

**Rabbitsfoot**  
*(Quadrula cylindrica cylindrica, Say 1817)*

**5-Year Review:  
Summary and Evaluation**



**Photo: Dr. Chris Barnhart, Missouri State University**

**U. S. Fish and Wildlife Service  
South Atlantic-Gulf & Mississippi-Basin Unified Interior Regions  
Arkansas Ecological Services Field Office  
Conway, Arkansas**

## 5-YEAR REVIEW

Rabbitsfoot (*Quadrula cylindrica cylindrica*, Say 1817)

### I. GENERAL INFORMATION

**A. Methodology used to complete the review:** In conducting this 5-year review, we relied on the best available information pertaining to historical and contemporary distributions, life histories, genetics, habitats, and threats of this species. We announced initiation of this review and requested information in a published *Federal Register* (FR) notice with a 60-day comment period (84 FR 14669). We received no public comments during the 60-day open comment period. We used the following information resources to conduct the review: (1) the final rules listing (78 FR 57076) and designating critical habitat (80 FR 24691) for this species under the Endangered Species Act (Act); (2) peer-reviewed scientific publications; (3) unpublished field observations by Federal, State, and other experienced biologists; (4) unpublished studies and survey reports; and (5) notes and communications from other qualified individuals. Staff from the lead field office prepared a draft review and sent it to other affected U.S. Fish and Wildlife Service (Service) field offices and 8 peer reviewers for review. Staff from the lead field office evaluated comments and incorporated them into this final document as appropriate (see Appendix A).

### B. Reviewers

**Lead Region:** South Atlantic-Gulf & Mississippi-Basin Unified Interior Regions, Aaron Valenta, (404) 679-4144

**Lead Field Office:** Arkansas, Ecological Services: Rebecca Peak; (501) 513-4475

**Cooperating Field Offices:** Matthew Mangan, Illinois (618) 998-5945; Marissa Reed, Indiana (812) 334 4261 ext. 215; Laura Mendenhall, Kansas (785) 539-3474 ext. 110; Andy Ford, Kentucky/Tennessee (931) 525-4982; Ariel Poirier, Louisiana (337) 291-3129; Paul Hartfield, Mississippi (601) 321-1125; Bryan Simmons, Missouri (417) 836-5302; Angela Boyer, Ohio (614) 416-8993 ext. 22; Richard Novak, Pennsylvania (814) 234-4090 ext. 7477

**Cooperating Regional Offices:** Laura Ragan, Great Lakes Region, (612) 713-5157; Craig Hansen, Missouri Basin Region, (303) 236-4749; Angela Anders, Arkansas-Rio Grande-Texas Gulf Region, (505) 248-7953; Marty Miller, North Atlantic-Appalachian Region (413) 423-8615.

### Background

- 1. FR Notice citation initiating this review:** April 11, 2019 (84 FR 14669)
- 2. Species status:** Stable (see *Updated Information and Current Species Status* below for further detail)

**3. Recovery achieved:** No recovery plan (0–25%)

**4. Listing history**

Original Listing

FR notice: 78 FR 57076

Date listed: September 17, 2013

Entity listed: species

Classification: Threatened

**5. Associated rulemakings:** April 30, 2015, 80 FR 24691 Designation of critical habitat for Neosho Mucket and Rabbitsfoot

**6. Review history**

Each year, the Service reviews and updates listed species information to benefit the required Recovery Report to Congress. Through 2013, we performed a recovery data call that included status recommendations for each species. We continue to show that species status recommendation as part of our 5-year reviews (see C.2. below).

5-Year Reviews

This is the first 5-year review for this mussel species.

Other Relevant Reviews and Documents

Roe, K. J. 2002. Conservation assessment for the rabbitsfoot (*Quadrula cylindrica*) Say, 1817. Department of Biological Sciences, Saint Louis University, St. Louis, Missouri, prepared for the U. S. Department of Agriculture, U. S. Forest Service, Eastern Region. 12 pp.

Butler, R. S. 2005. Status assessment report for the rabbitsfoot, *Quadrula cylindrica*, a freshwater mussel occurring in the Mississippi River and Great Lakes Basins. U. S. Fish and Wildlife Service prepared for the Ohio River Valley Ecosystem Team – Mollusk Subgroup. 204 pp.

**7. Recovery Outline**

*Recovery Outline for the Rabbitsfoot*, September 3, 2013

**8. Species' recovery priority number at start of review:** 12 (subspecies, moderate degree of threat, low recovery potential)

**9. Recovery plan**

No recovery plan has been prepared.

## II. REVIEW ANALYSIS

### A. Application of the 1996 Distinct Population Segment (DPS) policy

The Act defines species as including any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate wildlife. This definition limits listing DPSs to only vertebrate species of fish and wildlife. Because the DPS policy is not applicable to invertebrate species it is not addressed further in this review.

### B. Recovery Criteria

1. **Does the species have a final, approved recovery plan containing objective, measurable criteria?** No.
2. **Adequacy of recovery criteria.**
  - a. **Do the recovery criteria reflect the best available and most up-to date information on the biology of the species and its habitat?** We do not have a recovery plan to consider for this species.
  - b. **Are all 5 listing factors that are relevant to the species addressed in the recovery criteria?** We do not have a recovery plan to consider for this species.
3. **List the recovery criteria as they appear in the recovery plan and discuss how each criterion has or has not been met, citing information:** We do not have a recovery plan to consider for this species.

### C. Updated Information and Current Species Status

#### 1. Biology and Habitat

##### a. New information on the species' biology and life history

Like other freshwater mussels, adults feed by filtering food particles from the water. Juveniles are pedal feeders meaning they bring food that adheres to their foot into the shell because structures for filter feeding are not fully developed. Specific food habits of the Rabbitsfoot are unknown, but likely it consumes detritus, diatoms, phytoplankton, and zooplankton like other freshwater mussels (Churchill and Lewis 1924, Strayer et al. 2004).

Similar to other freshwater mussels, the Rabbitsfoot has a complex reproductive cycle that includes an obligate ectoparasitic stage that requires a fish host for successful reproduction. Males release sperm into the water column. Females deposit eggs in the interlamellar spaces, or water tubes, of the gills. The eggs are fertilized by sperm as females filter water through their incurrent siphon during feeding and respiration. Galbraith and Vaughn (2011) examined reproductive traits at 3 sites on the Little River in southeastern

Oklahoma and found that incidence of hermaphroditism ranged from 1–17%).

The modified larvae, called glochidia, begin maturation in the gills of females until they reach an obligate ectoparasitic stage that requires a fish host. Like other members of the genus *Quadrula*, female Rabbitsfoot use all four gills as a brooding pouch, called the marsupium, for the glochidia (LeFevre and Curtis 1912, Howard 1914, Ortmann 1919, Fobian 2007). The Rabbitsfoot is tachytictic meaning a short-term brooder, with females brooding between May and late August in the Spring, Black, and Little Rivers in Arkansas, Kansas, and Missouri (Barnhart and Baird 2000, Fobian 2007).

Female Rabbitsfoot release glochidia within conglomerates, which are defined as aggregates of eggs, formed as molds in the water tubes of the marsupial demibranch of the female (Lefevre and Curtis 1912). The females typically retain glochidia and fragmentary conglomerates in their mantle and attract sight-feeding minnows by using it as a visual lure (Barnhart et al. 2008; Figure 1). When a fish host approaches or touches the excurrent aperture, the female reflexively release small quantities of conglomerate fragments and free glochidia from it into the water column. The glochidia attach and encyst on the gills of suitable fish hosts that provide nourishment to glochidia to continue growing. When metamorphosis is complete, the juvenile mussels excyst from the fish host and drop onto the stream floor. If habitat is favorable, juveniles develop into adults.



Figure 1. A brooding female Rabbitsfoot displaying mantle lure, which consists of orange excurrent aperture encircled by a white mantle. Photo: Dr. Chris Barnhart, Missouri State University

Growth rates for freshwater mussels vary among species, but generally freshwater mussels grow relatively rapidly for the first few years

(Chamberlain 1931, Scruggs 1960; Negus 1966) then slow appreciably (Bruenderman and Neves 1993; Hove and Neves 1994). This reduction in growth rate with years is correlated with sexual maturity and hypothesized to be a result of the diversion of energy from growth to gamete production (Baird 2000). Fobian (2007) examined shell annuli and inferred age at sexual maturity of the Rabbitsfoot as between 4 to 6 years.

In general, freshwater mussels are sedentary animals (Fuller 1974). Fobian (2007) considered the Rabbitsfoot highly mobile relative to other mussel species. He observed sediment trails 1–2 m in length while walking along shallow banks in the Black River, Arkansas, and 1 individual move approximately 1.5 m in just a few hours after disturbance (Fobian 2007). He also reported observing large numbers of adults traveling up and down the bank toward shallower water during the summer months but not in the winter. He hypothesized that this lateral migration towards shallower water during the summer months may indicate seasonal movement to facilitate reproduction by increasing exposure to fish hosts. Further studies are needed to assess movement of adult Rabbitsfoot relative to other mussel species and as a reproductive strategy.

Adults rarely burrow into substrate, but rather lie horizontally on the surface (Fobian 2007), which may leave them vulnerable to excessive predation and fluctuating water levels, especially if they occur downstream of dams or during droughts or periods when water levels rapidly recede. Unlike adults, juvenile freshwater mussels primarily burrow in the sediment or into interstitial spaces in substrate where they shelter and feed until they develop into adults (Yeager et al. 1994, Strayer et al. 2004, Watters 2007, Geist and Auerswald 2007). Fobian (2007) observed that the populations of the Rabbitsfoot that he studied were often highly aggregated with many even-aged individuals suggesting juveniles excyst simultaneously from fish hosts and remain in the same general location throughout their entire life.

As a group, freshwater mussels are generally described as long-lived and slow-growing in large part based on data from the Freshwater Pearl Mussel (*Margaritifera margaritifera*), which grows slowly and reaches an age of 100–200 years (Bauer 1992, Ziuganov et al. 2000). Studies of other mussel species have reported shorter life spans. Michaelson and Neves (1995) used age-length keys to estimate average age for the Dwarf Wedgemussel (*Alasmidonta heterodon*) as 10 years. Fobian (2007) reported that shell length of 32 brooding females ranged from 82–122 mm and estimated age as 6–17 years. Yeager and Neves (1986) counted external growth rings of 39 gravid females belonging to the closely related Rough Rabbitsfoot (*Quadrula cylindrica strigillata*) and reported a range of 81–102 mm for shell length and estimated age as 10–22 years. As part of the same project, Yeager and Saylor (1995) estimated the age of gravid females of the Cumberland Monkeyface (*Quadrula intermedia*) as between 14–22 years. Christian et al. (2000)

estimated longevity for the Mapleleaf (*Quadrula quadrula*) as between 15–30 years. Sansom et al. (2016) estimated longevity for the Pimpleback (*Quadrula pustulosa*) and the Pistolgrip (*Quadrula verrucosa*) from the Little and Mountain Fork Rivers, Oklahoma, and estimated a maximum age between 25–34 years for both species. If the Rabbitsfoot is long-lived, it could persist decades under conditions of negative population growth, which would make it challenging to understand declines in abundance (Yeager and Neves 1986).

The *Quadrula metanevra* species group (Serb et al. 2003) primarily utilize cyprinids as fish hosts. Barnhart and Baird (2000) collected glochidia of the Rabbitsfoot from the Black River, Arkansas, and tested 5 species of fish as potential hosts. They observed transformation of glochidia on Blacktail Shiner (*Cyprinella venusta*) but not on Fathead Minnow (*Pimephales promelas*), Mimic Shiner (*Notropis volucellus*), Emerald Shiner (*Notropis atherinoides*) or Bluegill (*Lepomis macrochirus*). Fobian (2007) compared potential fish hosts for populations of the Rabbitsfoot from the Spring, Black, and Little Rivers in Arkansas, Kansas, and Missouri, and found Blacktail Shiner, Red Shiner (*Cyprinella lutrensis*), Bluntnose Shiner (*Cyprinella camura*), Spottfin Shiner (*Cyprinella spiloptera*), and Cardinal Shiner (*Luxilus cardinalis*) were suitable hosts for glochidia of all 3 populations of the Rabbitsfoot. Rosyface Shiner (*Notropis rubellus*), Striped Shiner (*Luxilus chrysocephalus*), and Emerald Shiner (*Notropis atherinoides*) also served as hosts for glochidia, but not in all populations tested (Fobian 2007). More recently, host fish trials have identified Scarlet Shiner (*Lythrurus fasciolaris*) and Striped Shiner as suitable hosts for glochidia collected from females in the Paint Rock River, Alabama (T. Fobian, Alabama Department of Conservation and Natural Resources [ADCNR], pers. comm., 2020).

Watters et al. (2009) confirmed transformation of glochidia collected from gravid female Rabbitsfoot on Rainbow Darter (*Etheostoma caeruleum*) and Striped Shiner. Yeager and Neves (1986) collected glochidia of the Rough Rabbitsfoot from the Clinch river, Virginia, and Powell River, Tennessee, and tested 34 species of fish as potential hosts. Only 3 species of Cyprinidae, Bigeye Chub (*Notropis amblops*), Spottfin Shiner, and Whitetail Shiner (*Cyprinella galactura*), served as suitable hosts for the glochidia. During the same project, Yeager and Saylor (1995) collected glochidia of the Cumberland Monkeyface from the Powell River, Tennessee, and identified two closely related cyprinids, Streamline Chub (*Erimystax dissimilis*), and Blotched Chub (*Erimystax insignis*), out of the 34 species of fish tested as suitable hosts for the glochidia. Fritts et al (2012) tested 90 fish species in 18 families as potential hosts for the Monkeyface (*Quadrula metanevra*) and found that 21 cyprinid species served as hosts for glochidia. These results demonstrate the ability of the *Quadrula metanevra* species group to utilize multiple cyprinids as fish hosts, which may enable the Rabbitsfoot to occupy a wide geographic range. However, more studies are needed to determine

suitable fish hosts across the range of the Rabbitsfoot and if hosts vary among populations.

**b. Abundance, population trends, demographic features, or demographic trends**

Most of the information contained in this section was initially presented in Butler (2005) as a compilation of published and unpublished data and museum records since the 1800s. The Service requested current information from biologists with various state and federal agencies, academia, museums, and other experts for use in the proposed listing rule and this status review. Methods used by biologists to conduct surveys vary temporally and spatially within and among populations. Most frequently, data are reported as number of live individuals, fresh dead specimens, and relict shells from mussel surveys where effort is not quantified and the Rabbitsfoot is not a focal species. Occasionally age is estimated and reproductive status of individuals is documented. Hence, we were not able to develop a standardized criteria with which to assess status of a population.

Neither Butler (2005) nor the proposed listing rule used a standardized spatial scale to define populations but rather used the available data for a given location to determine population status for the entire length of a river or creek; we retained that definition. For the purpose of this review, we considered a population extant if biologists reported live individuals or fresh dead specimens from the last 30 years, which represents approximately 3 generations. For populations where data were available to assess a trend, calculate a population or density estimate, infer recruitment or reproduction, etc. we used those data to categorize current status of extant populations as stable, improving, or declining. If we did not receive any new information about an extant population since publication of the proposed listing rule in 2012, we determined the current status of the population as unknown. We retained the status of extirpated as reported in Butler (2005; Appendix 3) unless biologists reported live individuals or fresh dead specimens since publication of the proposed listing rule. In those instances we changed current status to unknown. Ultimately, we relied on expert judgement of biologists working with a population to make the final determination regarding current status of a population.

