 and 2015 by Kuhajda et al. (2017) from TNACI. In a survey of 35 sites, Barrens Topminnows were found at 18 sites with evidence of successful reproduction (juvenile fish present) at 12 of these during the 3 year survey period. In 2015, the final year of the survey, topminnows were present at 17 sites, but evidence of successful reproduction was observed at 6 sites (Figure 2-2).

The Barrens Topminnow is currently found in Warren, Coffee, Franklin, Cannon, and Dekalb Counties in Tennessee. The native populations from the Duck River drainage were extirpated soon after discovery, before fish could be kept in an ark population or genetic samples taken. Sites within the drainage are currently stocked with fish from Witty Creek MU and/or the Hickory Creek MU.

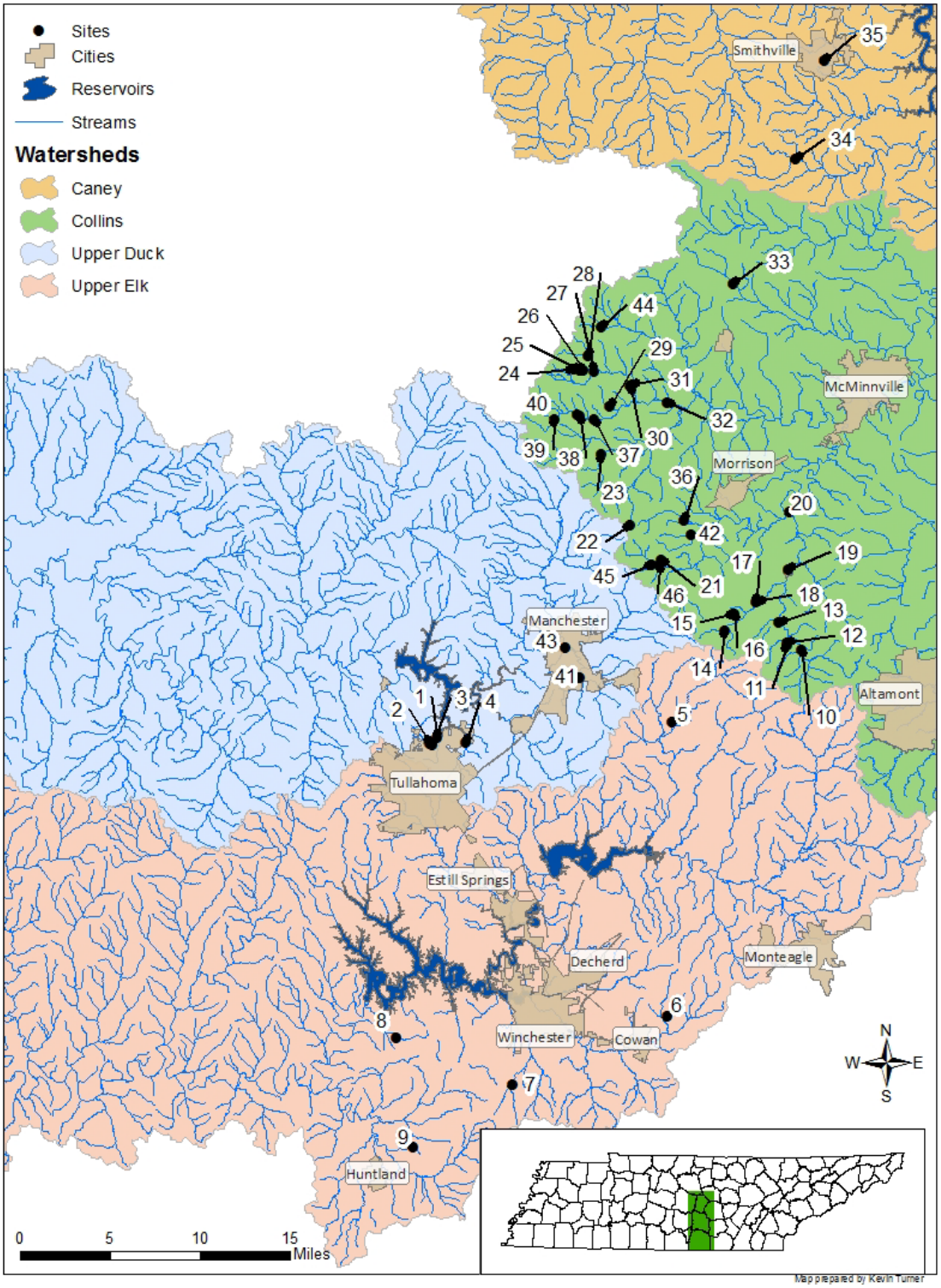


Figure 2-5. All known Barrens Topminnow sites, current and historic. Legend in Table 2-2

| | |
|---|---|
| 1) Marcum Spring | 2) Collier Spring |
| 3) Shamblee Site | 4) Short Spring |
| 5) Pond Spring | 6) Merkle Spring |
| 7) Farris Spring | 8) Hasty Site |
| 9) Rattlesnake Spring | 10) Sherwood Spring |
| 11) Christian Spring | 12) Crooks Site |
| 13) Hancock Spring | 14) Cunningham Dairy Barn Spring |
| 15) Clayborne Spring | 16) Sain Spring |
| 17) Upper Murphy Spring | 18) Lower Murphy Spring |
| 19) Ramsey Barn Spring | 20) Vervilla Spring |
| 21) Benedict Spring | 22) Jarrell Spring |
| 23) Pocahontas Spring | 24) Above Pedigo Hwy |
| 25) Just Above Pedigo Hwy | 26) Pedigo Hwy |
| 27) Pedigo Farm | 28) McMahan Creek Woodland Estates |
| 29) Cooper Branch | 30) Unnamed Spring McMahan Creek |
| 31) Unnamed Tributary McMahan Creek | 32) Lance Spring |
| 33) Charles Creek | 34) Blue Spring |
| 35) Greenbrook Pond | 36) Meadow Br above RR Bridge |
| 37) Unnamed Duke Cr | 38) Thompson Duke Cr |
| 39) Hershel Trail – Duke Cr | 40) Tucker Duke Cr |
| 41) Doak Spring | 42) Unnamed tributary to W. Fk. Hickory |
| 43) Little Duck River | 44) Redman Branch |
| 45) W. Fk. Hickory | 46) W. Fk. Hickory DS of Rock Rd |