Lower Great Lakes Sub-basin

The Great Lakes Basin represents the most zoogeographically (geographic distribution of an animal) distinct population center for the Rabbitsfoot (Butler 2005). Historically, biologists documented occurrence in 6 rivers and a feeder canal in this system (Call 1896*a, b*; 1900, Clark and Wilson 1912; Goodrich and van der Schalie 1944, Clark 1977). At the time of listing, Fish Creek was the only known remaining population (Appendix A).

*Fish Creek:* This 30-mile long river flows through northeastern Indiana and northwestern Ohio before converging with the St. Joseph River at Edgerton, Williams County, Ohio. Clark (1977) first reported collecting an unknown number of live specimens from Fish Creek, Williams County. From 1985–1986, Hoggarth (1986) collected 8 live and 10 fresh dead specimens from 4 sites in Williams County. Watters (1988) surveyed 19 sites located in DeKalb and Steuben counties, Indiana, and Williams County and reported 85 live and 7 fresh dead specimens from the lower most 10-mile reach of the creek, above its confluence with the St. Joseph River at Edgerton. In 1996 and 1999, (Watters 1996, 2000) resurveyed 5 of these sites and reported 2 live and 9 fresh dead specimens from 4 sites and 4 live and fresh dead specimens from 2 sites, respectively. Brady et al. (2005) sampled 64 mussel beds along a 24-mile reach of this creek in 2004 and recorded 1 live specimen at 2 different beds. They resurveyed these 2 beds in 2005 but did not locate any specimens. Ahlstedt (2009, 2010, 2011) reported 1 fresh dead specimen and 2 relict shells in 2009 and an unknown number of relict shells in 2010 and 2011 from Williams County. In 2012, EnviroScience, Inc. (2012) surveyed 4 sites in Williams County and reported 1 live specimen from a site on Fish Creek and 3 live specimens from a site at the confluence with the St. Joseph River at Edgerton. At the time of listing, biologists determined the status of this population as declining because it occurred in a <4-mile reach upstream from the confluence with the St. Joseph River at Edgerton, and comparison of data from several sites sampled in 1988, 1996, 2004, 2005, 2010, 2011, and 2012 indicated a decrease in records of occurrence (Table 1). We did not receive any new information about any of the Lower Great Lakes Sub-basin populations since publication of the proposed listing rule. The current status of this population is remains the same (Table 1).

#### Ohio River Basin

Historically, biologists documented occurrence of the Rabbitsfoot in 64 rivers located within this basin, 46% of the total populations in its range (Table 1). At the time of listing, biologists determined the status of 45 of these populations as extirpated, a 70% decline in occurrence (Table 1). Furthermore, biologists documented only 1 living or fresh dead specimen in 7 of the extant populations (Wabash, Eel, South Fork Kentucky, Barren, and Rough rivers and Big Darby Creek; reviewed in Butler 2005).

*Ohio River main stem:* Historically, biologists documented approximately 60 records of occurrence along the entire 981.0 river miles (RMs) of the main stem (Ortmann 1909, reviewed in Butler 2005). In 1967 and 1968, Williams (1969) surveyed 664 RMs between RMs 317.0 and 981.0 and did not locate any specimens. Williams and Schuster (1989) resurveyed this area in 1982 and reported 1 young specimen from a mussel bed just above Henderson, Henderson County, Kentucky. In 1994, Clarke (1995) reported an unknown number of live specimens from the Anderson Island mussel bed located between RMs 734.1 and 735.4, near Lewisport, Hancock County, Kentucky,

and 1 fresh dead specimen from the Owensboro North mussel bed located between RMs 759.3 and 763.2 near Owensboro, Davies County, Kentucky. In 1993, 1994, and 2006, biologists surveyed upstream of Tell City, Perry County, Indiana, near RM 726.0 and did not locate any specimens (Ecological Specialists Inc. [ESI], 1994, 2006).

At the time of listing, the largest populations in the Ohio River were located downstream of Lock and Dams 52 and 53 (Cummings and Mayer 1997). In 1993 and 1994, 1998, 1999, and 2001, biologists reported 1 live and fresh dead specimen, 8 live specimens, 6 live and 5 fresh dead specimens, and 5 live specimens, respectively from mostly below Lock and Dam 52 (RM 939.0) near Paducah, McCracken County, Kentucky (R. R. Cicerello Kentucky State Nature Preserves Commission [KNP], pers. comm., 2003). In 2002, biologists reported 8 live specimens of various age classes between RMs 949.0 and 949.3 near Fort Massac State Park, Massac County, Illinois, and 2 live specimens between RMs 969.5 and 970.0 in Pulaski County, Illinois, (J. E. Schwegman, Illinois Department of Natural Resources [IL DNR], retired, pers. comm., 2003). In 2005 and 2008, biologists surveyed some of the same sites in Massac and Pulaski counties and reported 1 live and fresh dead specimen and a relict shell (Illinois Natural History Survey [INHS] Museum Collection 2019, KNP Natural Heritage Database 2019). Because of high incidence of occurrence, evidence of recruitment, and lack of barriers to movement of fish hosts, biologists determined the status of this population as stable at the time of listing (Table 1).

Data collected since listing suggest this population remains stable. Fortenbery (2012*a, b*) surveyed between RMs 943.9 and 944.0, McCracken County, Kentucky, and between RMs 858.8 and 859.0 including a mussel placement site at RM 856.7, Union County, Kentucky, and did not record any specimens. Morgan (2015) and Morgan and Fortenbery (2015*a, b*; 2016*a, b*) surveyed between RMs 858.8 and 859.0, 928.3 and 928.9, 943.0 and 945.0, and at 929.0 in McCracken County, Kentucky, in 2015 and 2016 and did not locate any specimens. In 2015, biologists resurveyed the area from ESI (1994, 2006) and reported 1 live specimen with a relative abundance of 0.9% (ESI 2015). In 2015, biologists surveyed 2 sites in McCracken County and reported 2 live specimens, and 1 site in Perry County, Indiana, and reported 1 live specimen (KNP Natural Heritage Database 2019). Lewis Environmental Consulting, LLC (2015) delineated 7 of 49 known mussel beds described in Clarke (1995) and provided an updated species list. They reported 7 live specimens with a relative abundance of 0.02% and evidence of recruitment from a mussel bed located between RMs 724.7 and 726.3 upstream of Tell City, Perry County, Indiana, and 6 live specimens with a relative abundance of 0.07% and evidence of recruitment from a mussel bed located between RMs 733.9 and 735.7 near Lewisport, Hancock County, Kentucky. In 2018, Lewis Environmental Consulting, LLC (2018*a*) conducted a survey from RM 727.6

to 728.5 at Tell City, Perry County, Indiana, and reported 1 live specimen with a relative abundance of 0.06%, as well as evidence of recruitment.

*Allegheny River:* This 325-mile long river drains northwestern Pennsylvania and adjacent New York, before converging with the Monongahela River near Pittsburgh, Allegheny County, Pennsylvania, to form the Ohio River. Ortmann (1909, 1913) first reported records of occurrence for the Rabbitsfoot at 3 sites along this river from Armstrong County upstream to Warren County, Pennsylvania. From 1998–2001, biologists surveyed sites established as part of a bridge replacement at Kennerdell, Venango County, Pennsylvania, and reported from 1 to 3 specimens each year (Villemela and Smith 2002). Biologists surveyed 25 sites in the upper Allegheny River between Warren, Warren County, Pennsylvania, and Tionesta, Forest County, Pennsylvania, during 2001–2002 and reported 1 live specimen from Warren County, Pennsylvania (R. Villemela, U.S. Geological Survey [USGS], pers. comm., 2008). Villemela and Nelson (2006) surveyed from RM 53.2, below Tionesta to Kennerdell in 2005 and located an unknown number of specimens. In 2007, biologists surveyed 63 sites along 80 RMs and reported 6 specimens from 4 sites (R. Villemela, USGS, pers. comm., 2008). From 2006–2007, Smith and Meyer (2010) surveyed 5 sites in Armstrong County, Pennsylvania, and 1 site in Warren County, Pennsylvania, and did not locate any specimens. Because of decreasing records of occurrence and lack of evidence of recruitment, biologists determined the status of this population as declining at the time of listing (Table 1). In 2012 and 2013, biologists surveyed sites along the Allegheny River in Forest County but did not locate any specimens. We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*French Creek:* French Creek begins near Lowsville, Lewis County, New York, and flows for 117 miles through northwestern Pennsylvania to its confluence with the Allegheny River in Franklin County, Pennsylvania. Because no barriers to movement of fish hosts exist between them, biologists consider the lower Allegheny River and lower French Creek as a single population (Butler 2005).

Ortmann (1909) first reported specimens from French Creek in Venango, Crawford, Erie, and Mercer counties, Pennsylvania. Museum records dating from the 1970s occur from Crawford, Mercer, and Venango counties (reviewed Butler 2005). From 1985–1994, biologists collected specimens from 12 sites in Crawford County, Pennsylvania, and reported 1 fresh dead specimen in 1985, 2 fresh dead specimens in 1988, and 12 fresh dead specimens in 1991 (R. Evans, KNP, pers. comm., 2003). During the same time period, biologists collected specimens from 4 sites in Venango County

and reported 1 live specimen in 1987, 1 fresh dead specimen in 1989, 2 fresh dead specimens in 1991, and 2 live specimens in 1994 (R. Evans, KNP, pers. comm. 2003). From 1998–2001, biologists surveyed sites established as part of a bridge replacement over French Creek at Utica, Venango County, Pennsylvania, and reported 48 specimens in 1998, 62 in 1999, 60 in 2000, and 32 in 2001 (Vilarella and Smith 2002). Smith and Crabtree (2010) surveyed 29 sites in Erie, Crawford, Mercer, and Venango counties, Pennsylvania, in 2003 and reported 41 live specimens from 12 of them. In 2004, Smith and Crabtree (2010) resurveyed 10 of 29 sites surveyed in 2003 and reported 57 live and 7 fresh dead specimens from 7 of them and from 3 additional sites where they did not record any live specimens in 2003. They estimated abundance at the 7 sites as 43 to 372 individuals (SE = 30 to 123), density as 0.0001–0.0009 individuals/m<sup>2</sup> and reported the presence of several year classes and evidence of recruitment at 3 sites. Because of high records of occurrence, evidence of recruitment, and lack of barriers to fish host movement, biologists determined the status of this population as stable at the time of listing (Table 1).

Data collected since listing suggest this population remains stable. In 2013, EnviroScience (2017a) completed a mussel salvage and relocation project near Carlton, Mercer County, Pennsylvania. They conducted a post-construction survey of the area in 2017 and estimated abundance as 107 individuals/3,240 m<sup>2</sup> (SE = 53) and density as 0.033/m<sup>2</sup>. EnviroScience (2017b) conducted a survey adjacent to the former Norfolk Southern Meadville Yard, Meadville, Crawford County, Pennsylvania, and reported 4 live specimens with a relative abundance of 0.4%.

*LeBoeuf and Conneautee Creeks:* These creeks are tributaries of French Creek, Erie County, Pennsylvania. Biologists collected 1 relict shell from LeBoeuf Creek in 1991 (T. A. Smith, Service, 2006, pers. comm.). In 2006, biologists surveyed near the confluence of each creek with French Creek and reported 4 live and 4 weathered dead specimens from 5 sites on LeBoeuf Creek and 1 live specimen from 3 sites on Conneautee Creek. Biologists have not confirmed recruitment in either creek. Because no barriers to movement of fish hosts exist between them, some biologists consider these creeks and French Creek as a single population. At the time of listing, biologists determined the status of the Rabbitsfoot as unknown in these creeks due to few records of occurrence and no evidence of recruitment (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The status of this population remains unknown (Table 1).

*Muddy Creek:* Muddy Creek is a tributary of French Creek in Crawford County, Pennsylvania. Dennis (1971) surveyed 6 sites in western Pennsylvania and reported specimens from 2 of them near the confluence with French Creek. In 2003, Mohler et al. (2006) surveyed 20 sites along a 2-RM reach of this creek that flows through Erie National Wildlife Refuge (NWR)

in Crawford County, Pennsylvania, and collected 3 live specimens at 3 sites. Because of few records of occurrence and no evidence of recruitment, biologists determined the status of this population as declining at the time of listing (Table 1). We did not receive any new information about surveys conducted in this creek since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Shenango River:* This river begins in southeastern Crawford County, Pennsylvania, and flows due south for 75.0 RMs to its confluence with the Beaver River at New Castle, Lawrence County, Pennsylvania. Ortmann (1909, 1919) was the first to document the Rabbitsfoot in reaches of this river in Lawrence and Mercer counties, Pennsylvania. From 1968–1969, Bates (1970) surveyed 2 sites located in West Middlesex and Greenville Boroughs, Mercer County and did not locate any specimens. In 1983 and 1984, Bursey (1987) resurveyed sites previously surveyed by Bates (1970) and Ortmann (1919) and reported an unknown number of live specimens from 2 sites along the mainstem of the river in Mercer County. Butler (2005) reported the Rabbitsfoot extirpated from this river. In 2008, biologists surveyed a site at Sharpsville, Mercer County and did not locate any specimens. Nelson and Villela (2010) surveyed from Pymatuning Reservoir to Shenango River Lake in 2009 and reported 34 live specimens with a relative abundance of 0.01%. At the time of listing, biologists determined the status of this population as unknown (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The status of this population remains unknown (Table 1).

*Muskingum River:* The Muskingum River is a major tributary of the Ohio River. Bates (1970) and Stansbery and King (1983) surveyed 6 mussel beds in the lower Muskingum River from below Dam 5 (Luke Chute) to the confluence with the Ohio River and did not locate any specimens. In 1992, Watters and Dunn (1993–1994) resurveyed these 6 mussel beds and located the the first record from this river, a single subfossil valve. Biologists considered the Rabbitsfoot extirpated from this river until 2007 when they located 3 live specimens with evidence of recruitment near Dresden, Muskingum County, Ohio (EnviroScience 2009). At the time of listing, biologists determined the status of this population as declining (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Walhonding River:* This river begins in western Coshocton County, Ohio, at the confluence of the Mohican and Kokosing rivers, and then flows west approximately 23 miles where it converges with the Tuscarawas River, near Coshocton, Coshocton County, Ohio, to form the Muskingum River. Biologists first reported the Rabbitsfoot in this river in 1960 and collected  $\geq 38$  specimens including 12 live/fresh dead specimens in 1960, 8 in 1962, and 23

live and 16 fresh dead specimens in 1967 (The Ohio State Museum [OSUM] 2019). From 1991–1993, Hoggarth (1995–1996) surveyed 19 sites and reported 23 live specimens from 8 sites between RMs 23.3 and 11.1, 2 fresh dead specimens from 1 site, and 26 relict shells from 9 sites, with a relative abundance of 0.42%; two of the specimens were juveniles. In 2008, biologists surveyed 4 sites and reported 1 live specimen at C23 bridge crossing, Coshocton County (R. Alhstedt, USGS, pers. comm., 2009). In 2009, biologists conducted surveys near Six Mile Dam, Coshocton County and reported 5 live specimens from 4 sites upstream of the dam (EnviroScience 2010). Because of few records of occurrence and little evidence of recruitment, biologists determined the status of this population as declining at the time of listing (Table 1). Data collected since listing suggest this population may be improving (Table 1). In 2018 and 2019, biologists surveyed 4 sites near Six Mile Dam and reported 2 and 20 live specimens, respectively (Environmental Solutions and Innovations, Inc. 2019). Stantec Consulting Services, Inc. (2019) assessed habitat suitability at 4 sites in Coshocton County for relocation of mussel species from the Six Mile Dam removal project and reported 1 live specimen near the confluence with Killbuck Creek.

*Mohican River:* The Mohican River is a tributary of the Walhonding River located in north-central Ohio. At the time of listing, biologists considered this population extirpated (Table 1). Stantec Consulting Services, Inc. (2019) assessed habitat suitability at 3 sites in Coshocton County for relocation of mussel species from the Six Mile Dam removal project and reported 1 live specimen downstream of the TR-715 bridge approximately 200 meters upstream of the confluence with the Kokosing River. The current status of this population is unknown (Table 1).

*Olentangy River:* The Olentangy River is a tributary of the Scioto River located in north-central Ohio. At the time of listing, biologists considered this population extirpated (Table 1). In 2016, biologists conducting a survey in Delaware County, Ohio, located 1 live and 1 weathered specimen and 2 sets of subfossil valves (Stantec Consulting Services, Inc., 2016). The current status of this population is unknown (Table 1).

*Big Darby Creek:* This creek is a tributary of the Scioto River in central Ohio. The Ohio State University Museum houses 8 records collected by Stansbery (1972a, b) during the 1950s in Pickaway County, Ohio, 20 collected during the 1960s in Pickaway, Union, and Franklin counties, Ohio, and 5 collected during the 1970s from Pickaway and Franklin counties, Ohio. In 1962, Baby et al. (1966) collected 3 relict shells during an archeological survey of the O. C. Voss Mound, Big Darby Reservoir Area, Franklin County. D. G. Smith collected 16 live specimens in 1976 near Plain City, Union County (INHS Museum Collection, 2019). In 1983, a biologist reported 1 dead shell from Pickaway County (OSUM, 2019). Watters (1986) surveyed 35 sites between

RMs 0.0 and 80.0 and collected 5 weathered valves and 1 subfossil valve in Franklin and Pickaway counties. Watters (1990) resurveyed the same 35 sites as well as an additional 7 new sites and located 1 relict shell. In 1996, biologists recorded 1 dead specimen from Union County and 1 weathered specimen from Franklin County (Ohio Department of Natural Resources [OH DNR] Natural Heritage Database, 2019, OSUM, 2019). From 2000–2002, biologists reported 1 live and 1 fresh dead specimen, and 2 weathered valves from Pickaway Franklin, and Madison counties, Ohio, (OH DNR Natural Heritage Database, 2019, OSUM, 2019). At the time of listing, biologists considered the status of this population declining (Table 1). The Ohio State University Museum houses 1 weathered valve collected from Franklin County in 2015. The current status of this population is unknown (Table 1).

*Little Darby Creek:* This creek is the major tributary of Big Darby Creek and drains the western portion of the watershed. Stein (1965) reported the first records from Madison County, Ohio, in 1963. The Ohio State University Museum houses 5 records collected during the 1960s, including Stein (1965), from Madison and Union counties, Ohio, and 2 records collected during the 1970s from Madison County. Watters (1986) surveyed 16 sites between RMs 0.0 and 40.0 and collected 5 dead specimens in Madison County. Watters (1990) resurveyed the same sites as well as an additional 9 sites and reported 7 live specimens in Madison County. Biologists reported 2 dead specimens in 1987, 2 dead specimens in 1997, 26 living and 6 dead specimens in 1999, 8 live and 2 dead specimens in 2000, and 1 live specimen and 1 sub-fossil in 2006, all from Madison County (OH DNR Natural Heritage Database, 2019, OSUM, 2019). At the time of listing, biologists determined the status of this population as declining (Table 1). We did not receive any new information about surveys conducted in this creek since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*South Fork Kentucky River:* This river is 1 of 3 headwater tributaries of the Kentucky River in southeastern Kentucky that converge to form the latter near Beattyville, Lee County, Kentucky. In 1996, biologists collected a single weathered specimen in Owsley County, Kentucky (KNP Natural Heritage Database, 2019). In 1998, biologists located a single live specimen at the confluence with Indian Creek in Owsley County, Kentucky, and surveyed this site again in 2009, but did not locate any specimens (KNP Natural Heritage Database, 2019). In 2009, biologists reported 1 live specimen, approximately 20 years old, below the confluence of Buffalo Creek, north of Lida, Owsley County (KNP Natural Heritage Database, 2019). At the time of listing, biologists considered the status of this population as declining (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Green River:* This river is a major southern tributary of the lower Ohio River, in west-central Kentucky. The Ohio State University Museum houses 2 records collected in Green County, Kentucky, in 1908. From 1961–1967, Stansbery collected 1 live and 10 dead specimens near Horse Cave in Hart County, Kentucky (OSUM, 2019). In 1968, Williams (1969) surveyed from the Green-Taylor county line, Kentucky, to the mouth near Henderson, Henderson County, Kentucky, and reported 3 live specimens with a relative abundance of 0.24%. From 1984–1996, biologists surveyed 9 sites between Green River Lake Dam and Munfordville, Hart County, Kentucky, and reported 14 live, 2 fresh dead, and 4 weathered dry specimens (Cicerello 1999). Cicerello and Hannan (1990) surveyed 42 sites in Mammoth Cave National Park during 1988 and 1989 and reported only weathered specimens from 2 of the sites. From 1996 through 1998, Cicerello (1999) surveyed 38 sites from Green River Lake Dam to Mammoth Cave National Park and reported an unknown number of live and fresh dead specimens, including juveniles, with a relative abundance of 0.10%. From 2000 to time of listing, biologists reported at least 30 live and 50 fresh dead specimens, including juveniles, from 23 sites along this river in Green, Hart, and Taylor counties, Kentucky (KNP Natural Heritage Database 2019). In 2004 and 2009, biologists conducted surveys at Thomas Bend, Hart County and reported a relative abundance estimate of 0.29 and 0.25, respectively (McGregor et al. 2010). At the time of listing, biologists determined the status of this population as improving (Table 1) and Butler (2005) stated that the Green River probably contained the best remaining population of the Rabbitsfoot rangewide. Data collected since listing suggest this population is stable. In 2014 and 2015, biologists surveyed 10 sites along this river in Edmonson, Green, and Taylor counties and reported  $\geq 12$  live and 4 fresh dead specimens with no evidence of recruitment (KNP Natural Heritage Database, 2019).

*Nolin River:* The Nolin River is a 104-mile-long tributary of the Green River in central Kentucky. At the time of listing, biologists considered this population extirpated (Table 1). In 2013, biologists reported an unknown number of specimens from Hardin and Grayson counties, Kentucky (A. Boyer, Service, pers. comm., 2019). The current status of this population is unknown (Table 1).

*Barren River:* The largest tributary of the Green River, the Barren River flows in a northwesterly direction towards its confluence with the Green River in west-central Kentucky. Price (1900) collected the first specimen from this river in Warren County, Kentucky. In 1924, Ortmann (1926) reported an unknown number of specimens from Warren County. In 1927, Clench and van der Schalie (1944) surveyed 10 sites in Warren County and collected an unknown number of specimens from 2 of them. During 1988 and 1989, biologists surveyed 3 sites in Warren County and reported 4 weathered dry specimens (KNP Natural Heritage Database, 2019). From 1987–1995, biologists surveyed 7 sites in Warren, Allen, and Barren counties, Kentucky,

but only located 2 relict shells from 2 sites in Warren County and 1 from a site 1.5 miles downstream of the Barren River Reservoir Dam in Allen and Barren counties (INHS Museum Collection, 2019). In 1993, Gordon and Sherman (1995) surveyed 38 sites and reported 1 live specimen from an extreme eastern site in Warren County. In 2008, biologists surveyed 1 site in Warren County and reported 1 fresh dead specimen (KNP Natural Heritage Database 2019). At the time of listing, biologists determined the status of this population as declining (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Rough River:* This river is a major tributary of the Green River and flows westward towards its confluence in western Kentucky. Gordon (1991) surveyed between Caney Creek and Kentucky Highway 919 bridge, Ohio County, Kentucky, but did not locate any specimens. Gordon and Sherman (1995) surveyed 14 sites along this river in 1993 and collected 1 fresh dead specimen from the lower main stem in Ohio County. Madison and Layzer (1998) surveyed 5 sites along this river but did not locate any specimens. In 2012, biologists surveyed from Rough River Lake to the confluence with the Green River at Livermore, McLean, County, Kentucky, and reported 5 live specimens (Slack et al. 2012). At the time of listing, biologists determined the status of this population as declining (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Wabash River:* The largest northern tributary of the Ohio River, the Wabash River originates in west-central Ohio, flows across northern Indiana from east to west, and then turns south to form the boundary between southwestern Indiana and southeastern Illinois until its confluence with the Ohio River, 475 miles from its source. Say (1817) first described the Rabbitsfoot from the Wabash River and Call (1900) and Daniels (1903) considered this mussel species as common throughout it. In 1966 and 1967, Meyer (1974) reported 1 relict shell approximately 1 mile upstream of Hutsonville, Crawford County, Illinois. From 1987–1991, Cummings et al. (1992) surveyed 53 sites along the Wabash River and collected 1 live specimen in 1988 from Lafayette, Tippecanoe County, Indiana, and 64 relict shells at various sites in 12 counties across Illinois and Indiana. Frankland (1996) resurveyed 23 of the sites from Cummings et al. (1992) and reported 1 relict shell from Sullivan County, Indiana, and 2 from both Knox and Vigo counties, Indiana. In 2004, EnviroScience, Inc. (2005) surveyed 5 sites on the Wabash River in Tippecanoe, Carroll, and Cass counties, Indiana, and only reported relict shells from 2 sites. Fisher (2006) used data collected from 900 sites within the Wabash River drainage, Indiana, between 1995 and 2006 to assess status within the drainage and determined reproducing populations of the Rabbitsfoot historically found in the main stem of the Wabash River were

now restricted to its tributaries. From 2008–2012, biologists surveyed sites in Crawford, Lawrence, Vermilion, Wabash, and White counties, Illinois, and in Knox, Sullivan and Gibson counties, Indiana, and reported only relict shells (INHS Museum Collection, 2019, B. E. Fisher, Indiana Department of Natural Resources [IN DNR], pers. comm., 2019, B. Metzke, IL DNR, pers. comm., 2019). At the time of listing, biologists determined the status of this population as declining (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Eel River:* This river is a northern tributary of the Wabash River, which drains a portion of north-central Indiana. Daniels (1903) was the first to report the Rabbitsfoot from this river and considered it common throughout. The Ohio State University Museum houses a fresh dead specimen collected in 1970 from Wabash County, Indiana. In 1986, Henchsen (1987) surveyed 28 sites in Cass, Kosciusko, Miami, and Wabash counties, Indiana, and reported an unknown number of live and fresh dead specimens from 4 sites in Miami County and dead weathered specimens from most of the other sites. Biologists reported 1 weathered and 1 live specimen from Cass County in 2000 and 2002, respectively, and 1 weathered specimen from Miami County in 2002 (B. E. Fisher, IN DNR, pers. comm., 2019). From 2007–2012, biologists reported 10 live specimens from Cass County, 8 live specimens from Miami County, 1 live and 1 fresh dead specimen from Wabash County, and an unknown number of weathered specimens (B. E. Fisher, IN DNR, pers. comm., 2019). At the time of listing, biologists determined the status of this population as declining because they documented only 1 live adult specimen in <20 RMs of the lower main stem (Table 1). Data collected since listing suggest the status of this population remains the same. From 2013–2017, biologists reported 18 live, an unknown number of weathered dead specimens, and juveniles from several sites in Cass, Wabash, and Miami counties (B. E. Fisher, IN DNR, pers. comm., 2019). The occurrence in Wabash County represents a new record upstream of its known distribution in the watershed (B. E. Fisher, IN DNR, pers. comm., 2019).

*Tippecanoe River:* The largest tributary of the upper Wabash River system, the Tippecanoe River flows across north-central Indiana until its confluence with the Wabash River. Call (1900) and Daniels (1903) described the Rabbitsfoot as common throughout this river. In 1987, Cummings and Berlocher (1990) surveyed 16 sites in Lafayette, Carroll, White, Pulaski, Fulton, Marshall, and Kosciusko counties, Indiana, and reported 9 live specimens from 3 sites in Pulaski County with a relative abundance of 0.6%, and relict shells from 2 sites in Fulton County and 1 site each in Carroll and Tippecanoe counties. Ecological Specialists, Inc. (1993) surveyed 30 sites in 1991 and 1992 and reported 28 live specimens from 7 sites in Tippecanoe, Carroll, and Pulaski counties, relict shells from Tippecanoe, Pulaski, Fulton, and Kosciusko counties, and juveniles from a few sites. They determined a

relative abundance of 4.1% for the middle reach of the river and 1.9% for the lower reach. As part of a study to investigate the response of freshwater mussels to point-source pollution, ESI (1998) measured the length of 22 specimens from 10 sites along the middle reach of the river and estimated their ages as 3–20 years with shell lengths of 50.8–135.0 mm. They also reported presence of juveniles at some of the sites. Watters (2001) reported 9 live specimens from Carroll County. Ecological Specialists Inc. (2003) resurveyed 12 sites in Pulaski and White counties from Cummings et al. (1987) and ESI (1993) and reported 5 live specimens from 2 sites. In 2003, EnviroScience, Inc. (2005) reported 9 live specimens in Pulaski County, 4 during quantitative sampling consisting of 20 paired quadrat samples for a relative abundance of 2.45% and a density estimate of 0.08 individual/m<sup>2</sup> and 5 during quantitative sampling consisting of 120 quadrat samples for a relative abundance of 1.73% and a density estimate of 0.16 individual/m<sup>2</sup>. Length of 3 of the specimens ranged from 50.8–63.5 mm indicating recent recruitment into the population. From 2004–2011, biologists annually surveyed sites in Fulton, Pulaski, Tippecanoe, and White counties and reported from 1–13 live specimens and 1–7 fresh dead specimens (B. E. Fisher, IN DNR, pers. comm., 2019). Because the Rabbitsfoot consistently occurred with evidence of recruitment at highly disjunct sites along the lower two-thirds of this river (50 RMs) in Fulton, Pulaski, White, Carroll, and Tippecanoe counties, Indiana, biologists determined the status of this population as stable at the time of listing (Table 1). Data collected since listing suggests this population remains stable. In 2012 and 2013, biologists surveyed sites in Fulton, Pulaski, White, Carroll, and Tippecanoe counties and reported from 1–31 live specimens and an unknown number of fresh dead and weathered specimens at some sites. From 2014–2017, biologists reported 0–7 live specimens including juveniles throughout the Tippecanoe River from Fulton County in the upper reaches downstream through Tippecanoe County to its confluence with the Wabash River (B. E. Fisher, IN DNR, pers. comm., 2019).