Table 2-2. All known Barrens Topminnow Sites, current and historic

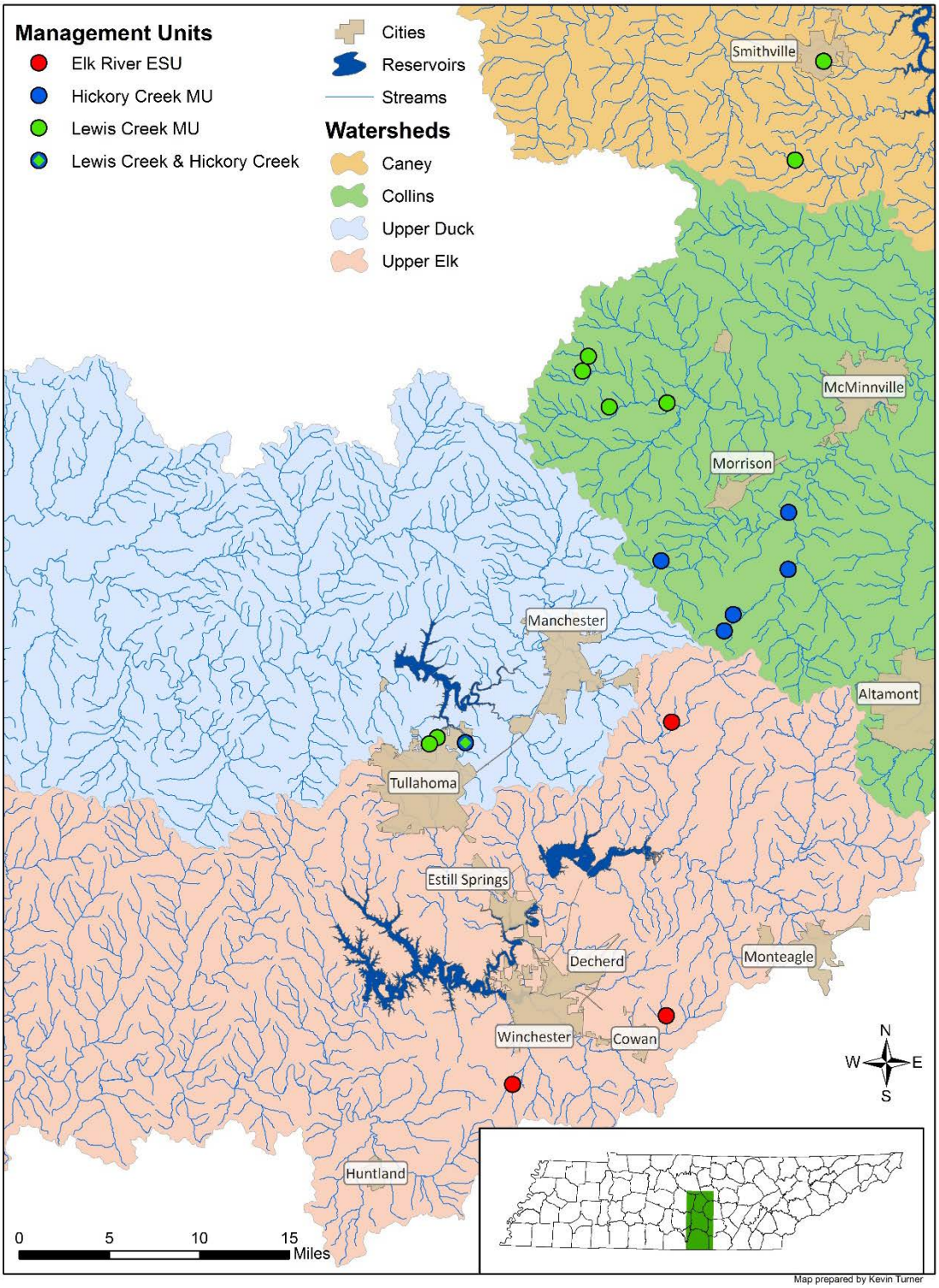


Figure 2-6. Barrens Topminnow Management Units and current range.

## CHAPTER 3. FACTORS INFLUENCING VIABILITY

*Predation*

Western Mosquitofish

The Western Mosquitofish (*Gambusia affinis*) poses the largest and most direct threat to the continued existence of the Barrens Topminnow. This small, live-bearing fish is native to Tennessee, but not naturally found on the Barrens Plateau. These fish were likely first introduced to the plateau in the 1960s as an effort to control mosquitos. With human help and natural expansion, Western Mosquitofish are now found in most streams on the Barrens Plateau. Western Mosquitofish are adapted to expand rapidly into unoccupied habitat. They display active exploratory and aggressive behaviors that allow them to find new habitats and are very tolerant of poor habitat and water quality allowing them to disperse through potential barriers such as water less than an inch deep. Females can store sperm from multiple mates over multiple seasons so that a single fish can populate an area with limited genetic impacts (Rehage and Sih 2004, entire). These adaptations allow mosquitofish numbers to balloon once they have invaded a new area, greatly increasing competition in an area (Figure 3-1).

Adult mosquitofish prey on terrestrial and aquatic arthropods as well as larval fishes (Etnier and Starnes 1993, p. 372). Where the two species co-occur, mosquitofish prey upon (<16mm; .6in.) and harass larval and juvenile Barrens Topminnows, leading to higher juvenile mortality and little to no recruitment in populations with mosquitofish present (Laha and Mattingly 2006, entire). Large mosquitofish also harass adult topminnows. In laboratory settings and in the wild, where mosquitofish occur, topminnows are often found with tattered fins from the harassment. This harassment can lead to disruptions in spawning due to the use of the male topminnows' fins in the courtship display as well as the direct interference of the mosquitofish. The injuries and elevated stress the mosquitofish cause also increases the chance of disease in the topminnows (Laha and Mattingly 2006, entire). In repeated cases, within a few years of Western Mosquitofish introduction to a spring system, the Barrens Topminnow population collapses (Kuhajda 2017, USFWS unpublished data).

It is thought that in large springs with diverse, high quality habitat, topminnows can coexist with mosquitofish (Laha and Mattingly 2006, entire; Pat Rakes, pers. comm). When the Pond Spring population of Barrens Topminnows was first discovered, Western Mosquitofish were already present; however, both mosquitofish and topminnows were found together in the spring for almost 20 years until cattle gained access to the spring and the habitat degraded, after which the topminnows were extirpated (Pat Rakes, pers. comm.).

Figure 3-1. Western Mosquitofish collected in 20 seine hauls at the Ramsey Barn site, 27 May 2014. Only 3 Barrens Topminnows were collected. (Photo courtesy of Bernard Kuhajda, TNACI).

Native Predators

Various centrarchid (sunfish) species such as Green Sunfish (*Lepomis cyanellus*) are found in the same habitats as Barrens Topminnows (Rakes 1989, p. 48). These fishes are predatory and are known to occasionally prey on Barrens Topminnows. A variety of riparian predators (kingfishers, herons, watersnakes, etc.) also likely prey on topminnows. In sufficient habitat and with healthy population numbers, it is unlikely that these sources of predation pose a threat to the continuation of a population (resilience).

*Habitat Alteration*

Livestock Influence

Many of the springs where Barrens Topminnows have historically been found are used as water sources for cattle. Cattle access is known to increase bank erosion, increasing turbidity and sedimentation in the springs. Topminnows require clear water for their spawning displays to be successful and clean vegetation for egg laying. Sedimentation from cattle also has the potential to fill in spring pools and runs, reducing habitat area. The increased turbidity and reduced riparian vegetation leads to increased water temperatures which reduce dissolved oxygen levels and can stress topminnows and increases the competitive advantage for mosquitofish. Influxes of large amounts of cattle waste increases the amount of nutrients in the water and further reduces visibility which can impact the spawning displays of Barrens Topminnows. Higher nutrients lead to higher biological oxygen demand and reduce the dissolved oxygen levels in the water. Increased bacterial levels may also reduce egg viability and increase the risk of infection (Pat Rakes, pers. comm.).

Riparian Vegetation Removal

An activity often associated with livestock operations is the clearing of vegetation up to the edge of the springs and runs that the Barrens Topminnows rely on. Trees and shrubs are cleared to allow for easier access for cattle or to provide views of the stream. Riparian vegetation acts to stabilize banks and reduce overland runoff, so when it is removed, sedimentation increases (Barling and Moore 1994, p. 544; Beeson and Doyle 1995, p. 989). Removal of riparian vegetation can also lead to an increase in water temperature because the stream is no longer shaded (Brazier and Brown 1973, p. 4; Barton et al. 1985, p. 373; Pusey and Arthington 2003, p. 4). However, a fully shaded stream will reduce the amount of filamentous algae and other submerged vegetation, which is needed as habitat for the Barrens Topminnow.

Drought

Droughts reduce springhead discharge. Reduced discharge leads to a reduction of available habitat, and if the spring dries up completely, fish become stranded and easier targets for predators. In conjunction with livestock access, drought-reduced spring discharge can result in a very high concentration of animal waste in topminnow habitats. Benedict Spring, the type locality for Barrens Topminnow has dried completely during droughts on multiple occasions, necessitating the rescue of the fish in the spring pool. When the latest rescue of fish from Benedict Spring and Pedigo Farm was carried out in October 2016, the drought index for the

Barrens area was only classified as a moderate drought by the United States Drought Monitor. Since 2006, type locality fish have been rescued five times due to drought. Prior to human alteration of Barrens area, during drought, fish were able to move out of drying springs, downstream, to more permanent water, or, if the site was extirpated, topminnows could recolonize the springs once conditions improved. Manmade barriers and invasive mosquitofish in the lower reaches of the streams inhabited by topminnows prevent this movement from happening.

Figure3-2. Type Locality (Benedict Spring) showing remaining water during drought, 26 October 2016. Over 100 Barrens Topminnows were rescued from the remaining puddle.

Potentially exacerbating the effects of drought, is groundwater withdrawal. Throughout the Barrens, wells are a common domestic water source. Groundwater is also used as an irrigation source for tree and flower nurseries, sod farms and row crops on the Barrens. These forms of agriculture are common in the area, and the city of McMinnville, in the Barrens, is the self-proclaimed "Nursery Capital of the World" due to the more than 400 nurseries in Warren County alone (City of McMinnville, http://www.mcminnvilletenn.com/city_government/index.php). The use of groundwater for irrigation can lead to reductions in spring discharge in nearby areas if aquifer recharge is not sufficient (Siebert et al. 2010, pp. 1863-1864; Sophocleous 2002, pp. 93-112). Irrigation and water withdrawals in general increase during droughts, thereby exacerbating that stressor.

Impoundment

A few of the springs where Barrens Topminnows occur have been dammed for use as water sources as well as for fishing and aesthetic opportunities. These impoundments become warmer than what is typical in a flowing spring. The deeper water of these impoundments also reduces the growth of aquatic vegetation that the Barrens Topminnow uses for cover and as a spawning

substrate. A population at Lewis Farm was lost when the spring was impounded. Small impoundments are also popular targets for introduction of Western Mosquitofish with the intention of controlling mosquito larvae. However, in other instances the construction of berms or other minor impounding structures has created a barrier to prevent mosquitofish from moving up into habitat occupied by Barrens Topminnows such as at Benedict Spring.

A large portion of the Duck River watershed ESU was reduced with the construction of Normandy Dam that impounded multiple known locations, leaving only a few other locations where Barrens Topminnows were outcompeted by mosquitofish (Etnier and Dinkins 1983, Rakes 1989).

*Demographic Effects*

Small Population Sizes and Restricted Range

The range of the Barrens Topminnow is restricted to spring-fed streams of the Barrens Plateau in Middle Tennessee. With loss of the natural populations in the Duck and Elk watersheds and multiple populations in Caney Fork watershed, the Barrens Topminnow range is now restricted to a single self-sustaining, natural population in the Caney Fork watershed and six self-sustaining introduced or reintroduced populations. Habitat fragmentation has subjected the small populations to genetic isolation, reduced space for rearing and reproduction, reduced adaptive capabilities, and increased the likelihood of extinction. Small, isolated populations are also vulnerable to the Allee effect (a positive relationship between individual fitness and either numbers or density of conspecifics) (Stephens et al. 1999, p.186).

Low Genetic Diversity

Species that are restricted in range and population size are more likely to suffer loss of genetic diversity due to genetic drift, potentially increasing their susceptibility to inbreeding depression, decreasing their ability to adapt to environmental changes, and reducing the fitness of individuals (Soule 1980, pp.157-158; Hunter 2002, pp. 97-101; Allendorf and Luikart 2007, pp.117-146).

It has been estimated that effective population sizes may range from 500 individuals (Franklin and Frankham 1998, pp. 69-70) to avoid deleterious effects of genetic drift over several generations, up to 5,000 individuals (Lande 1995, p.789) for long-term survival. The long-term viability of a species is founded on the conservation of numerous local populations throughout its geographic range (Harris 1984, entire). These separate populations are essential for the species to recover and adapt to environmental change (Harris 1984, entire; Noss and Cooperrider 1994, p. 267).

As discussed above, Hurt et al. (2017, entire) found very low genetic diversity in populations of Barrens Topminnows. They also found low effective populations for several sites where a number could be generated; however, due to a small sample size and a low number of alleles, the confidence intervals were very wide for the estimates (Hurt and Kuhajda 2017, p. 14).

*Conservation Actions*

There have been many targeted efforts since the late 1970s to conserve the Barrens Topminnow in an effort to conserve the species without listing it under the Act. In 2001, the Barrens Topminnow Working Group, consisting of state and federal agencies (TWRA, USFWS), Universities, and nonprofit organizations, was created to coordinate actions such as habitat improvement, propagation and stocking. Since the initiation of the stocking program more than 44,000 Barrens Topminnows have been stocked into twenty-seven sites deemed to have appropriate habitat. Brood fish were taken from McMahan Creek watershed at the Pedigo farm and Woodland Estates, Hickory Creek watershed at the type locality, and Elk River watershed from Pond Spring. The fish were propagated at CFI and the TNACI and grown out at Dale Hollow and Wolf Creek National Fish Hatcheries as well as the propagating institutions. Stocking has proved unsuccessful at most of these sites either because of insufficient or marginal habitat or the invasion of Western Mosquitofish into these areas (Goldsworth and Bettoli 2005, entire). At the 2016 working group meeting, the decision was made to stop the stocking program because it was no longer needed to maintain populations at suitable sites without mosquitofish and at other sites, continued stocking was unlikely to establish self-sustaining populations.

One of the stocked sites, Vervilla, was situated in the Hickory Creek watershed on land opportunistically purchased by USFWS for Barrens Topminnow reintroduction. When the land came under the management of Tennessee National Wildlife Refuge, mosquitofish were present in the spring on the property and topminnows were not. To improve habitat for topminnows at the site, spring pools were deepened, a concrete low water barrier was installed and the mosquitofish removed with a piscicide. Fish from the type locality were then stocked above the barrier. This population maintained viability until 2010 when mosquitofish reinvaded the spring during a flood.

In addition to the stocking, a monitoring program was implemented at all of the known sites until 2015. These surveys were conducted using standardized techniques with assistance from TNACI, CFI, Tennessee Wildlife Resources Agency (TWRA), and USFWS. These efforts allowed the success of the stocking program to be assessed and updated (Kuhajda et al. 2014, entire; updated by Kuhajda 2017).

At several sites, Partners for Fish and Wildlife worked with landowners to exclude livestock from the springs and spring runs in an effort to curb sedimentation. None of these agreements are still active, however there are still buffers in place at some of the sites. Unfortunately many of these sites have been impacted by mosquitofish.

## CHAPTER 4. CURRENT MU CONDITION AND SPECIES VIABILITY

Current habitat and population conditions are described below. This section details specific stressors acting within the occupied watershed. Additionally, collection history and qualitative abundance is provided. Current population resilience is assessed for each location and Management Unit specifically, followed by a summary of range-wide redundancy and representation.

To qualitatively assess current viability we considered 6 components that broadly relate to either characteristics about the population specifically ("Population Elements") or the physical environment ("Habitat Elements"). Habitat elements consisted of an evaluation of physical habitat, presence of mosquitofish, and susceptibility to drought. Population elements consisted of an estimation of approximate abundance, evidence of reproduction, and support from stocking. We further defined how each of these components might vary in terms of condition (see Table 4-1).

For our analysis, we divided the species range into the ESUs (Caney Fork, Elk River, extirpated Duck River) and genetic MUs (within the Caney Fork ESU: Hickory Creek (Type Locality) and Witty Creek) as defined by Hurt et al. (2017, entire) as well as addressing individual, extant populations found by Kuhajda (2017).

### Population Elements

To evaluate the population elements, we used the results of a recent (2013-2015) range-wide survey for Barrens Topminnow conducted by TNACI (Kuhajda 2017) as well as additional collections conducted since 2015 discussed at the 2017 Barrens Topminnow Working Group meeting. The surveyors visited sites that were found to be extant in the exhaustive survey conducted by Rakes (1996, entire), sites where topminnows had been introduced, as well as other potential sites. The recent survey used standardized methods targeted at collecting Barrens Topminnows of every size class with a fairly high likelihood of capture.

Because of variability across years in the capture numbers, abundance was characterized as "low," "medium," or "high" based on the average number of topminnows collected across the three years in the TNACI survey (see Table 4-1). A site was considered extirpated if no fish were captured two years in a row.

Presence of Barrens Topminnows under 40mm was used as evidence of reproduction in the population. This threshold was based on length frequency data generated as part of the survey as well as from the life history work conducted by Rakes (1989, pp.46-48).