*North Fork Vermilion River:* The headwaters of this river originate in Benton County, Indiana. From there this river flows west, southwest into eastern Illinois until its confluence with the Vermilion River in Danville, Illinois. One of three major tributaries of the Vermilion River, more records exist for the Rabbitsfoot in the North Fork Vermilion River than the rest of the Vermilion River system combined. However, biologists reported records from only 4 sites in an approximately 6-RM reach. Baker (1922) reported the Rabbitsfoot as rare in the Vermilion River drainage. In 1958, M. R. Matteson (unpublished 1956–1958 survey; INHS Museum Collection, 2019) reported 18 live specimens near Alvin and 6 live specimens near Bismark, Vermilion County, Illinois. Suloway et al. (1981) reported 4 live specimens in 1980 from the site near Bismark. Every 3 to 5 years between 1980–2008, researchers surveyed the same sites near Alvin and Bismark and reported 8 and 7 live specimens, with no evidence of recruitment (INHS Museum Collection, 2019). In 2011, biologists reported 14 adult specimens ranging in

length from 72.0–120.0 mm and in age from 8–18 years old (Stodala et al. 2013). At the time of listing, biologists determined the status of this population as declining because of reports of only live adult specimen and no evidence of recruitment (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Middle Branch North Fork Vermilion River:* A tributary of the North Fork Vermilion River, the headwaters of the Middle Branch North Fork Vermilion River drain northwestern Warren County, Indiana, and northeastern Vermilion County, Illinois. The Illinois Natural History Survey Museum houses the first record, a relict shell collected in 1998 from the lowermost reach of this river near Alvin, Vermilion County. In 2002, biologists reported 1 live specimen near Alvin (INHS Museum Collection, 2019). From 2011–2013, biologists reported 7, 3, and 7 live specimens, and 1 fresh dead specimen, respectively, and a relict shell near Alvin (INHS Museum Collection, 2019). Because no barriers to movement of fish hosts exist between them, biologists consider the Middle Branch North Fork Vermilion River population as part of the North Fork Vermilion River population (Butler 2005). Because of few records of occurrence and lack of evidence of recruitment, biologists determined the status of this population as declining at the time of listing (Table 1). Data collected since listing suggest this population has continued to decline. In 2014, biologists documented 1 live specimen near Bismark (INHS Museum Collection, 2019).

*Flatrock River:* Flatrock River is a tributary of the East Fork of the White River located in east-central Indiana. At the time of listing, biologists considered this population extirpated (Table 1). In 2012, biologists located 3 live specimens from Shelby County, Indiana (B. E. Fisher, IN DNR, pers. comm., 2019). The current status of this population is unknown.

#### Cumberland River Basin

Historically, the Cumberland River Basin was one of the most diverse in the world for freshwater mussel species with 85 reported from it to date, second only to the Tennessee River Basin with 94 (reviewed in Starnes and Bogan 1988). Biologists reported occurrence of the Rabbitsfoot in the main stem and 12 tributaries (Table 1) with most of the records dated prior to 1950. From 1977–1979, Parmalee et al. (1980) examined piles of mussel shells taken by commercial shellers from 3 mussel beds located near Rome, Smith County, Tennessee, and identified shells of the Rabbitsfoot. In September 1979, they surveyed the same 3 mussel beds but did not locate any specimens. At the time of listing, biologists determined the status of the main stem and 10 tributaries as extirpated (Cicerello et al. 1991, Layzer and Anderson 1992, Layzer et al. 1993, Schmidt et al. 1989), an 85% decline in occurrence (Table 1). Biologists attributed changes in distribution and abundance of mussels in the Cumberland River Basin to alteration of flow regime due to construction

of impoundments, 5 dams on the mainstem and 6 on major tributaries, and land use practices like mining and agriculture (Layzer et al. 1993). Currently, the East Fork Stones and Red rivers are the only tributaries with extant populations.

*East Fork Stones River:* The East and West Fork Stones rivers are 2 major headwater tributaries, which converge to form the Stones River in Rutherford County, Tennessee. From 1964–1967, researchers from the OSUM and Tennessee Valley Authority (TVA) surveyed numerous pre-impoundment sites and reported  $\leq 3$  specimens from 2 sites (reviewed Butler 2005). Schmidt et al. (1989) surveyed 23 sites from 1980–1981 and reported the Rabbitsfoot from two of the sites. Ahlstedt (2002) surveyed 2 sites in Rutherford County to evaluate this river for future mussel restoration efforts and reported 1 fresh dead specimen. At the time of listing, biologists determined the status of this population as declining (Table 1). In 2014, the Tennessee Wildlife Resources Agency (TWRA), along with the help of partners removed Browns Mill Dam, a low head dam located near Murfreesboro, Rutherford County, from the East Fork Stones River (D. W. Hubbs, TWRA, pers. comm. 2019). Biologists from TWRA conducted pre- and post-surveys at the site but did not locate any specimens (D. W. Hubbs, TWRA, pers. comm. 2019). The current status of this population is unknown.

*Red River:* A large tributary of the lower Cumberland River, the Red River drains southwestern Kentucky and northwestern Tennessee. Despite its size, biologists have never conducted a thorough survey of the river. The Ohio State University Museum houses 4 records collected in Logan County, Kentucky, and Robertson County, Tennessee, during surveys conducted in the 1960s, 1970s, and 1980s (OSUM database 2019). In 1981, Hatcher and Ahlstedt (1982) surveyed 4 sites in Robertson County and did not locate any specimens. In 1988 and 1990, biologists reported 13 live and 4 fresh dead specimens from  $\geq 6$  different sites in Logan County (INHS Museum Collection, 2019, KNP Natural Heritage Database 2019). In 1990 and 1992, Aquatic Resources Center (1993) surveyed a reach of the main stem of the Red River in Robertson County and reported 3 and 1 live specimen(s), respectively, and no evidence of recruitment. Because of reports of few live specimens and no evidence of recruitment, at the time of listing biologists determined status of this population as declining (Table 1). Biologists have not surveyed the Red River since time of listing (D. W. Hubbs, TWRA, pers. comm. 2019). The current status of this population is unknown.

#### Tennessee River Basin

Historically, biologists documented occurrence of the Rabbitsfoot from the entire length of the Tennessee River and 17 of its tributaries. By 1971, the TVA had impounded over 2,300 RMs behind 9 dams on the main stem of the Tennessee River and other dams on the Holston, Little Tennessee, Clinch, Elk, and Duck rivers, and Bear Creek destroying hundreds of miles of riverine

habitat for the Rabbitsfoot and other freshwater mussel species (TVA 1971). At the time of listing, biologists determined the status of 14 populations in this river basin as extirpated, a 74% decline in occurrence, with extant populations remaining in the Tennessee, Duck, Paint Rock, and Elk rivers, and Bear Creek (Table 1).

*Tennessee River main stem:* The Tennessee River is the largest tributary of the Ohio River and originates with the confluence of the Holston and French Broad rivers near Knoxville, Tennessee. It flows southwest to Guntersville, Alabama, where it turns northwest and flows across northern Alabama. Below Muscle Shoals, Alabama, this river flows directly north through western Tennessee to Paducah, Kentucky, where it enters the Ohio River. During the 20<sup>th</sup> century, biologist reported the most diverse unionoid mussel fauna ever known, 69 species, from the middle reaches of the Tennessee River in northern Alabama, in an area called Muscle Shoals (Garner and McGregor 2001). Ortmann (1918, 1925) reported specimens from the Tennessee River and some of its larger tributaries. Van der Schalie (1939) reported an unknown number of specimens from collections made by Dr. M. M. Ellis, who surveyed the lower Tennessee River in 1931. Morrison (1942) collected specimens during an archeological survey of 7 shell mounds in the Pickwick Landing Basin in Colbert and Lauderdale counties, Alabama. Biologists conducting surveys along the mainstem of the river from 1956–1999 reported that they did not locate any specimens (reviewed in Garner and McGregor 2001). At the time of listing, the only extant populations occurred downstream of RM 206.7 (Pickwick Landing Dam), Hardin County, Tennessee, and RM 22.4 (Kentucky Lake Dam), Livingston and Marshall counties, Kentucky, which collectively comprise <25 RMs (D. W. Hubbs, TWRA, pers. comm. 2008). At the time of listing, biologists determined their status as stable (Table 1).

In 1991, biologists reported >20 live specimens from the Pickwick Lake tail waters (J.T. Garner, ADCNR, pers. comm., 2003). Biologists reported 2 live specimens at RM 196.8 (Diamond Island), Hardin County, Tennessee, and at RM 200.0 in 1998 and evidence of recruitment from the same general reach of the river in 2003 (D.W. Hubbs, TWRA, pers. comm., 2003). From 1993–2000, biologists reported an unknown number of live and fresh dead specimens near Diamond Island (J.B. Layzer Tennessee Tech University, pers. comm., 2005). Biologists reported evidence of recruitment from these areas in 2008 and 2009 (D. W. Hubbs, TWRA, pers. comm. 2008, 2009). Data collected since listing suggest the population downstream of Pickwick Landing Dam remains stable. In 2014 and 2015, Hubbs (2015a) conducted surveys between RMs 190.0 and 192.0 (Wolf Island) and RM 197.0 (Diamond Island) and reported 2 and 3 live specimens for a relative abundance of 0.04% and 0.06%, respectively. In 2016 and 2017, Hubbs and Hua (2017) conducted surveys between RMs 190.0 and 193.0 (Wolf Island) and RMs 195.0 and 200.0 (Diamond Island) and reported 1 live specimen for a relative abundance

of 0.03% from Diamond Island but did not record any specimens from Wolf Island. Lewis Environmental Consulting (2017) reported 2 live specimens with evidence of recruitment near Wolf Island in 2017.

From 1985–2005, biologists reported 4 to 10 live specimens every 2 to 3 years from several sites located downstream of Kentucky Lake Dam (Butler 2005). In 1999, biologists reported evidence of recruitment from RM 17.5 (J.E. Schwegman, IL DNR retired, pers. comm., 2003). In 2011, biologists reported >80 live specimens from below Kentucky Lake Dam to the confluence with the Ohio River near Paducah, McCracken County, Kentucky. Fortenbery (2012c) and Morgan and Fortenbery (2013) surveyed from RM 11.1 to 12.0 and 12.5 to 13.5 and reported 26 and 83 live specimens, respectively, and evidence of recruitment from both reaches in 2012 and 2013. Data collected since listing suggest the population downstream of Kentucky Lake Dam remains stable. In 2017, Lewis Environmental Consulting, LLC (2017) conducted a survey between RMs 20.0 and 20.7, Livingston County, Kentucky, and collected 3 specimens for a relative abundance of 0.05% and with evidence of recruitment. As part of a mussel salvage project in Livingston County, Lewis Environmental Consulting, LLC (2018b, c) collected 42 live and 2 fresh dead specimens between RMs 17.5 and 18.4, and 1 live specimen between RMs 19.4 and 19.8 for a relative abundance of 0.01%. This population is likely contiguous with the population in the lower Ohio River, although it appears to be concentrated between RMs 16.0 and 32.0 (Butler 2005).

*Paint Rock River:* This river is a northern tributary of the Tennessee River in northeastern Alabama and adjacent Tennessee. Historically, the main stem of the Paint Rock River and its 3 headwater tributaries, Estill and Larkin Forks and Hurricane Creek, comprised a metapopulation. Ortmann (1925) reported the Rabbitsfoot from 3 of 6 sites surveyed along the main stem. From 1965–1967, Isom and Yokley (1973) surveyed 5 sites along the main stem and collected specimens from 3 of them. In 1980, Ahlstedt (1991) conducted the first comprehensive survey of the main stem and 3 tributary sites and reported only 2 live specimens from the middle reaches of the main stem. Ahlstedt (1995–1996) surveyed 18 sites in 1991 and collected 35 specimens from 8 sites. McGregor and Shelton (1995) surveyed 1 site and collected 3 fresh dead specimens and 9 relict shells. Godwin (2002) reported 1 live specimen from the main stem for a relative abundance of 0.29%. In 2004, biologists reported 2 live and an unknown number of fresh dead specimens at a site on the lower main stem (P. Freeman, The Nature Conservancy, pers. comm., 2004). In 2008, Fobian et al. (2014) surveyed 42 sites between RMs 5.0 and 60.0 and reported 218 live specimens from 18 sites for an overall relative abundance of 12.0% and mean relative abundance of 4.2% per site and observed evidence of recruitment. Based on these results, biologists determined the status of this population as improving at the time of listing (Table 1). Data collected since listing suggest this population continues to

improve. In 2013, Buntin et al. (2019) established and conducted surveys at 4 sites along the main stem and 1 site on the Estill Fork and resurveyed the sites in 2018. They did not record any specimens from the Estill Fork site either year but reported 2 and 1 live specimen(s) from RM 21.2, 9 and 17 live specimens from RM 33.3, and 0 and 1 live specimen from RM 56.7 for a density estimate of 0.05 individuals/m<sup>2</sup>, in 2013 and 2018, respectively, and 1 live specimen from RM 50.7 in both years.

*Elk River:* A northern tributary of the Tennessee River, the Elk River drains portions of south-central Tennessee and north-central Alabama. The Illinois Natural History Survey Museum houses the first verified record of occurrence collected in 1892 from Lincoln County, Tennessee. Ortmann (1925) reported no records of occurrence for the Elk River. From 1965–1967, Isom et al. (1973) resurveyed the stations from Ortmann (1925) as well as other parts of the Elk River and reported specimens from 3 of 9 sites but did not record numbers of individuals. Ahlstedt (1983) surveyed 108 sites in 1980 between RMs 28.0, Limestone County, Alabama, and 200.0, Grundy County, Tennessee, and reported 10 live specimens from 6 sites in Lincoln County, Tennessee. In 1999, biologists surveyed from RM 37.0 to RM 77.0, Giles and Lincoln counties, Tennessee, respectively, and reported 2 specimens from RM 76.0 (Service 1999). Ahlstedt et al. (2005) surveyed 5 sites in Lincoln County and reported 3 live specimens. In 2008, biologists resurveyed these 5 sites and 1 additional site and reported 1 fresh dead specimen at 1 site and 2 live specimens at a second site for a relative abundance of 0.4% (C. Howard, TVA, pers. comm., 2012). Because of few records of occurrence and lack of evidence of recruitment, biologists determined the status of this population as declining at the time of listing (Table 1). In 2012 and 2018, biologists resurveyed the 6 sites from 2008 and reported 2 live and 1 fresh dead specimen and 1 fresh dead specimen, respectively. Since the TVA altered tail water releases from Tims Ford Dam in 2008 to reduce severity of flow fluctuations and increase water temperatures to provide more ecologically suitable conditions for imperiled aquatic species downstream of the dam, biologists have observed evidence of recruitment for the Rabbitsfoot and determined the status of this population as stable (T. Amacker, TVA, pers. comm., 2020; Table 1).