Requirement of stocking is a determination of whether marginal populations would require continued stocking of fish to maintain numbers at a site. This determination was made based on evidence of low numbers and low recruitment despite past stocking efforts or extirpation. The value assigned to each site was determined based on a presentation and comments made by species experts at the April 2017 Barrens Topminnow Working Group meeting (Kuhajda 2017).

**Habitat Elements**

Physical habitat was evaluated by determining whether it suited the needs of the Barrens Topminnow. We also considered any threats to the habitat such as livestock access, development, pesticide use, and timber activity. Habitat was assessed as part of the range-wide survey, so the habitat determinations were based on the report for that survey (Kuhajda et al. 2014, entire). Though not the main threat to the Barrens Topminnow, the loss of the population in Charles Creek can likely be attributed to physical habitat alteration. Kuhajda et al. (2014, pp. 76-77) noted that this historic site was now incised, eliminating the slow-water habitat required by topminnows. Stream incision is associated with landuse that increases the rate of runoff (Booth 1991, p. 409).

Mosquitofish were noted in the TNACI survey and as well as later observations at a few of the sites. Because of the ability of mosquitofish to invade aggressively, their populations balloon rapidly, and given their profound and rapid negative effect on topminnow recruitment, any mosquitofish presence resulted in the assignment of the low score.

Drought resistance was based on known drying events as well as observations of hydrology and habitat availability in the TNACI report (Kuhajda et al. 2014, entire). Where drought resistance was unknown, it was assumed to be high.

| Quality | High | Medium | Low | Unsuitable |
|---|---|---|---|---|
| Physical Habitat | No known alteration | Known low level alterations to habitat | Habitat heavily altered and recognized as impacting species | Unable to support survival |
| Presence of mosquitofish | Absent | | Present | |
| Drought Resistance | Not known to dry during drought and deep water habitat available | Known to dry at ≥10 year intervals, or not known to, but deep water limited | Known to dry at 1-10 year intervals | |
| Approximate Abundance | Recent Survey found >75 individuals in a year | 25-75 in a year | <25 in a year | Extirpated |
| Evidence of Reproduction | Young of the year present in the most recent survey | | Young of the year absent from the most recent survey | Extirpated |
| Sustained by continued stocking | No | | Yes | |

Table 4-1. Definitions of conditions for components used to assess current conditions

## Current Management Units and Population Status

For the Barrens Topminnow to exhibit high representation, all ESUs should have high resilience and all of the representative MUs should be extant. These MUs should occur at a wide extent across the Barrens Plateau where the species is native. Within each MU should be multiple viable, occupied sites to reduce the chance of extirpation. Any extirpation of a MU compounds the already hindered representation of the species caused by the loss of the native populations within the Duck River watershed that represented an additional MU and probably another ESU.

High redundancy for the Barrens Topminnow is characterized by having multiple resilient and representative populations distributed within the species' ecological setting and across its range. Increased connectivity would further improve redundancy by reinforcing existing populations and increase the likelihood for reestablishment of lost populations.

### Caney Fork ESU

Hickory Creek MU

Within the Hickory Creek MU, there are six sites occupied by Barrens Topminnows: one natural site from which all other sites have been stocked (the type locality, Benedict Spring), two extant introduced sites purely of Hickory Creek stock, one site of mixed Hickory Creek and Witty Creek stock which will be treated as part of this MU in this assessment (located in the Duck River watershed), and two recently extirpated stocked sites. Barrens Topminnows have been extirpated from at least four other natural sites in the Hickory Creek watershed (e.g., West Fork Hickory at Hwy 55, West Fork Hickory downstream of Rock Rd, Unnamed Tributary to West Fork Hickory, and Meadow Branch above the railroad bridge; Etnier 1983, entire) and other sites where establishing stocked populations proved unsuccessful.

Within the Hickory Creek watershed, Western Mosquitofish are widespread in the streams and in many of the springs and spring runs. All of the stocked sites in this MU have mosquitofish present except for Short Spring which is geographically located in the Duck River watershed and was stocked with a mix of fish from the type locality and Witty Creek. The type locality for the species, Benedict Spring, is the only remaining natural site in the MU; however, it has dried up roughly every 5 years requiring the topminnows to be removed to hatcheries and returned when conditions improved. This population is vulnerable to drought because there a small impounding structure on the outlet of the spring. While this barrier prevents the mosquitofish found below it from making it into the spring where the topminnows are, it also prevents the topminnows from finding a refuge in more permanent waters downstream and then reestablishing in the springhead. This regular drying of the source population has repeatedly created genetic bottlenecks in this MU. Hurt et al. (2017) found genetic bottlenecks in all of the sites stocked from this population.

Nearly all of the property within the Hickory Creek watershed is privately held and in agriculture. One parcel, Vervilla, is owned and managed by Tennessee National Wildlife Refuge. This property was acquired expressly for Barrens Topminnow conservation. When acquired, mosquitofish were present in the spring and topminnows were absent, so a low barrier was built

to exclude mosquitofish, deeper pools were excavated to improve habitat, mosquitofish were removed with piscicide (fish poison), and Barrens Topminnows from the type locality were introduced. A flood overtopped the barrier in May 2010 and mosquitofish returned to the site, and by 2013, the topminnows were eliminated. In the Duck River watershed, Short Spring (mixed stock) is located on Short Spring State Natural Area which is managed by the Tennessee Department of Environment and Conservation (TDEC).

Because of the small number of sites that still have Barrens Topminnows (4), the high proportion that have mosquitofish present (4/5), the high proportion that would require continued stocking or rescue for continued existence (5/5), the bottlenecked genepool and the overall low connectivity in a small geographic area, the Hickory Creek MU is considered to have a **low** resilience to stochastic events.

Witty Creek MU

In the Witty Creek MU, there are two extant natural sites, three stocked sites within the Witty Creek watershed, and four stocked sites outside of the watershed: two of pure stock in the Duck River watershed, and one pure stocked in the Caney Fork watershed, but outside the historic range of the species. There were also at least 5 other sites where Barrens Topminnows were known from but are now extirpated: Duke Creek at Herschel Trail, Duke Creek at the Tucker and Thompson Farms, Duke Creek at an unnamed farm road, Charles Creek at Hwy 287, and Redman Branch at Red Hill Rd (Etnier 1983, Rakes 1996). There have been other sites stocked that were unsuccessful.

Mosquitofish are widespread throughout the Witty Creek watershed as well as around the sites geographically in the Duck River drainage that were stocked with Witty Creek fish. One of the natural sites, Pedigo, was first found to have mosquitofish present throughout in November 2016 when fish were being collected to protect them from the site going dry during the drought. Pedigo had a large population of topminnows in 2015, with Kuhajda (pers. comm.) reporting collecting approximately 80 individuals in a single seine haul, but in 2016, only 64 topminnows were collected after exhaustive sampling along with multitudes of mosquitofish. The other natural site, near Woodland Estates, has a medium sized population, but no mosquitofish, making it the only self-sustaining, native site without mosquitofish. There are mosquitofish known from 1.12 stream kilometers (km) (0.7 stream miles (mi.)) downstream, with only a 0.3 meter (m) (1 foot (ft.)) high barrier at Geedsville Road preventing mosquitofish from invading the McMahan Creek site. The Greenbrook site is in a city park in Smithville, TN. While this site is free of mosquitofish, it is outside the Colins River portion of the Caney Fork drainage where this MU is native. Within the Duck River drainage are 3 sites that have been stocked from this MU. Short Spring of mixed stock is addressed in the Hickory Creek MU. Marcum (Ovoca) was a Duck River site that had been extirpated by the 1960s by the invasion of mosquitofish. The private construction of a fishing pond at the site created an area without mosquitofish that was protected by a barrier (though they are just below), and Witty Creek fish were stocked into the springheads feeding this pond. The other Witty site in the Duck River watershed, Collier Spring, has mosquitofish and low abundance, but at last survey (2015) there was still evidence of reproduction. Of the other three Witty MU stocked sites in the Witty Creek watershed, all have

low abundance (0 were captured at Blue Spring in 2015), 2 have mosquitofish present (Cooper Branch does not), and all would require stocking for continued occupation. Excepting Greenbrook in the Smithville city park and Short Spring on the State Natural Area, all of the sites in this MU are on private land.

Because mosquitofish are in or adjacent to a high proportion of sites with mosquitofish in or adjacent to (63%), the low abundance of topminnows at half the sites, and two of the best sites are outside of the historic range of Witty Creek, this MU is considered to have a **low** resilience to stochastic events.

Elk River ESU/MU

Within the Elk River drainage, there is a limited distribution of Barrens Topminnows. The only known native site in the watershed was Pond Spring, found in Etnier's survey (1983). Other sites have been stocked from this population, but only 2 were recently extant (Merkle Spring and Faris Spring).

Pond Spring is a large (0.42 hectare, 1 acre) spring pool complex with dense vegetation and a large amount of groundwater discharge (Figure 4-1). Mosquitofish coexisted with topminnows at this site for over 20 years. Conservation agreements were put in place with the landowner to fence cattle out of the spring and improve the septic system on the cabin adjacent to the spring. Flooding damaged the fence, allowing cattle to gain access to the spring, altering habitat by increasing the turbidity, adding nutrients, and likely warming the spring. Collectively, this habitat alteration likely provided the mosquitofish a competitive advantage leading to the extirpation of the Barrens Topminnow population. Land clearing and an expansion of center-pivot irrigated row crop agriculture on the parcel adjacent to the spring might have also contributed to this habitat shift.

The two other stocked sites were of marginal habitat quality and the fish stocked were only observed in low densities in follow up surveys. Merkle Spring has mosquitofish present and no sign of reproduction. Fish are no longer stocked into this site, and it is thought that this site has been extirpated and that it persisted due only to continued stocking (Kuhajda 2017). Faris Spring is free of mosquitofish, but like Merkle, only persisted due to continued stocking and is likely extirpated. There is still an ark population of Elk River topminnows being held by TNACI, CFI, and USFWS hatcheries, but no sites are currently slated for these fish to be stocked, and the small number of fish in the ark increases the likelihood of inbreeding depression.

The core of the Elk River ESU, Pond Spring, has been extirpated, and the two stocked sites that were still recently occupied, Merkle and Faris Springs, are likely extirpated as well or exist at extremely low population numbers meaning that the Elk River ESU may exist only as an **ark population** of a few hundred individuals.

Figure 4-1. Pond Spring main pool. (Photo from Kuhajda et al. 2014, p.21)

*Native Duck River populations*

Barrens topminnows were first found in the Duck River drainage and were known from four or more sites. Topminnows were last collected from the Duck River drainage in the 1960s despite intense efforts to locate extant populations in the 1980s and 1990s. Barrens Topminnows from the Caney Fork ESU were stocked in several sites in the 2000s; however, the native Duck River populations are considered **extirpated**.

| | Physical Habitat | Presence of Mosquitofish | Drought Resistance | Approximate Abundance | Reproduction | Requires Stocking | Current Condition |
|---|---|---|---|---|---|---|---|
| Caney Fork ESU | | | | | | | **Low** |
| Witty Creek MU | | | | | | | **Low** |
| Pedigo | Low | Yes | Medium | Medium | Yes | N/A | Low |
| McMahan Creek | Medium | No | Medium | Medium | No | N/A | Low |
| Marcum (Ovoca)* reintroduced (Duck watershed) | Low | No | High | High | Yes | No | Medium |
| Collier* (Duck watershed) | Medium | Yes | High | Low | Yes | No | Low |
| Geenbrook* | Low | No | Medium | High | Yes | No | Medium |
| Lance* | Medium | Yes | High | Low | No | Yes | Low |
| Cooper Branch* | Medium | No | High | Low | Some | Yes | Low |
| Blue Spring* | Medium | Yes | High | Low (0 in 2015) | No | Yes | Low |
| Hickory Creek MU | | | | | | | **Low** |
| Benedict Spring (Type Locality) | Medium | No | Low | Medium | Yes | Yes | Low |
| Clayborne* | Medium | Yes | Medium | Medium | No | Yes | Low |
| Cunningham Dairy* | Medium | Yes | Medium | 0 | 0 | Yes | Extirpated |
| Vervilla* | High | Yes | High | 0 | 0 | Yes | Extirpated |
| Ramsey Barn* | Medium | Yes | High | Low | No | Yes | Low |
| Short Spring** (Duck watershed) | High | No | High | Medium | Yes | No | Medium |
| Elk River ESU | | | | | | | **Low/ Arked** |
| Pond Spring | Low | Yes | High | 0 | 0 | Yes | Extirpated (Arked) |
| Merkle (Big) Spring* | Low | Yes | Medium | Low | No | Yes | Low/ Likely Extirpated |
| Faris Spring* | Low | No | Medium | Low | No | Yes | Low/ Likely Extirpated |
| Duck River ESU | | | | | | | **Extirpated** |

Table 4-2. Current resilience of Barrens Topminnow populations (* indicates stocked sites, ** mixed Hickory Creek and Witty Creek stock).

## Current Species Level Status

*Representation*

Representation describes the ability of a species to adapt to changing environmental conditions over time and encompasses the "ecological and evolutionary patterns and processes that not only maintain but also generate species" (Shaffer and Stein 2000, p. 308).

The Barrens Topminnow does not currently exhibit high representation due to the loss of the Duck River ESU and the reduction of the Elk River ESU to an ark population. We estimate that the Barrens Topminnow has **low** adaptive potential due to limited representation in two MUs within the same ESU. The genetic diversity of the species was found to be very low. Hurt et al. (2017) found only three mitochondrial haplotypes for the entire species, only one of which was represented in the entire Caney Fork ESU, which is extremely low variation compared to the 46 mitochondrial haplotypes found in a small portion of the range of the related Mummichog (*Fundulus heteroclitus*). Analysis of the nuclear genome found higher genetic variability, but also found evidence of genetic bottlenecking at Benedict Spring, the stocking source of the Hickory Creek MU, Pedigo, the stocking source for the Witty MU; and Pond Spring, the only native site in the Elk ESU (Hurt 2017). All sites are essentially isolated from one another by unsuitable habitat, mosquitofish, stream barriers, or drainage divides meaning that there is no opportunity for genetic exchange between sites, even within MUs, reducing the adaptive potential of the species as a whole.

*Redundancy*

Redundancy describes the ability of a species to withstand catastrophic events. It "guards against irreplaceable loss of representation" (Redford et al. 2011 p. 42; Tear et al. 2005 p. 841) and minimizes the effect of localized extirpation on the range-wide persistence of a species (Shaffer and Stein 2000, p. 308). It is characterized by having multiple, resilient populations distributed throughout the species ecological setting and across its range. For a species to exhibit greater redundancy the populations should not be completely isolated and immigration and emigration between populations should be achievable. The Barrens Topminnow is regarded to have **low** redundancy due to the loss of the Duck River populations, the likely extirpation of the Elk River ESU, the low resilience of the Caney Fork MUs, and the isolation of sites within the two Caney Fork MUs. The likelihood that a catastrophic event, such an extreme drought, chemical spill, or sudden invasion of mosquitofish, would cause the extirpation of a MU is fairly high and there is little or no opportunity for any eliminated sites from being recolonized naturally.

## CHAPTER 5: FUTURE SCENARIOS AND SPECIES VIABILITY

In this chapter, we describe how current viability of the Barrens Topminnow may change over a period of 3-5 years and a period of 20-30 years. Like in current condition discussion, we evaluate species viability in terms of resilience at the population scale, and representation and redundancy at the species scale (3 Rs). Here we describe three plausible future scenarios and whether there will be a change, from current conditions, to any of the 3 Rs under each scenario. Our future scenarios differ by considering variations that are predicted in three main elements of change: mosquitofish distribution, conservation levels, and climate. These scenarios capture the range of likely viability outcomes that the Barrens Topminnow will exhibit by 2040 or 2050.