*Bear Creek:* Bear Creek is a southern tributary of the Tennessee River primarily located in northwestern Alabama with approximately 25 miles flowing through Tishomingo County, Mississippi. Ortmann (1925) first reported an unknown number of specimens from Burleson, Franklin County, Alabama. In 1965, Isom and Yokley (1968a) surveyed 2 sites along this creek and did not record any specimens. In 1977, biologists reported 3 live specimens near RM 56.0, Franklin County, Alabama (Butler 2005). From 1996 to 2001, McGregor and Garner (2004) surveyed 40 sites and reported an unknown number of live and fresh dead specimens from RM 39.5 and 41.0 near the Natchez Trace Parkway of the National Park Service (NPS) in

Colbert County, Alabama. In 2002 and 2005, biologists reported 1 live and 8 fresh dead specimens from Tishomingo County (Butler 2005). In 2012, biologists surveyed 4 sites in Colbert County and reported 1 live specimen and a weathered dead specimen. Because of few records of occurrence and lack of evidence of recruitment, biologists determined the status of this population as declining at the time of listing (Table 1). Data collected since listing suggest this population may be improving. In 2018, biologists conducted surveys in Colbert County and reported 3 live individuals for a relative abundance of 5.8%. In 2019, biologists reported 10 live specimens from 3 sites in Colbert County with evidence of reproduction as shell lengths ranged from 47–90 mm (T. Amacker, TVA, pers. comm., 2020).

*Duck River:* The Duck River is formed at 3 springs near Hoodoo, Coffee County, Tennessee, and flows in a westerly direction approximately 309 RMs where it joins the Tennessee River, Humphreys County, Tennessee. Hinkley and Marsh (1885) first reported the Rabbitsfoot from the Duck River in 1884 while sampling a site near Columbia, Maury County, Tennessee. From 1921–1923, Ortmann (1924) surveyed 11 sites and reported an unknown number of live and fresh dead specimens near Ben and Columbia, Maury County, and near Lillard’s Mill and Wilhoite, Marshall County, Tennessee. Van der Schalie (1939, 1973) surveyed 5 sites in 1931 and again in 1972 and reported an unknown number of specimens from 3 of them in Marshall and Maury counties. In 1965, Isom and Yokely (1968b) resurveyed the sites from Ortmann (1924) and 2 additional sites. They found an unknown number of specimens at 3 sites where Ortmann did not report the Rabbitsfoot. Ahlstedt (1981, 1991) surveyed 18 sites in 1976 and 1978 and 99 sites in 1999 and reported an unknown number of specimens from 2 sites and 23 live specimens from 11 sites, respectively. In 1981, Barr et al. (1993–94) reported a density of 0.0002 individuals/m<sup>2</sup> and estimated that 591 live specimens occurred at Lillard’s Mill. In 1988, Layzer and Gordon (1993) collected 20 specimens from Lillard’s Mill and translocated them to a site in Bedford County, Tennessee. Hubbs (1993) collected live specimens from RM 37.0 and 38.0, Hickman County, Tennessee, which extended the range of the Rabbitsfoot in the lower Duck River. Schilling and Williams (2002) surveyed 11 sites in Hickman and Humphreys counties, Tennessee, and reported an unknown number of specimens from 4 sites. In 2002, Ahlstedt et al. (2017) surveyed 112 sites and reported 1–83 live specimens from 34 of the sites and observed evidence of recruitment at the Lillard’s Mill site where Layzer and Gordon (1993) translocated specimens in 1993. In 2010, Hubbs et al. (2011) surveyed 6 sites in Bedford and Hickman counties and reported 23 live specimens from 4 of them. Because of consistent records of occurrence and evidence of recruitment, biologists determined the status of this population as improving at the time of listing (Table 1). According to Ahlstedt et al. (2017), the population of the Rabbitsfoot in the Duck River is one of the most well-studied populations rangewide with many of the same sites surveyed over multiple years. Data collected since listing suggest this population continues

to improve. In 2014 and 2015, Hubbs (2015b) surveyed 7 sites between RMs 0.0 and 24.0 in Humphreys County and reported 2 live specimens from 2 of the sites, with a relative abundance of 2.38% and 0.10%, respectively. Hubbs (2015c) resurveyed sites from Hubbs et al. (2011) and reported 57 live specimens from 3 of 5 sites.

*Buffalo River:* The Buffalo River is the largest tributary of the Duck River and is in west-central Tennessee. The historical mussel fauna of the Buffalo River is documented in a few publications (Ortmann 1924, Isom and Yokley 1968b, van der Schalie 1973), none of which reported records for the Rabbitsfoot. In 1980, Ahlstedt (1991) surveyed 20 sites and did not locate any specimens. In 2002, Ahlstedt et al. (2017) conducted surveys at 5 sites previously surveyed by biologists but did not report any specimens. At the time of listing, biologists considered this population extirpated (Table 1). In 2012 and 2013, Reed et al (2019) conducted surveys at 47 sites along the Buffalo River and reported live specimens with evidence of recruitment from 3 sites including 6 live specimens from 5 quadrats at 1 site. The current status of this population is unknown (Table 1).

#### Lower Mississippi River Sub-basin

Historically, biologists documented occurrence of the Rabbitsfoot in 5 rivers of this system (Call 1895, Bogan 1990, Hartfield and Rummel 1985). At the time of listing, biologists determined the status of 2 populations as extirpated, a 40% decline in occurrence, with extant populations remaining in the St. Francis, Big Sunflower, and Big Black rivers (Table 1).

*St. Francis River:* The St. Francis River originates in southeastern Missouri and continues southward before joining the Mississippi River near Helena, Phillips County, Arkansas. Call (1895) was the first to report the Rabbitsfoot from the St. Francis River in Arkansas and considered it abundant. In 1941, the U. S. Army Corps of Engineers (USACE) completed construction of Wappapello Dam, Wayne County, Missouri, which impounds 28 miles of the main stem (Bo1 2001). Local drainage districts and the USACE further altered this river system by constructing a system of ditches and levees to drain adjacent agricultural land (Ahlstedt and Jenkinson 1991). In 1978, Bates and Dennis (1983) surveyed a 312-mile reach of the main stem in Arkansas and Missouri and did not locate any specimens. In the 1980's and 1990's, biologists conducted numerous surveys of the main stem, floodway, and ditches in Arkansas and only located relict shells (Clarke 1985, Ahlstedt and Jenkinson 1991, Jenkinson and Ahlstedt 1988, Posey 1997). Christian (2006) reported 3 live specimens in 2005 from Cane Island Slough Ditch near Lake City, Craighead County, Arkansas, which converges with Big Slough and ultimately flows into the old St. Francis River channel.

In 2002, Hutson and Barnhart (2004) surveyed 32 sites along the main stem and reported 16 live specimens from 3 sites located between RMs 218.0 and

172.1 in Wayne County, Missouri, for a relative abundance of 0.21%. Biologists had previously surveyed 28 of these sites at various times between 1965–1985. A comparison of data suggested the Rabbitsfoot may have been more abundant at those sites during past surveys relative to 2002, but sampling efforts varied among surveys. In 2005, 2006, and 2010, biologists reported 10, 6, and 103 live specimens, respectively, from sites along the same reach of river in Wayne County (S. E. McMurray, Missouri Department of Conservation, [MDC] mussel database, 2019). At the time of listing, biologists determined the status of this population as declining with most records of occurrence limited to a <20-mile reach of the main stem in Wayne County (Table 1). Data collected since listing suggest this portion of the population in Wayne County, Missouri, is stable. In 2014 and 2016, biologists reported 20 and an unknown number of live specimens, respectively, with evidence of recruitment both years from sites along this same reach of river (S. E. McMurray, MDC mussel database, 2019). However, the status of the overall population continues to decline (Table 1).

*Big Sunflower River:* A major tributary of the Yazoo River, the Big Sunflower River drains a large portion of the Mississippi Delta in west central Mississippi. Florida Museum of Natural History houses the first record of the Rabbitsfoot collected from this river by F. Thompson in 1969 near Indianola, Sunflower County, Mississippi. Biologists reported an unknown number of live and fresh dead specimens in 2010 from west of Blaine, Sunflower County, downstream to near the confluence with the Quiver River (R. L. Jones, Mississippi Department of Wildlife, Fisheries, and Parks [MS DWFP], pers. comm., 2011). At the time of listing, biologists determined status of this population as declining (Table 1). Data collected since listing suggest the current status of this population remains the same. From 2014–2017, biologists surveyed sites near Indianola and reported 19 live and 40 fresh dead specimens with evidence of recruitment from 5 sites.

*Big Black River:* The Big Black River is a tributary to the lower Mississippi River that drains central and southwestern Mississippi. Hartfield and Rummel (1985) were the first to report the Rabbitsfoot from this river in 1981. They recorded 19 dead specimens from 9 sites along a 15-mile reach of the river in Hinds and Warren counties, Mississippi. A biologist reported the only other record, a fresh dead specimen, for this river in 2000 (R. L. Jones, MS DWFP, pers. comm., 2011). At the time of listing, biologists determined the status of this population as declining (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule as channel degradation continues to severely impact access to this reach of the river (P. D. Hartfield, Service, pers. comm., 2019). The current status of this population is unknown (Table 1).

### White River Basin

Historically, biologists documented occurrence of the Rabbitsfoot throughout much of the main stem and in 11 tributaries (Table 1). At the time of listing, 9 of 12 populations were extant, although biologists determined the status of 5 (56%) as declining (Table 1). When the Rabbitsfoot was listed, the White River Basin had more sizeable populations than any other river basin (Butler 2005). Biologists once categorized the main stem and tributaries as a metapopulation, and prior to listing, believed that the Black, Spring, and Strawberry rivers may still constitute one (Butler 2005).

*White River main stem:* A large western tributary of the Mississippi River, the White River originates in the Ozark Plateaus in northwestern Arkansas, flows northeasterly into south-central Missouri, then southeasterly back into Arkansas with the last 260 miles flowing through the Mississippi Alluvial Valley, a former course of the Mississippi River (Gordon et al. 1980). The Academy of Natural Sciences houses the first records of the Rabbitsfoot collected from the main stem by C. B. Moore in 1908, near Saint Charles, Arkansas County, Arkansas. In 1951, the Service surveyed 34 mussel beds between Jacksonport, Jackson County, Arkansas, and Des Arc, Prairie County, Arkansas, and collected 87 live specimens for a relative abundance of 4.6%. From the late 1940s through the mid-1960s, the USACE constructed 5 dams and 4 reservoirs along the upper portion of the river. In 1981, Gordon (1982) surveyed 13 sites located from above Lake Sequoyah, in Washington and Madison counties, Arkansas, to St. Charles and reported an unknown number of live specimens from Newport, Jackson County, and St. Charles and large numbers of relict shells from Cotter, Baxter County, Arkansas. He concluded that utilization of hypolimnetic release at the reservoirs had rendered half the main stem of the river as unsuitable for most mussel species with recovery of populations occurring near Batesville, Independence County, Arkansas. Bates and Dennis (1983) surveyed 25 sites from the confluence with the Black River, Jackson County, Arkansas, downstream almost to the confluence with the Mississippi River, Desha County, Arkansas, and reported an unknown number of live specimens from 2 of the sites and relict specimens from 3 others. They concluded that channel maintenance for navigation had destroyed most suitable mussel habitat and that an aggregate of approximately 50 miles in the reach of the river between Arkansas-Post Canal, Arkansas County, Arkansas and Newport potentially remained suitable to produce mussels. In 1992, Christian (1995) evaluated the status of 110 historical mussel beds of the lower White River from the confluence with the Black River downstream to the confluence with the Arkansas Post Canal. He reported 1 live specimen from 4 sites in the middle portion of the river and 9 live specimens from 7 sites in the lower portion of the river and used data from the lower 6 mussel beds to calculate a population estimate of 928 individuals for them. In 1999, Harris and Christian (2000) resurveyed a portion of the mussel beds from U. S. Fish and Wildlife Service (1951) and

Christian (1995) and reported 5 live specimens for a relative abundance of 0.1%.

At the time of listing, biologists determined the status of this population as stable (Table 1). It was restricted to 2 disjunct reaches of the lower portion of the river separated by approximately 100 RMs (Arkansas Game and Fish Commission [AGFC] mussel database 2011). The uppermost reach extended from Batesville Dam at Batesville downstream to the confluence with the Little Red River north of Georgetown, White and Woodruff counties, Arkansas. The lowermost reach extended from U. S. Highway 79 at Clarendon, Monroe County, Arkansas, downstream to Arkansas Highway 1 near St. Charles (AGFC mussel database 2011). Bouldin et al. (2013a) surveyed 12 sites along 14.7 RMs from Washington County Road 183, Durham downstream to Arkansas Highway 45 (excluding Lake Sequoyah), Washington County, Arkansas, and did not locate any specimens. The current status of this population is unknown (Table 1).

*War Eagle Creek:* This small creek is an eastern tributary of the upper White River in northwest Arkansas. The Ohio State University Museum houses the first record collected in 1974, near Huntsville, Madison County, Arkansas (OSUM database 2019). In 1981, biologists collected 1 live specimen and in 2004 reported 2 fresh dead specimens near Huntsville (AGFC mussel database 2011). At the time of listing, biologists determined the status of this population as unknown (Table 1). Data collected since listing suggest this population may be improving. Bouldin et al. (2013a) surveyed 17 sites along 42.2 RMs from Arkansas Highway 23 at Withrow Springs State Park, Madison County, Arkansas, downstream to Benton County Road 9 at War Eagle Mill, Benton County, Arkansas, and reported 76 live specimens for a relative abundance of 2.8% and ranging in length from 84.6–139.2 mm.