Western Mosquitofish first found their way onto the Barrens Plateau as part of efforts to control mosquito larvae. They had been distributed to farmers in the past and thereby were given a wide range on the plateau. Western Mosquitofish are behaviorally and physiologically poised to successfully invade new available habitat and thereby spread further into the streams of the Barrens on their own. Mosquitofish take advantage of high water events to move into peripheral habitats, moving through very shallow water and being poised to reproduce rapidly once even a few are established in an area. They can also be spread accidently through game fish stocking in private ponds or through the release of baitfish. In the future, accidental stockings or the overtopping of barriers could allow mosquitofish to make their way into areas now occupied only by Barrens Topminnows. Warming water would also increase the competitive advantage of mosquitofish over Barrens Topminnows (Laha and Mattingly 2006b, entire).

Under most circumstances, once mosquitofish have been found at a Barrens Topminnow site, recruitment ceases within a year or two, and within 3-5 years, the last adult Barrens Topminnows have died without replacement, resulting in extirpation from the site. This pattern has been seen at Vervilla and other sites where the first collection of mosquitofish is known. In Pond Spring, the two species coexisted for at least 20 years before Barrens Topminnow was extirpated, but it is a very large spring with complex habitat and an abundant amount of groundwater discharge. We will consider the proximity of known mosquitofish populations and barriers and different chances of introduction when predicting our scenarios.

Over the past 20 years, there has been considerable conservation effort focused on the Barrens Topminnow. Recently however, partners have begun to reassess those efforts and decide whether or not they should be continued. Federal, state, and nongovernmental partners are perennially limited by available funds, personnel, facilities. These ongoing conservation efforts the clearest impact on Barrens Topminnow resilience at those sites that require continued stocking or rescue from drought to maintain the populations. At the 2015 Barrens Topminnow Working Group Meeting, partners decided to cease stocking efforts at sites that were not self-sustaining since they did not meet the needs of the species. Continued conservation effort is also needed to maintain relationships with landowners and follow up on conservation projects that have been done, such as livestock exclusion fencing. The creation of barriers to prevent the invasion of mosquitofish into topminnow inhabited springs could also be used to conserve the species. There has also been discussion of using automatic pumps to provide well water at springs that are

susceptible to drought. We will use different levels of conservation commitment to determine differences in future scenarios.

In the Southeast, the clear trends in climate predictions are limited. Variability in weather is predicted to increase, resulting in more frequent and more extreme dry years and wet years over the next century, though increases in variability are already being seen (Mulholland et al. 1997, entire, Ingram et al. 2013, entire). Average and extreme temperatures are also expected to increase over time. More droughts will increase the likelihood that a Barrens Topminnow site is impacted by reduced groundwater discharge, resulting in the reduction or elimination of populations. Droughts will also increase the reliance on groundwater for irrigation of crops in the Barrens and may force municipalities to use secondary water sources which has the potential to further reduce spring discharge. More wet weather will result in more flooding and allow movement of mosquitofish to uninvaded Barrens Topminnow sites when barriers are overtopped. Warming temperatures overall would contribute to warming waters. Warmer water in Barrens Topminnow habitat would further reduce the likelihood of topminnows and mosquitofish coexisting in even the best springs. We will use either little or no noticeable change in climate over our projected time span, moderate change in climate, or strongly noticeable change in climate in the prediction of our future scenario.

**Scenarios**

*Status Quo*

In the Status Quo Scenario, mosquitofish are expected to expand into a few places and replace Barrens Topminnows where the species currently co-occur within 3-5 years and expand and replace further in 20-30 year timeframe. The current trend in climate continues, and within the next 3-5 years, a few sites are impacted by either drought or flood and the water warms slightly, and in the long term drought affects marginal habitat sites. Sites are not stocked by conservation partners, though efforts are taken to rescue better sites that are impacted by drought.

Resilience

Caney Fork ESU, Hickory Creek MU

Under the Status Quo scenario, within the Hickory Creek MU the Clayborne and Ramsey Barn sites will be extirpated within 3-5 years due to the presence of mosquitofish and lack of continued stocking. Benedict Spring will likely remain free of mosquitofish because of the barrier and landowners who understand the threat they pose. Within the short term Benedict Spring it is very likely to be impacted by another drought, but a portion of the remaining fish will be rescued by conservation partners and returned when the spring refills. Over 20-30 years, Benedict spring will dry 5 or 6 times based on the current pattern, resulting in a bottleneck event every time. Short spring will likely be stable given that it is owned by the City of Tullahoma and surrounded by state owned land (Short Spring SNA). Given the reduction of occupied sites to 2 of 6 (one of which is outside the natural area of the MU and of mixed stock) within 3-5 years and further bottlenecking of Benedict Spring, we expect this MU to have a **low** resilience in the short term and the long term, and worse than the current low resilience.

Caney Fork ESU, Witty Creek MU

Within the Witty Creek MU 4 sites (Pedigo, Collier, Lance, and Blue Spring) will be extirpated within 3-5 years. Within 20-30 years, Cooper Branch will be extirpated because stocking sites will be discontinued. Within 20-30 years it is likely that mosquitofish will have gained access to the occupied portion of McMahan Creek due to the lack of a known barrier in the 1.6km (1mi.) between the occupied reach and the confluence of the Pedigo Spring run where mosquitofish are known to occur. This would result in the loss of the McMahan population. The two sites in the Duck River will not likely be impacted by mosquitofish, but the low abundance at Collier Spring leaves it vulnerable to stochastic events. Greenbrook is likely to remain safe though it is vulnerable to mosquitofish introduction due to traffic from the general public. Short Spring is addressed in the Hickory Creek MU. This MU is predicted to be reduced to 3 of 8 pure sites and one mixed site, all of which are outside the historic geographic extent of the MU, resulting in a **low** resilience that is worse than the current condition.

Elk River ESU

Because Merkle and Faris Springs are no longer being stocked, they will be extirpated with 3-5 years if they are not already extirpated. Pond Spring has been extirpated since 2013. Therefore, the Elk River ESU will be **Extirpated** from the wild within 3-5 years, represented only as a small ark population held in captivity.

| | Physical Habitat | Presence of Mosquitofish | Drought Resistance | Approximate Abundance | Reproduction | Requires Stocking | Forecast Condition |
|---|---|---|---|---|---|---|---|
| Caney Fork ESU | | | | | | | **Low** |
| Witty Creek MU | | | | | | | **Low** |
| Pedigo | Low | Yes | Medium | 0 | 0 | N/A | Extirpated |
| McMahan Creek | Medium | Yes | Medium | Medium | 0 | N/A | Extirpated |
| Marcum (Ovoca)* reintroduced (Duck watershed) | Low | No | High | Medium | Yes | No | Medium |
| Collier* (Duck watershed) | Medium | Yes | High | Low | Yes | No | Extirpated |
| Geenbrook* | Low | No | Medium | Medium | Yes | No | Low |
| Lance* | Medium | Yes | High | 0 | No | N/A | Extirpated |
| Cooper Branch* | Medium | No | High | 0 | Some | N/A | Extirpated |
| Blue Spring* | Medium | Yes | High | 0 | No | N/A | Extirpated |
| Hickory Creek MU | | | | | | | **Low** |
| Benedict Spring (Type Locality) | Medium | No | Low | Medium | Yes | Yes | Low |
| Clayborne* | Medium | Yes | Medium | 0 | 0 | N/A | Extirpated |
| Cunningham Dairy* | Medium | Yes | Medium | 0 | 0 | N/A | Extirpated |
| Vervilla* | High | Yes | High | 0 | 0 | N/A | Extirpated |
| Ramsey Barn* | Medium | Yes | High | 0 | 0 | N/A | Extirpated |
| Short Spring** (Duck watershed) | High | No | High | Medium | Yes | No | Medium |
| Elk River ESU | | | | | | | **Arked** |
| Pond Spring | Low | Yes | High | 0 | 0 | N/A | Extirpated |
| Merkle (Big) Spring* | Low | Yes | Medium | 0 | 0 | N/A | Extirpated |
| Faris Spring* | Low | No | Medium | 0 | 0 | N/A | Extirpated |

Table 5-1. Resilience under the Status Quo Scenario

Representation

Representation of the Barrens Topminnow is expected to further decline under the Status Quo Scenario. The extirpation of the Elk River ESU and large reductions in the number of sites within the two remaining MUs within 3-5 years will result in **low**. Over 20-30 years, further losses leave fish at a single natural site that is maintained by human intervention in the case of drought and 4 stocked sites outside the geographic range of their respective MUs, one of which is outside the historic range of the species and one of mixed stock, resulting in a **very low** level of representation for the species.