*Buffalo River:* A western tributary of the upper White River, the Buffalo River originates in the Boston Mountains, Newton County, Arkansas, and flows in an easterly direction to its confluence with the White River south of Mountain Home, Baxter County, Arkansas. In 1910, Meek and Clark (1912) recorded the location and relative species composition of mussel beds from 26 stations located along the entire length of the river from Pruitt, Newton County, Arkansas, downstream to the confluence with the White River, Searcy and Marion counties, Arkansas. They collected 59 specimens from 11 of the stations located in the lower 25 RMs, Searcy County, Arkansas. Harris (1996) resurveyed 16 stations from Meek and Clark (1912) in 1995 and reported 9 live specimens from 3 sites, with 6 specimens encountered at one of the sites, for a relative abundance of 0.7%. During 2004 and 2005, Matthews et al (2009) resurveyed 41 sites from Harris (1996) and reported 7 live specimens from 3 sites for a relative abundance of 0.2%. In 2008, biologists collected 4 live specimens near the confluence with Cedar Creek near Rush, Marion County, Arkansas (S. W. Hodges, NPS, pers. comm.,

2011). Flooding in 2009 and 2011 changed the geomorphology of the channel, which covered this entire site with sand. Biologists resurveyed it in 2011 and reported 1 live specimen. They relocated the specimen to more suitable habitat downstream where they encountered 2 fresh dead specimens and 23 relicts. In 2011, biologists also collected 2 live specimens from 2 sites located between Arkansas Highway 7, Newton County, Arkansas, and U.S. Highway 65, Searcy County, Arkansas (C. L. Davidson, Service, 2011, pers. comm.). At the time of listing, biologists determined the status of this population as declining (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Black River:* The Black River is the largest tributary of the White River. It drains much of southeastern Missouri and northeastern Arkansas before flowing south to its confluence with the White River near Newport, Jackson County, Arkansas. In 1973, Oesch (1984) collected 2 live specimens in the reach from Markham Spring, Wayne County, Missouri, to Hendrickson, Butler County, Missouri. Biologists reported 100 live and fresh dead specimens and 43 live specimens from a site below the confluence with the Spring River, Lawrence County, Arkansas, in 1978 and 1980, respectively (OSUM database, 2019). In 1981 and 1982, Buchanan (1996) surveyed 17 sites in Butler and Wayne counties and did not locate any specimens. Bates and Dennis (1983) surveyed an approximately 95-mile reach from near Newport, upstream to Pocahontas, Randolph County, Arkansas in 1982 and reported an unknown number of live specimens from 2 of 7 sites located in Lawrence County. Gordon et al. (1984) surveyed 11 sites along a 28-mile reach from 6 miles above Pocahontas to Black Rock, Lawrence County, Arkansas, in 1983 and reported an unknown number of live specimens. In 1985, Miller and Hartfield (1986) surveyed 44 sites in Lawrence and Randolph counties and reported 55 live specimens for a relative abundance of 8.8% from 4 sites near the Lawrence-Randolph county line and 5 live specimens from 2 sites for a mean density of 0.005 individuals/m<sup>2</sup>. The Rabbitsfoot was 1 of the 5 most abundant mussel species among 23 species they collected from these sites. In 1991 and 1992, Rust (1993) surveyed 48 sites and reported 58 live specimens from 4 sites located between RMs 65.0 and 77.0 for a relative abundance of 0.3–5.1%. In 2003, Hutson and Barnhart (2004) surveyed 31 sites along this river in Butler and Wayne counties but did not locate any specimens. In 2005, AGFC collected 25 live specimens from a site located approximately 1 RM upstream of U.S. Highway 63 at Black Rock (AGFC mussel database 2011). At the time of listing, biologists considered the Black River population one of the largest remaining rangewide and determined its status as declining (Butler 2005, Table 1). Data collected since listing suggest this population continues to persist. In 2014, Harris (2014) surveyed a mussel bed located 4 RMs downstream of Pocahontas and reported 8 live specimens from 1 site for a relative abundance of 2.1% and no evidence of recruitment.

*Current River:* A major headwater tributary of the Black River, the Current River originates in southeastern Missouri and flows into the Black River near Pochontas, Randolph County, Arkansas. In 1981 and 1982, Buchanan (1996) surveyed 22 sites and reported 5 live specimens from a site located 3 miles west of Success, Clay County Arkansas, and 1 live specimen from a site located 8 miles south of Doniphan, Ripley County, Missouri, for a relative abundance of 0.3%. In 1983 and 1984, biologists reported 1 live and 1 fresh dead specimen from Randolph and Clay counties, respectively (ANHC mussel database 2018). At the time of listing, biologists determined the status of this population as declining (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Spring River:* The Spring River is a large tributary of the Black River that originates from an underground spring at Mammoth Spring, Fulton County, Arkansas, and drains south-central Missouri and northeastern Arkansas. In 1983, Gordon et al (1984) surveyed 14 sites from U. S. Highway 62 bridge at Imboden, Lawrence County, Arkansas, to the confluence with the Black River near Black Rock, Lawrence County, Arkansas, and reported 1 to 20 live specimens from 5 sites and an unknown number of relict shells from 7 sites. In 1985, Miller and Hartfield (1986) conducted surveys from Imboden to the confluence with the Eleven Point River, Lawrence County, Arkansas, but did not locate any specimens. In 1991, Rust (1993) surveyed 6 sites in Lawrence County, Arkansas, and reported 29 live specimens from 5 of the sites for a relative abundance of 1.9–4.0%. Harris et al. (2007) conducted surveys from near Ravenden to Imboden, Lawrence County, Arkansas, during 2004 and 2005 and reported 68 live specimens. In 2005, biologists surveyed 7 sites between Mammoth Spring and Hardy, Sharp County, Arkansas, and reported 54 live specimens from 6 of the sites (Trauth et al. 2007). Biologists reported 300 live specimens from 1 RM below the U. S. Highway 62 bridge at Imboden and 26 live specimens from a site in Fulton County, Arkansas, in 2005 and 2006, respectively (AGFC mussel database 2011). At the time of listing, biologists determined the status of this population as declining (Table 1). Data collected since listing suggest this population continues to persist. In 2018, biologists resurveyed mussel bed number 5 from Rust (1993), which extends from 1 RM downstream of Imboden to the confluence with Davis Creek, Lawrence County, Arkansas, and reported 12 live specimens for a relative abundance of 0.29% (J. L. Harris, Arkansas State University, pers. comm., 2019).

*South Fork Spring River:* A large tributary of the Spring River, the South Fork Spring River drains portions of Howell County, Missouri, and Fulton and Sharp counties, Arkansas. Biologists first reported the Rabbitsfoot from this river in 2002 from a site in central Fulton County, Arkansas (Harris et al. 2007). In 2003, biologists reported an unknown number of fresh dead

specimens and relict shells from a site near Salem in Fulton County (AGFC mussel database 2011). In 2006, biologists surveyed 35 sites located across Howell County, Missouri, and Fulton and Sharp counties, Arkansas, and did not locate any specimens but did report 1 live specimen from the river a week later (Martin et al. 2009). At the time of listing, biologists determined the status of this population as declining (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Strawberry River:* A western tributary of the Black River, the Strawberry River originates in Fulton County, Arkansas, and drains portions of northeastern Arkansas. Henry Robison first reported the Rabbitsfoot in 1976 from a site located in Lawrence County, Arkansas (AGFC mussel database 2011). In 1998, biologists collected the furthest upstream record of a live specimen; 1.8 RMs upstream of Hars Creek southeast of Franklin, Izard County, Arkansas (AGFC mussel database 2011). From 1983–2006, biologists collected 84 live specimens, including some juveniles, from 14 sites extending from the furthest upstream record downstream 50 RMs through Sharp and Lawrence counties, Arkansas (AGFC mussel database 2011). At the time of listing, biologists determined the status of this population as unknown (Table 1). Data collected since listing suggest this population may be improving (Table 1). Bouldin et al. (2013a) surveyed 17 sites along 3 reaches in Sharp County: (1) from the Simstown Spring AGFC Access downstream to Sharp County Road 91; (2) from Sharp County Road 31 downstream to Arkansas Highway 115 and; (3) from Arkansas Highway 25 downstream to the Riverview School AGFC Access for a total of 33.7 RMs. They reported 18 live specimens for a relative abundance of 1.3% and ranging in length from 62.1–115.1 mm providing some evidence of recruitment. In 2016, biologists surveyed 3 sites near the AGFC Simstown access in Sharp County and did not locate any specimens (Moles 2016) and 5 sites, 4 miles south of Smithville, Lawrence County, Arkansas, where they reported 5 live specimens (Harris 2016). Sanchez-Gonzalez (2018) surveyed 7 sites along a reach extending from Evening Shade, Sharp County, to Saffell, Lawrence County, Arkansas, and reported 47 individuals with evidence of recruitment for a relative abundance of 1.3–4.8% and a combined population estimate of 709 individuals.

*Middle Fork Little Red River:* The Middle Fork Little Red River is a headwater tributary of the Little Red River in north-central Arkansas. Harris (1992) first discovered the Rabbitsfoot in this river in 1991 while conducting surveys at 23 sites extending from the confluence with Meadow Creek, Stone County, to 2.5 miles downstream of Shirley, Van Buren County, Arkansas. In 2001, Winterringer (2003) surveyed 14 sites located from Arkansas Highway 65 bridge, Searcy County, Arkansas, to 2.5 miles downstream of Shirley and reported 27 live specimens with evidence of recruitment at a site downstream

of Shirley. In 2009, biologists reported 7 live specimens from 2 sites in the same reach of the river as Winterringer (2003) (AGFC mussel database 2011). At the time of listing, biologists determined the status of this population as stable (Table 1). In 2016, biologists surveyed 22 sites along the entire river and found 18 live specimens at 3 sites between Tick Creek and Greers Ferry Reservoir, Van Buren and Cleburne counties, Arkansas (C. L. Davidson, Service, pers. comm. 2020). The current status of this population is declining (Table 1).

#### Arkansas River Basin

In the Arkansas River Basin, the distribution of the Rabbitsfoot is restricted to tributaries that drain the western fringe of the Ozark Plateaus and adjacent Central Lowlands physiographic provinces located in east-central and southeastern Kansas, northeastern Oklahoma, extreme northwestern Arkansas, and extreme southwestern Missouri. Historically, biologists documented the Rabbitsfoot throughout hundreds of miles of rivers and creeks in the basin (Popenoe 1885, Call 1885*a, b*; Scammon 1906; Utterback 1915; Isely 1924). Scammon (1906) described the Rabbitsfoot as "seeming to be nowhere abundant, it is not a rare species in [the Spring, Neosho, and Verdigris rivers]." At the time of listing, biologists determined the status of 4 populations as extirpated, a 50% decline in occurrence, with extant populations confined to reaches of the Verdigris, Neosho, Spring, and Illinois rivers (Table 1).

*Neosho River:* This large tributary of the Arkansas River drains a significant portion of east-central and southeastern Kansas and northeastern Oklahoma. Historically, biologists documented occurrence of the Rabbitsfoot along most of the 460-RM long main stem. Popenoe (1885) collected an unknown number of specimens in the early 1880s near Burlington, Coffey County, Kansas. In 1911, Isely (1924) did not locate live specimens of any mussel species while conducting surveys along the lower portion of the river in Cherokee County, Kansas, and Wagner County, Oklahoma, but in 1912 reported live mussels including 2 Rabbitsfoot near Chetopa, Cherokee County, Kansas, and several shells of this species in a pile collected by shellers near Miami, Ottawa County, Oklahoma. Franzen and Leonard (1943) collected 2 valves near Oswego, Labette County, Kansas. During the 1970s, biologists reported only fresh dead and weathered specimens from Coffey, Woodson, Allen, Neosho, Labette, and Cherokee counties, Kansas (Liechti and Huggins 1977, Schuster and Dubois 1979, Cope 1979). From 1993–1995, Obermeyer et al. (1995) surveyed 19 sites along a 267-mile reach of the river from downstream of Council Grove Lake, Morris County, Kansas, to the Kansas-Oklahoma border and reported 2 live specimens from 2 sites along a 1.5-RM reach located between Iola and Humboldt, Allen County, Kansas, and an unknown number of relict shells from 9 additional sites. In 1999, Mulhern et al. (2002) reported a live juvenile immediately downstream from the Humboldt City Dam. This finding extended the known distribution of the

Rabbitsfoot in the Neosho River to 7.45 RMs and suggested presence of a small breeding population in Allen County, Kansas. Sherraden-Chance and Edds (2004) compared freshwater mussel assemblages in 19 sites of the old and 7 sites of the new channel in Neosho River, Neosho County, Kansas, and reported an unknown number of relict shells from the old channel. At the time of listing, biologists thought the Rabbitsfoot was extirpated from the Oklahoma portion of the river and determined the status of the population remaining in the Kansas portion of the river as declining (Table 1). Data collected since listing indicate that the current status of this population is unknown. In 2016 and 2017, biologists surveyed 6 sites extending from 12 RMs upstream and 1.5 RMs downstream of Miami, Ottawa County, Oklahoma, and did not locate any specimens (EcoAnalysts 2018).

*Spring River:* The Spring River is a tributary of the Neosho River that originates from numerous springs near Aurora, Lawrence County, Missouri, and flows westerly through southwest Missouri, south through southeast Kansas, and into northeast Oklahoma to its confluence with the Neosho River near Wyandette, Ottawa County, Oklahoma. Call (1885*a, b*) reported the Rabbitsfoot from the Spring River in Kansas in the 1880s. From 1961–1964, Branson (1966) surveyed 15 sites located across Kansas, Missouri, and Oklahoma and did not locate any specimens. In 1984, Cope (1985) resurveyed the 15 sites from Branson (1966) as well as an additional 22 sites and reported 3 live specimens from 2 sites in Cherokee County, Kansas. Mather (1990) surveyed 2 sites near Quapaw, Ottawa County, Oklahoma, and 1 site in Baxter Springs, Cherokee County, Kansas, but did not locate any specimens. From 1993–1995, Obermeyer et al. (1995) surveyed 3 sites in Cherokee County, Kansas, and reported 1 live specimen and an unknown number of relict shells. In 1995, Clarke and Obermeyer (1996) surveyed 11 sites from near Waco, Jasper County, Missouri, to near Verona, Lawrence County, Missouri, and reported 4 live specimens from the 3 most downstream sites. This finding extended the known distribution of the Rabbitsfoot in the Spring River upstream from the Kansas-Missouri state line to 2.5 miles from Neck City, Jasper County, Missouri. From 2003–2006, biologists surveyed a site near Neck City, 6 sites extending from Kansas-Missouri Highway YY to Baxter Springs, and 3 sites near Quapaw. They did not locate any specimens at the Oklahoma sites, but reported 2 live specimens from the Missouri site and 33 live specimens, including 5 gravid females, from the Kansas sites (Fobian 2007, Angelo et al. 2007, Miller 2011, S. McMurray, MDC, mussel database, 2019). At the time of listing, biologists considered the Rabbitsfoot confined to the portion of the Spring River extending from Missouri Highway 96 in Carthage, Jasper County, Missouri, downstream to the confluence of Turkey Creek north of Empire, Cherokee County, Kansas, and determined the status of the population as declining (Table 1). Data collected since listing indicate that the current status of this population remains the same. In 2016 and 2017, biologists surveyed 15 sites extending from 500 m downstream of the confluence with the North Fork Spring River, Jasper County, Missouri, to

7.45 miles upstream of the confluence with the Neosho River, Ottawa County, Oklahoma (EcoAnalysts 2018). They reported 2 live specimens from 2 sites in Missouri and 2 live specimens from 2 sites in Kansas.

*Illinois River:* This northern tributary of the Arkansas River drains portions of northwestern Arkansas and northeastern Oklahoma. Results of surveys conducted along the Illinois River suggest the Rabbitsfoot was never a common species. Isely (1924) surveyed a site east of Tahlequah, Cherokee County, Oklahoma, in 1911, but did not locate any specimens. In the 1970s, Gordon et al. (1979) surveyed 16 sites between Hogeys, Washington County, Arkansas, and Siloam Springs, Benton County, Arkansas, and reported a single shell. In 1989, Mather (1990) surveyed 12 sites extending from near Lake Frances, Adair County, Oklahoma, to near the confluence with the Arkansas River, Sequoyah County, Oklahoma. He did not locate any specimens of the Rabbitsfoot and remarked “Nowhere along the Illinois River were there ‘mussel beds’ where mussels of many species are concentrated in large numbers”. In 1994, Harris (1998) surveyed 22 sites along a 30-RM reach located in Washington and Benton counties, Arkansas, and reported 34 live specimens from 7 sites. Vaughn (1997a) surveyed 52 sites in Adair, Cherokee, and Delaware counties, Oklahoma, in 1995 and reported 5 live specimens from 2 sites in Cherokee County. In 2008, biologists surveyed 15 sites in Benton and Washington counties and reported 10 live specimens from 2 sites just upstream of Muddy Fork to the Arkansas Highway 59 Bridge (AGFC mussel data base 2011). At the time of listing, biologists considered the Rabbitsfoot confined to disjunct sites in Cherokee County, Oklahoma, and Benton and Washington counties, Arkansas, and determined the status of the population as declining (Table 1). Data collected since listing indicate that the current status of this population remains the same. In 2017, biologists surveyed 4 sites in this same reach and reported 8 live and 3 dead specimens from 1 site (C. L. Davidson, pers. comm. 2020).

*Verdigris River:* The Verdigris River is a tributary of the Arkansas River that originates in the Flint Hills in southeastern Kansas (upper Verdigris River) and flows south into Oklahoma (lower Verdigris River) where it joins the Arkansas River near Muskogee, Muskogee County, Oklahoma. In the 1880s, Call (1885a, b) reported the Rabbitsfoot from the Verdigris River near Neodesha, Wilson County, Kansas. Isely (1924) described the Oklahoma portion of this river as having among the richest mussel fauna in the state. In 1911, he surveyed along a 50-RM reach from Mingo Ferry, Wagoner County, Oklahoma, upstream to Catoosa, Rogers County, Oklahoma, and collected an unknown number of shells east of Catoosa and in 1912 1 live specimen at Coffeyville, Montgomery County, Kansas. In 1974, the USACE significantly altered the river by constructing Oologah Dam, Rogers County, Oklahoma, and dredging the lower reaches to create a navigation channel to the Arkansas River (USACE 2007). From 1972–1978, Schuster (1979) summarized mussel data collected at 13 sites located across Greenwood, Lyon, Montgomery,

Woodson, and Wilson counties, Kansas, and determined the status of the Rabbitsfoot as extirpated because it had not been collected since Call (1885a, b). In 1989, Mather (1990) surveyed 5 sites extending from 2 miles southeast of Coffeyville to below Oologah Lake, Rogers County, Oklahoma, and did not locate any specimens. From 1993 to 1995, Obermeyer et al. (1997a, b) surveyed 14 sites in Montgomery and Wilson counties, Kansas, and reported an unknown number of relict shells from 8 sites. They concurred with Schuster (1979) regarding the status of the Rabbitsfoot as extirpated in the Kansas portion of the river. In 1991, 1997, and 2003, Miller and Lynott (2006) resurveyed 8 sites from Cope (1983) located along an 8.2-RM reach in Montgomery and Wilson counties; neither study located any specimens. Vaughn (1998) surveyed 20 sites above Oologah Lake, Nowata County, Oklahoma, in 1996 and 12 sites below Oologah Lake, Rogers County, Oklahoma, in 1997, and reported only relict shells from 10 sites. In 2006, Boeckman and Bidwell (2008) resurveyed Vaughn (1998) and reported 41 live specimens from 3 sites downstream of Oologah Lake, below Highway 20 near Claremore, Rogers County, Oklahoma. At the time of listing, biologists considered the Rabbitsfoot extirpated from the Kansas portion of the river (upper Verdigris River) and from reaches upstream of Oologah Lake in Oklahoma, extant in a short reach from Oologah Dam north of Claremore downstream to Interstate 44 west of Catoosa, and determined the status of the population as unknown (Table 1). Data collected since listing indicate that the current status of this population remains unknown. In 2016 and 2017, biologists observed 33 live specimens, of which 19 were gravid and at least two specimens were <5 years of age, downstream of Verdigris Public use area below Oologah Dam (Barnhart 2017). In 2018, biologists resurveyed Barnhart (2017) and reported 13 brooding females (M. Fullerton, Oklahoma Department of Wildlife Conservation, pers. comm., 2020).

### Red River Basin

Populations of the Rabbitsfoot located in this basin represent the southwestern terminus of its range. Historically, biologists documented occurrence of the Rabbitsfoot in 11 rivers that drain the Ouachita Mountains in southeastern Oklahoma and southwestern Arkansas, as well as parts of southern Arkansas and northern Louisiana (Table 1). By the 1990s, the entire mussel fauna in the Blue River (Vaughn 1997b) and Mountain Fork Little River (Vaughn and Taylor 1999) were nearly decimated by impoundments constructed in the 1960s, pollution, or other factors. At the time of listing, biologists determined the status of 4 populations as extirpated, a 64% decline in occurrence, with extant populations remaining in the other 7 (Table 1).

*Little River:* The Little River is a 217-mile long northern tributary of the Red River that drains portions of southeastern Oklahoma and southwestern Arkansas. Three impoundments influence the Little River: (1) Pine Creek Reservoir, McCurtain County, Oklahoma; (2) Millwood Reservoir, Little River County, Arkansas; and (3) Broken Bow Reservoir, McCurtain County,

Oklahoma, on the Mountain Fork Little River, a tributary of the Little River (Vaughn and Taylor 1999). Isley (1924) first reported 1 live specimen from Little River in 1910 near Garvin, McCurtain County, Oklahoma. Ecosearch, Inc. (1987) surveyed 11 sites extending from near Idabel, McCurtain County, Oklahoma, to above Millwood Reservoir, but did not locate any specimens. During 1992 and 1993, Vaughn (1994) surveyed 11 sites from directly below Pine Creek Reservoir to the Highway 70 bridge north of Idabel and reported 20 live specimens from 4 sites and relict shells from 2 sites. In 1994, Vaughn et al. (1994) surveyed 14 sites from directly above Pine Creek Reservoir to 3 miles east of Honobia, Pushmataha County, Oklahoma, and reported 1 relict shell. Vaughn et al. (1995) surveyed 14 sites in 1994 on the Little River NWR (LRNWR), McCurtain County, Oklahoma, and 5 sites in Sevier County, Arkansas, and reported 1 live specimen from a site on the refuge and relict shells from 2 sites in Oklahoma and 1 site in Arkansas. Vaughn and Taylor (1999) surveyed 37 sites along a 149-mile reach from above Pine Creek Reservoir to the Arkansas-Oklahoma state line and reported live specimens from 6 sites located between the confluences with the Glover River and the Mountain Fork Little River for a relative abundance of 0.6–8.0%. From 2003–2005, Galbraith et al. (2008) surveyed 5 known mussel beds on the LRNWR and reported an unknown number of live specimens from 4 sites with a mean density of 1.26 individuals/m<sup>2</sup> and evidence of recruitment. However, they revisited the sites in 2006 and collected 160 fresh dead specimens on the bank of this mussel bed that ranged in size from 33–103 mm.

Prior to 1983, biologists limited mussel surveys on the Little River in Arkansas to a few sites with pedestrian access along the reach from the Arkansas-Oklahoma state line, Sevier County, Arkansas, to Millwood Reservoir. In 1983, biologists surveyed sites in Sevier and Little River counties and reported 6 live specimens (AGFC mussel database 2011). Ecosearch (1987) surveyed 11 sites from the Arkansas-Oklahoma state line to near Alleene, Little River County, Arkansas, during 1986 and 1987 and did not locate any specimens. In 2002, Farris et al. (2003) surveyed 14 sites downstream of Millwood Reservoir to the confluence with the Red River, Hempstead and Little River counties, Arkansas, and did not locate any specimens. Fobian (2007) compared reproductive biology and life history of the Rabbitsfoot in the upper Arkansas, White, and Red River Systems and collected 4 live specimens including 3 gravid females in 2006 from a site in Sevier County, Arkansas. From 2006–2008, biologists collected 89 live specimens from 13 sites extending from near the Arkansas-Oklahoma state line to near U.S. Highway 71, Ashdown, Little River County, Arkansas (AGFC Mussel Database, 2011).

At the time of listing, biologists determined the status of this population as stable and considered it one of the most significant throughout the range of the Rabbitsfoot (Table 1). At least 3 large, stable, and reproducing mussel beds

occurred from just above Idabel through upper portions of LRNWR (Galbraith et al. 2008) with additional sites in Little River and Sevier counties, Arkansas. Data collected since listing suggest the population remains stable. During 2015 and 2016, Vaughn et al. (2017) assessed the status of mussel species at 42 sites from below Pine Creek Reservoir to the Arkansas-Oklahoma state line with a focus on LRNWR and reported an unknown number of live specimens from 22 sites with a mean density of 4.00 individuals/m<sup>2</sup> in large mussel beds. Biologists surveyed 8 sites in McCurtain County, Oklahoma, in 2018 and reported 2 live specimens (J. L. Harris, Arkansas State University, pers. comm., 2019). In 2013 Davidson et al. (2014) delineated 24 mussel beds along a 35-RM reach starting at the Arkansas-Oklahoma state line and ending at Millwood Reservoir. They collected 60 live and 64 fresh dead specimens for a relative abundance of 1.46%. In 2016, Davidson (2017) resurveyed 14 of the mussel beds delineated during Davidson et al. (2014) and collected 49 live specimens for a relative abundance of 0.46%.

*Glover River:* The Glover River occurs in the Ouachita Highlands of southeastern Oklahoma and is the only remaining unimpounded tributary of the Little River. The Ohio State University Museum and the North Carolina Museum of Natural Sciences (NCMNS) house 72 and 18 records, respectively, collected from 1969 to 1972 near Glover, McCurtain County, Oklahoma, (NCMNS and OSUM databases 2019) suggesting a sizable population of the Rabbitsfoot once occurred there. From 1993–1995, Vaughn (2000) resurveyed the site near Glover and reported an unknown number of live specimens. Vaughn (2003) conducted surveys at 22 sites in McCurtain County in 1996 and reported 1 live specimen from each of 2 sites for a relative abundance of 0.7% and 3.0%. At the time of listing, biologists considered the Rabbitsfoot extant at 2 sites in a short reach of the Glover River separated by several miles of unsuitable habitat and determined the status of the population as declining (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Cossatot River:* A major tributary of the Little River, the Cossatot River drains portions of southwestern Arkansas. The North Carolina Museum of Natural Sciences houses the first records, 4 live specimens with evidence of recruitment, collected in 1970 near Lockesburg, Sevier County, Arkansas (NCMNS database 2019). In 1983, biologists collected 12 live specimens at a site near Lockesburg (AGFC mussel database 2011). In 2003, biologists surveyed along a 5-mile reach in Sevier County, Arkansas, and did not locate any specimens (AGFC mussel database 2011). At the time of listing, biologists determined the status of the population as declining although they had not conducted any comprehensive mussel surveys of the river (Table 1). Data collected since listing suggest the current status of this population remains the same. In 2013, biologists surveyed 77 sites along a 50-mile reach

in Sevier County, Arkansas, and reported 20 live specimens and evidence of recruitment from 6 sites for a relative abundance of 0.4% (Bouldin et al. 2013b).

*Ouachita River:* At 605 RMs in length, the Ouachita River is the largest tributary of the Red River. It originates in the Ouachita Mountains, Polk County, Arkansas, and drains a large portion of the Gulf Coastal Plain in southern Arkansas and eastern Louisiana. Three reservoirs, Lakes Ouachita, Hamilton, and Catherine, separate the headwaters in the Ouachita Mountains from the portion located in the Gulf Coastal Plain. Call (1895) considered the Rabbitsfoot “abundant” in this river. In 1911, Wheeler (1918) collected an unknown number of live specimens near Arkadelphia, Clark County, Arkansas. The only documented occurrence of this mussel species in Louisiana are specimens collected in the 1900s from Morehouse, Union, and Ouachita parishes, Louisiana (The University of Michigan Museum of Zoology database, 2019, Vidrine 1993). From 1983–1988, Gordon and Harris (1983) and Harris and Gordon (1988) surveyed approximately 30 sites in Clark, Montgomery, and Polk counties, Arkansas, and reported 13 live specimens and an unknown number of relict shells from 4 sites. From 1992–1995, Posey (1997) surveyed 61 mussel beds extending from the confluence with the Little Missouri River, Ouachita County, Arkansas, to the Arkansas-Louisiana state line, Union County, Arkansas. They collected 8 live specimens from 4 mussel beds between RMs 340 and 350 for a relative abundance of 0.20–1.60% and total population estimate for the 4 beds of 1,456 individuals. In 1998, Harris (1999) surveyed 23 sites along a 25-mile reach in Hot Springs County, Arkansas, and reported 3 live specimens from 2 sites for a relative abundance of 0.10%. From 2002–2005, biologists surveyed sites along a 45-mile reach centered at Camden, Ouachita County, Arkansas, and reported 27 live specimens. At the time of listing, biologists considered the Rabbitsfoot extirpated in the Louisiana portion of the river, extant at 2 sites in the reach of the river extending from Arkansas Highway 379 south of Oden, Montgomery County, downstream to Arkansas Highway 298 east of Pencil Bluff, Montgomery County, Arkansas (AGFC mussel database 2011), and determined the status of the population as stable (Table 1). Data collected since listing suggest that the current status of this population remains stable. In 2013, biologists surveyed sites in Clark and Ouachita counties, Arkansas, and reported 12 live specimens (AGFC mussel database 2011).

*Little Missouri River:* The Little Missouri River originates in the Ouachita Mountains, Polk County, Arkansas, and flows southeasterly 115 miles to its confluence with the Ouachita River north of Chidester, Ouachita County, Arkansas. In 1996, Davidson (1997) sampled 4 mussel beds starting at the mouth of the river and extending upstream 10 miles through Clark and Ouachita counties, Arkansas, and reported the first record of the Rabbitsfoot for this river, 1 live specimen for a relative abundance of 0.80% and density of 1.40 individuals/m<sup>2</sup>. Christian and Harris (2004) surveyed 131 sites starting at

Arkansas Highway 195 bridge, Pike County, Arkansas, and ending downstream of Arkansas Highway 53 bridge, Clark County, Arkansas, but did not locate any specimens. At the time of listing, biologists considered this population a metapopulation with the population in the Ouachita River and determined the status of the population as declining (Table 1). We did not receive any new information about surveys conducted in this river since publication of the proposed listing rule. The current status of this population is unknown (Table 1).