Redundancy

The Barrens Topminnow is expected to be limited to 2 MUs in a single ESU within 2-3 years. Few sites, and low numbers will greatly reduce the adaptive ability of the species and its ability to withstand catastrophic events. This will result in a **very low** level of redundancy.

*Best Case Scenario*

Under the best case scenario, mosquitofish will be limited from expanding and removed in a few circumstances due to conservation efforts such as the construction of barriers; however, sites where mosquitofish already occur will probably be extirpated in the short term. Agreements will be struck with landowners to conserve the Barrens Topminnow habitat or properties purchased for Barrens Topminnow management. A few sites will be rehabilitated and restocked by conservation partners. Droughts will occur, but conservation measures will be taken to increase the resilience of sites to drought and actions will be taken to reduce municipal water demand that would require tapping into springs.

Resilience

Caney Fork ESU, Hickory Creek MU

Under the Best Case Scenario, a well with an automatic pump would be put in place at Benedict Spring within 3-5 years to maintain water levels in the case of drought circumventing the need to rescue the fish in the future as well as reducing the chance of future bottleneck events. The two sites with mosquitofish present will likely be extirpated within 3-5 years. However over the 20-30 year span, Vervilla will be rehabilitated to remove the mosquitofish, improve a barrier for their exclusion, and reintroduce fish from the type locality into the site resulting in medium abundance. Short Spring will likely be protected from mosquitofish invasion and will not be used for drinking water supply. These sites will still potentially experience problems from having been bottlenecked in the past and lack a way to exchange genetic material due to barriers and mosquitofish in the stream mainstems. There will only be 3 sites, one of which is of mixed stock and outside the geographic area of the MU resulting in **low** resilience.

Caney Fork ESU, Witty Creek MU

Under the Best Case Scenario, the sites with mosquitofish will be extirpated within 3-5 years except Pedigo, where Barrens Topminnows will be moved above the highway culvert where there are currently no mosquitofish. Over the long term, the mosquitofish will be removed, the

culvert downstream will be fashioned to create a barrier to mosquitofish and livestock will be fenced out of the spring run. McMahan Creek will be protected from mosquitofish invasion over the 20-30 year span. The sites outside the Witty Creek watershed will remain stable, and agreements will be made to protect them. Cooper Branch will have habitat improvements done to improve the population of Barrens Topminnows. These actions will result in 6 of 8 sites extant, but with viability equal or better than current, half of which are outside the Witty Creek watershed resulting in a resilience of **low-medium**.

Elk River ESU

Within 3-5 years, the Elk River ESU will be extirpated in the wild. Under the best case scenario, over the 20-30 year timeframe, one of the current sites or perhaps another site will be chosen for habitat improvements, mosquitofish removal and/or exclusion, and stocking of fish from the ark population. This reintroduction will result in the resilience of this ESU to improve from extirpated to **low**.

Representation

Under the best case scenario, representation would be improved by the reestablishment the Elk River population in the wild, but the reduction in sites overall and the prevention of genetic exchange between sites and MUs means that the representation would be **low**.

Redundancy

Under the best case scenario, redundancy would be improved by the reintroduction of a wild population in the Elk River drainage. However, the reduction in the total number of sites and the inability for extirpated sites to be naturally reestablished results in a **low** level of redundancy.

| | Physical Habitat | Presence of Mosquitofish | Drought Resistance | Approximate Abundance | Reproduction | Requires Stocking | Forecast Condition |
|---|---|---|---|---|---|---|---|
| Caney Fork ESU | | | | | | | **Low** |
| Witty Creek MU | | | | | | | **Low/** Medium |
| Pedigo | Low | Yes | Medium | Medium | No | N/A | Medium |
| McMahan Creek | Medium | Yes | Medium | Medium | No | N/A | Medium |
| Marcum (Ovoca)* reintroduced (Duck watershed) | Low | No | High | High | Yes | No | Medium |
| Collier* (Duck watershed) | Medium | No | High | Low | Yes | No | Low |
| Geenbrook* | Low | No | Medium | High | Yes | No | Medium |
| Lance* | Medium | Yes | High | Low | No | Yes | Extirpated |
| Cooper Branch* | Medium | No | High | Low | Some | Yes | Low |
| Blue Spring* | Medium | Yes | High | Low | No | Yes | Extirpated |
| Hickory Creek MU | | | | | | | **Low** |
| Benedict Spring (Type Locality) | Medium | No | Medium | Medium | Yes | No | Medium |
| Clayborne* | Medium | Yes | Medium | Medium | No | N/A | Extirpated |
| Cunningham Dairy* | Medium | Yes | Medium | 0 | 0 | N/A | Extirpated |
| Vervilla* | High | No | High | Medium | Yes | No | Medium |
| Ramsey Barn* | Medium | Yes | High | 0 | 0 | N/A | Extirpated |
| Short Spring** (Duck watershed) | High | No | High | Medium | Yes | No | Medium |
| Elk River ESU | | | | | | | **Very Low** |
| Pond Spring | Low | Yes | High | Low | 0 | Yes | Low |
| Merkle (Big) Spring* | Low | No | Medium | 0 | | Yes | Extirpated |
| Faris Spring* | Low | No | Medium | 0 | 0 | Yes | Extirpated |

Table 5-2. Species Resilience under the Best Case Scenario

*Worst Case Scenario*

Under the worst case scenario, mosquitofish spread on their own and through private introductions into likely and commonly accessed locations. Increased flooding improves the ability for mosquitofish to invade. Droughts become more frequent and intense, causing some sites to go dry and forcing cities to use springs as additional municipal water sources where they are the backup supply. Except for enforcement of laws at the current capacity, conservation efforts are shifted to other species, resulting in the cessation of stocking and rescuing fish at vulnerable sites.

Resilience

Caney Fork ESU, Hickory Creek MU

In the Worst Case Scenario, all of the sites with mosquitofish would be extirpated within 3-5 years. Benedict Spring would be likely to go dry in 3-5 years, and would go dry at some point in the next 20-30 years, eliminating the population of Barrens Topminnows since they would not be held in captivity during the drought. With only one low viability site of mixed stock outside the native range of the ESU remaining, under this scenario, this MU has a **very low** resilience and may be **functionally extirpated**.

Witty Creek MU

Under this scenario, all of the sites with mosquitofish present, as well as those that require stocking, will be extirpated within 3-5 years. Over the course of 20-30 years, McMahan Creek will be impacted by a drought, reducing the population at the site. In the same period of time, mosquitofish will expand up McMahan Creek from the junction of the Pedigo spring run and extirpate that site. It is likely that Marcum and Greenbrook ponds would have accidental or intentional mosquitofish introductions, either through bait, gamefish stocking, or mosquito control attempts, eliminating those populations and resulting in the extirpation of all the pure strain sites in this MU. Short Spring, the mixed stock site in the Duck River watershed, would be the only remaining site resulting in a **very low/functionally extirpated** outcome for this MU.

Elk River ESU

Under this scenario, all three sites in this ESU would be **extirpated** within 3-5 years due to the presence of mosquitofish and the lack of supportive stocking. It is also likely that the ark population would lost or degraded under this scenario due to the expense, facility space, and complex management needed for the proper genetic upkeep of an ark population.

| | Physical Habitat | Presence of Mosquitofish | Drought Resistance | Approximate Abundance | Reproduction | Requires Stocking | Forecast Condition |
|---|---|---|---|---|---|---|---|
| Caney Fork ESU | | | | | | | **Very Low** |
| Witty Creek MU | | | | | | | **Very Low/ Functionally Extirpated** |
| Pedigo | Low | Yes | Low | 0 | 0 | N/A | Extirpated |
| McMahan Creek | Medium | Yes | Low | 0 | 0 | N/A | Extirpated |
| Marcum (Ovoca)* reintroduced (Duck watershed) | Low | Yes | Medium | 0 | 0 | No | Extirpated |
| Collier* (Duck watershed) | Medium | Yes | Medium | 0 | 0 | No | Extirpated |
| Geenbrook* | Low | Yes | Medium | 0 | 0 | No | Extirpated |
| Lance* | Medium | Yes | Medium | 0 | 0 | Yes | Extirpated |
| Cooper Branch* | Medium | No | Medium | 0 | 0 | Yes | Extirpated |
| Blue Spring* | Medium | Yes | Medium | 0 | 0 | Yes | Extirpated |
| Hickory Creek MU | | | | | | | **Very Low/ Functionally Extirpated** |
| Benedict Spring (Type Locality) | Medium | No | Low | 0 | 0 | Yes | Extirpated |
| Clayborne* | Medium | Yes | Low | 0 | 0 | Yes | Extirpated |
| Cunningham Dairy* | Medium | Yes | Medium | 0 | 0 | Yes | Extirpated |
| Vervilla* | High | Yes | Medium | 0 | 0 | Yes | Extirpated |
| Ramsey Barn* | Medium | Yes | Medium | 0 | 0 | Yes | Extirpated |
| Short Spring** (Duck watershed) | Low | No | Medium | Low | Yes | No | **Low** |
| Elk River ESU | | | | | | | Extirpated |
| Pond Spring | Low | Yes | High | 0 | 0 | Yes | Extirpated |
| Merkle (Big) Spring* | Low | No | Medium | 0 | 0 | Yes | Extirpated |
| Faris Spring* | Low | No | Medium | 0 | 0 | Yes | Extirpated |

Table 5-3. Species Resilience under the Worst Case Scenario

Representation

Representation is expected to decline sharply under the worst case scenario. Within 3-5 years, the species will be limited to a single site in the Hickory Creek MU and 1-4 sites in the Witty MU. Due to additional losses, in 20-30 years the species will be represented by a mixed stock Witty MU/ Hickory MU site located outside of the geographic area of the Caney Fork ESU, therefore leaving **no** true **representation**.

Redundancy

With only 1-4 sites left within 3-5 years, the redundancy of the species is greatly reduced in this scenario. Within a 20-30 year timeframe, the species would be reduced to a single site, resulting in **no redundancy**.

**Status Summary**

*Future viability*

The future scenario assessment has sought to understand how viability of the Barrens Topminnow may change over the course of 20-30 years in the terms of resilience, representation, and redundancy. To account for considerable uncertainty, associated with future projections, we defined three scenarios that would capture the breadth of changes likely to be observed on the Barrens Plateau to which the Barrens Topminnow will be exposed. These scenarios considered three elements of change: mosquitofish distribution, levels of conservation effort, and climate change. While we consider these scenarios plausible, we acknowledge that each scenario has a different probability of materializing at different time steps. To account for this difference in probability, probability categories were used was used to describe the likelihood a scenario will occur (Table 5-5).

| Confidence Terminology | Explanation |
|---|---|
| **Very likely** | Greater than 90% certain |
| **Likely** | 70-90% certain |
| **As likely as not** | 40-70% certain |
| **Unlikely** | 10-40% certain |
| **Very unlikely** | Less than 10% certain |

Table 5-4**.** Explanation of confidence terminologies used to estimate the likelihood of a scenario (after IPCC guidance, Mastrandrea et al. 2011)

| | Status Quo | Best Case | Worst Case |
|---|---|---|---|
| **3-5 years** | Very Likely | As likely as not | As likely as not |
| **20-30 years** | Likely | Unlikely | Likely |

Table 5-5. Likelihood of a scenario occurring at 3-5 and 20-30 years.

In the Status Quo Scenario, it was assumed that conservation efforts would be decreased as has been the case, and droughts/floods would continue to happen at their same rates and mosquitofish would spread at a similar rate. Under this scenario, the Elk River ESU would be lost in the wild, and the remaining two MUs would be reduced to one low viability site in the Hickory Creek MU, two low and one medium viability sites as part of the Witty MU outside of

the native watershed, and one site of mixed stock of the two MUs, outside the native watershed. This scenario will reduce overall redundancy and representation for the species. This scenario is considered very likely in 3-5 years, and likely over the next 20-30 years.

Under the Best Case Scenario, increased, intensive conservation actions would be taken for the species, mosquitofish will be limited from spreading, and drought prone sites will be protected. In this scenario, the Elk River ESU would be extirpated in the short term, but would be reestablished from the ark at one site over the long term. In the Witty MU, 2 sites would be lost, but due to the rehabilitation of a couple sites in the long term and measures to exclude mosquitofish at others, there would be 4 sites with medium viability and 2 with low viability. In the Hickory MU, 2 additional sites will be lost in the short term, but viability will be improved at the type locality by the installation of a pump to prevent drying and Vervilla will be reestablished. Redundancy and representation for the species will be slightly improved with the reestablishment of an additional ESU and the improved resilience of the other two MUs, though the species will still show signs of repeated bottlenecking. This scenario is anticipated to be as likely as not in 3-5 years and unlikely in the 20-30 year time frame.

The Worst Case Scenario assumes that mosquitofish will spread aggressively, extreme climate events will become more common, and conservation efforts for the species will be shifted elsewhere. Under this scenario, the Elk River ESU will be lost irrevocably, and the Caney Fork ESU will be reduced to a single, low viability site of mixed stock from the Hickory and Witty MUs. This would result in no redundancy and minimum representation for the species. This scenario is considered as likely as not in the short term and likely in the long term.

*Uncertainty*

Our analysis of current and future conditions contains uncertainty because we are unable to know the exact current status of the Barrens Topminnow and our future scenarios are projections based only on current trends. The following are uncertainties recognized in the report:

- Because of the nature of the Barrens Topminnow's habitat and limited sampling in the past, it is impossible to truly know how many sites were historically occupied by this species. Similarly, sampling has been limited to known sites and sites where permission was granted to access the sites. It is possible that there could be additional sites.
- Without genetic material, it is unknown what level of differentiation existed between the historic Duck River populations of Barrens Topminnows and the populations in the Elk and Caney Fork drainages, but they were likely distinct based on the level of differentiation seen between the extant drainages.
- Mosquitofish spread at opportunistic times, so the conditions for invasion are difficult to predict; this includes introductions by people, accidental or intentional. Because of this, the predictions of which sites are invaded when could be overestimated or under estimated.
- Plant nursery activities within the range of the Barrens Topminnow may have a larger effect on the water quantity and quality in the springs.

- Future conservation efforts are dependent on funding opportunities and the capacities of our partners, so only a portion of actions may be taken.
- Many of the sites occupied by Barrens Topminnows may dry during droughts, but for most, it is unknown whether they do and at what severity of drought.

**Overall Summary**

Currently, the Barrens Topminnow is known from the headwaters of three river basins, though genetically represented by ESUs of two of those watersheds and only one of those is subdivided into separate MUs. The populations in the Duck River basin were historically extirpated. The Elk River ESU is likely currently extirpated, only being represented by an ark population. The remaining MUs both exhibit low resilience due to low abundance, small number of occupied sites as well as stressors affecting the viability of the populations at those sites. Representation and redundancy are also low for this species because of the loss of two watersheds and the low resilience of the remaining MUs. The main threats to the Barrens Topminnow are competition from introduced Western Mosquitofish, and the drying of springs during droughts.

Our future scenarios assessment considered the current viability of the species to project likely future viability given plausible scenarios of mosquitofish invasion, drought recurrence, and conservation effort. Only under the Best Case Scenario did Barrens Topminnows persist in all extant MUs. However, in this scenario, the species would still show genetic signs of multiple bottlenecking events, and resilience remained low to moderate for all of the MUs. Under the Status Quo scenario, only two MUs persisted at very low resilience, resulting in similarly low redundancy and representation. The Worst Case Scenario reduced to species to a single, low resilience, mixed stock site, leaving no redundancy and very limited representation.

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