*Saline River:* This river originates as 4 distinct tributaries in Garland and Saline counties, Arkansas, and is the largest undammed river in the state. The tributaries converge with the main stem near Benton, Saline County, Arkansas, which flows southward before reaching its confluence with the Ouachita River at Felsenthal NWR, Ashley County, Arkansas. Call (1895) considered the Rabbitsfoot “abundant” in the Saline River. The Illinois Natural History Survey Museum houses a single fresh dead specimen collected by biologists in 1993 from Grant County, Arkansas (INHS Museum Collection, 2019). In 1996, Davidson (1997) sampled 10 mussel beds starting 0.25 mile downstream of Godfrey, Bradley County, Arkansas, to 1 mile upstream from the confluence with the Ouachita River but did not locate any specimens. During 2001 and 2002, Davidson and Clem (2002) sampled 95 mussel beds along 99 RMs from near Tull, Grant County, Arkansas, to near Warren, Cleveland County, Arkansas, and reported 6 live specimens from 3 sites within a 2-mile reach of the river in Cleveland County for a relative abundance of 0.05%. From 2003–2004, Davidson and Clem (2004) surveyed 74 mussel beds along 51 RMs from where they ended in 2002 to Felsenthal NWR and reported 20 live specimens from 9 sites for a relative abundance of 0.20%, with an unknown number of relict shells reported from an additional 3 sites. In 2005, Harris (2006) resurveyed 4 of the beds from Davidson and Clem (2004) located in Ashley and Bradley counties and collected 14 live specimens, for a relative abundance of 0.1–0.8% at 3 sites. Biologists resurveyed these sites in 2011 and collected 4 live specimens, representing 0.0–0.10% of the total mussel community (C. L. Davidson, Service, pers. comm., 2012). In 2008, biologists surveyed two beds identified by Davidson and Clem (2004) near Mt. Elba in Cleveland County and collected 11 and 10 live specimens, respectively, for a relative abundance of 0.3–0.4%. In 2011, biologists resurveyed the same sites and collected 9 live specimens. From 2010–2015, biologists surveyed 18 beds and collected a total of 58 live specimens (C. L. Davidson, Service, pers. comm. 2020). Biologists reported an unknown number of dead specimens of the Rabbitsfoot near the shoreline, apparently having succumbed to desiccation caused by severe drought conditions (C. L. Davidson, Service, 2012, pers. comm.). At the time of listing, biologists determined the status of the population as declining due to limited distribution and lack of evidence of recruitment (C. L. Davidson, Service, pers. comm. 2011; Table 1). Since listing biologists updated the current status of this population as stable (C. L. Davidson, Service, pers.

comm, 2020; Table 1). In 2014, Davidson (2015) sampled 13 mussel beds along 10 RMs in Felsenthal NWR but did not locate any specimens.

*Bayou Bartholomew*: A major tributary of the Ouachita River, Bayou Bartholomew originates in southeastern Arkansas and flows south into Louisiana. The only records of occurrence for the Rabbitsfoot are from the Louisiana portion of the bayou. George and Vidrine (1993), first reported 3 live specimens in 1992, while conducting surveys within a 6-mile reach extending from the western edge of Chemin-A-Haut State Park to 1 mile downstream of the Highway 425 bridge crossing, north of Log Cabin, Morehouse Parish, Louisiana. In 2000 and 2001, Alley (2005) conducted surveys at 50 sites in Morehouse Parish and reported 1 live specimen for a relative abundance of 0.20%. From 2004–2005, biologists reported 5 live and 6 dead specimens from a site near Log Cabin and 1 relict shell from a site just below the Arkansas-Louisiana state line, Union Parish, Louisiana (J. A. Brooks, University of Louisiana, pers. comm., 2005). In 2004, Brooks et al. (2008) surveyed 50 sites starting at the headwaters near Pine Bluff, Jefferson County, Arkansas, and ending at the Arkansas-Louisiana state line and did not locate specimens. At the time of listing, biologists determined the status of this population as declining due to few records of occurrence from 2 disjunct sites in Morehouse Parish and 1 site near the Arkansas-Louisiana state line and no evidence of recruitment (J. A. Brooks, University of Louisiana, pers. comm., 2005; Table 1). Data collected since listing suggest that the status of this population may be improving. In 2016, biologists surveyed sites downstream of Highway 425 bridge crossing north of Log Cabin and reported 12 live and 9 fresh dead specimens with evidence of recruitment (L. A. Trahan, Service, pers. comm., 2019). In 2017, biologists surveyed 10 sites in Morehouse Parish and reported high numbers of fresh dead specimens due to extremely low water levels from 2 of the sites. They counted 327 and 11 fresh dead specimens of the Rabbitsfoot near the Highway 425 bridge crossing north of Log Cabin and Point Pleasant, Morehouse Parish, respectively (T. R. Slack, U. S. Army Engineer Research and Development Center Environmental Laboratory, pers. comm., 2019).

**c. Genetics, genetic variation, or trends in genetic variation**

Sproules et al. (2006) sequenced mitochondrial NADH dehydrogenase subunit 1 (*nadh1*) to characterize genetic structure of populations of the Rabbitsfoot in the Duck, Illinois, Green, and Ouachita rivers. They found that individuals from the Green and Ouachita rivers separated into their own unique groups, suggesting that these populations have little if any genetic exchange with the Illinois and Duck rivers and recommended that augmentation for populations in the Green and Ouachita rivers carefully consider the source population. Fobian (2007) presented results of a genetic analysis that compared DNA sequences of 600 base pairs of *nadh1* among female Rabbitsfoot from the Spring, Black, Little, Verdigris, and St. Francis rivers. The samples showed no discernible genetic differences for females among these rivers. These

results demonstrate the need to conduct more studies that elucidate genetic structure among populations of the Rabbitsfoot across its historical range. Results of such studies will provide essential information for future propagation and reintroduction efforts.

**d. Taxonomic classification or changes in nomenclature**

Say (1817) originally described the Rabbitsfoot as *Unio cylindrica*. The type locality is the Wabash River (Parmalee and Bogan 1998), probably near New Harmony, Posey County, Indiana, and adjacent Illinois. Taxonomists have assigned the Rabbitsfoot to the genera *Unio*, *Mya*, *Margarita*, *Margarona*, and *Orthonymus* at various times in history. Lewis (1870) was the first taxonomist to assign the Rabbitsfoot to the genus *Quadrula*. Turgeon et al. (1998) recognized *Quadrula cylindrica* as 2 subspecies, the Rabbitsfoot (Say 1817) and the Rough Rabbitsfoot (Wright 1898). Serb et al. (2003) used nucleotide sequences of the mitochondrial *nadh1* gene to construct a molecular phylogeny of the genus *Quadrula* and continued to recognize the Rabbitsfoot as a member of the monophyletic *Metanевра* species group (Simpson 1900). They stated that they did not examine enough samples to reliably assess the taxonomic validity of the Rough Rabbitsfoot as a subspecies. Sproules et al. (2006, entire) sequenced *nadh1* to examine variation among populations of the Rabbitsfoot from the Duck River, Tennessee, Illinois and Ouachita rivers, Arkansas, and Green River, Kentucky, and a population of the Rough Rabbitsfoot from the Clinch River, Tennessee. Their results indicated that populations in the Ouachita and Green rivers represented unique populations that warrant special conservation measures for protection. However, because of the small sample sizes and use of only *nadh1* in this pilot study they were not able to resolve the relationships between populations in the other 3 rivers. They recommended a comprehensive study using multiple genetic markers, increased sample sizes, and life-histories to reliably assess the phylogenetic relationships among the 3 other populations. Williams et al. (2017) used Turgeon et al. (1998), Serb et al. (2003), Sproules et al. (2006), their own unpublished research, and discussions with other experts on mussel systematics to develop a revised taxonomic classification and comprehensive list of the freshwater mussels of the United States and Canada that reflected recent refinement of mussel systematics. Williams et al. (2017) reassigned the Rabbitsfoot as *Theliderma cylindrica* and stated that the Rough Rabbitsfoot would no longer be recognized as a subspecies based on the results of molecular analyses from Serb et al. (2003) and Sproules et al. (2006). Since reassignment, Lopes-Lima et al. (2019) used *nadh1* and mitochondrial cytochrome c oxidase subunit 1 (*cox1*) gene markers to reexamine phylogenetic relationships and taxonomy within Tribe Quadrulini (*Cyclonaias*, *Quadrula*, *Theliderma*, *Trittogonia*). This study did not include new *nadh1* sequences or additional markers for the Rabbitsfoot, so it did not provide new information on the validity of the

Rough Rabbitsfoot as a subspecies. However, by including *cox1* it identified 2 distinct clades for the closely related *Theliderma metanevra*, one corresponding to specimens from the Tennessee basin and the other to specimens from the Mobile basin. This result demonstrates the importance of examining multiple genetic markers, as *nadh1* analyses alone did not detect this separation. It also provides further support of the need to evaluate the taxonomic validity of reassignment of the Rabbitsfoot and the Rough Rabbitsfoot as *Theliderma cylindrica* given that it did not include new *nadh1* sequences or additional markers for the Rabbitsfoot and that there may be a separation among these populations similar to that found for *Theliderma metanevra* using *cox1*. The Service has neither recognized the change in nomenclature nor reassignment of both subspecies as *Theliderma cylindrica* through the rule-making process.

**e. Spatial distribution, trends in spatial distribution, or historical range**

At the time of listing, the historical range of the Rabbitsfoot included Alabama, Arkansas, Georgia, Illinois, Indiana, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Ohio, Oklahoma, Pennsylvania, Tennessee, and West Virginia (Figure 2). Biologists considered the Rabbitsfoot extirpated in Georgia and West Virginia. Within the lower Great Lakes Sub-basin and Mississippi River Basin, biologists documented occurrence of the Rabbitsfoot in 139 rivers or creeks. Of those 139 rivers or creeks, they determined status of 51 of the populations as extant (stable, improving, declining, or unknown), a 63% decline in historical occurrence (Table 1). Butler (2005; Appendix 3) determined status of a population as extirpated when results of mussel surveys from the past few decades failed to detect the presence of live individuals or fresh dead specimens. We retained the status of extirpated as reported in Butler (2005; Appendix 3) as did the proposed listing rule (Table 1).

Since publication of the proposed listing rule in 2012, biologists have reported records of occurrence for the Rabbitsfoot from 10 additional rivers or creeks, some of which pre-date listing (Table 1). In 2008, biologists with the USACE, Memphis District, reported the first record of occurrence from the Hatchie River, which occurs in the Lower Mississippi River Sub-basin (Table 1). Biologists located a fresh dead specimen at the Highway 70 crossing, southwest of Brownsville, Haywood County, Tennessee (J. Koontz, USACE, personal communication, 2019). This is the first record of occurrence for the Rabbitsfoot from a direct tributary of the Mississippi River in west Tennessee. In 1995, biologists reported 2 live specimens from the North Fork Spring River, near Neck City, Jasper County, Missouri (S. E. McMurray, MDC mussel database, 2019). The North Fork Spring River is a tributary of the Spring River and occurs in the Arkansas River Basin (Table 1).

Biologists reported records of occurrence from additional rivers or creeks in the Ohio River Basin. In 2010, biologists collected the first record, 1 live specimen, from Jordan Creek, Vermilion County, Illinois (Table 1; INHS Museum Collection, 2019). Jordan Creek is a tributary of the Middle Branch North Fork Vermilion River. In 2012, biologists also reported 1 live specimen from Sugar Creek, a tributary of the East Fork White River, Shelby County, Indiana, and an unknown number of weathered shells from the creek in Shelby and Johnson counties, Indiana (Table 1). This is the first record of occurrence for this creek and the current status of this population is unknown (Table 1). The Sugar Creek population included in the proposed listing rule is a tributary of the Wabash River and its current status remains extirpated (Table 1). In 2006 and 2008, biologists reported the first record of occurrence, a weathered dead specimen, from both Big Monon Creek, White County, Indiana, and Pipe Creek, Madison County, Indiana, respectively (Table 1). Big Monon Creek is a tributary of the Tippecanoe River and Pipe Creek a tributary of the West Fork White River (Table 1). From 2005–2013, biologists have reported weathered dead specimens from the Salamonie River, Huntington and Wells counties, Ohio (Table 1). The Salamonie River is a tributary of the Wabash River.

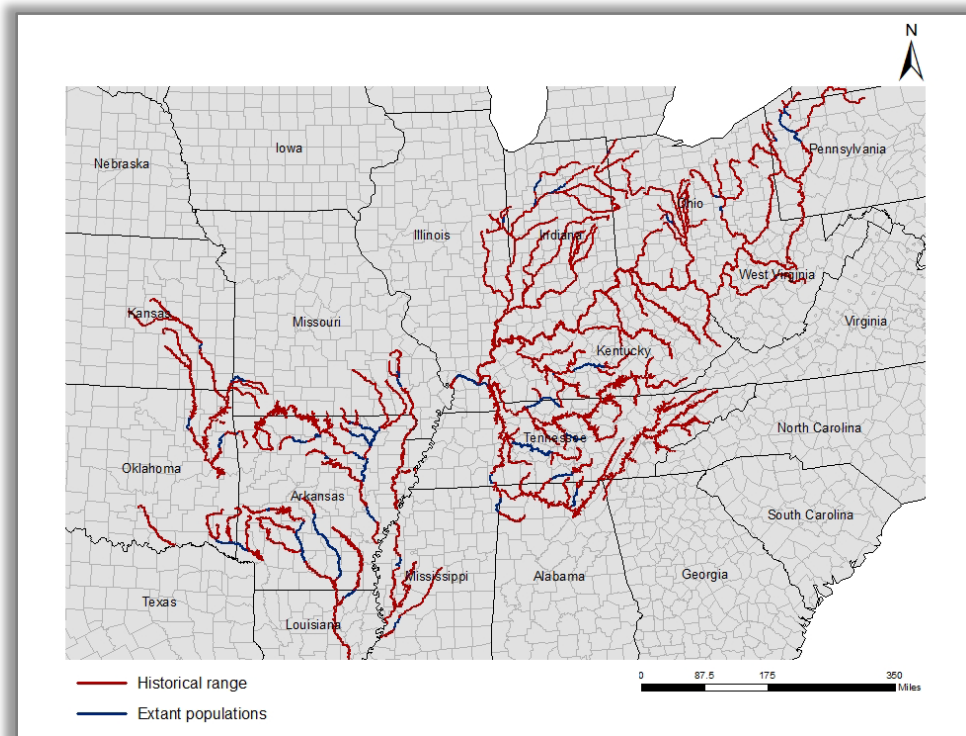


Figure 2. Historical range and populations considered extant at the time of listing.

The last 3 additional rivers where biologists reported the first records of occurrence are located in the Red River Basin. In 2017, biologists reported 2

live specimens from Bayou D'Arbonne upstream of Louisiana Highway 143 at the boundary of D'Arbonne NWR, Ouachita Parish, Louisiana (Table 1; Louisiana Department of Wildlife and Fisheries Wildlife Diversity Program, 2019). Bouldin et al. (2013b) reported the first records for the other 2 rivers in this basin. They surveyed 34 sites along Rolling Fork Little River in Little River and Sevier counties, Arkansas, and reported 3 live specimens from 2 sites in Sevier County for a relative abundance of 0.20%. They also surveyed 45 sites along the Saline River in Howard and Sevier counties, Arkansas, and reported 6 live specimens from 5 sites in Sevier County, Arkansas, for a relative abundance of 0.40%. The Saline River listed in proposed listing rule is a tributary of the Ouachita River whereas this Saline River is a tributary of the Little River (Table 1).

Currently, biologists consider Rabbitsfoot extant in 63 of 149 rivers, a 58% decline in historical occurrence. Of the 63 extant rivers, 25% are considered stable or improving, while 17% are considered declining (Table 1). We considered the current status of 36 extant populations (57%) as unknown either because biologists did not report any new information since publication of the proposed listing rule in 2012 with which to assess population status or reported the first records of occurrence for a river or creek since publication of the proposed listing rule (Table 1).

#### **f. Habitat**

Suitable habitat for the Rabbitsfoot occurs in small- to medium-sized streams and some larger rivers (Gordon and Layzer 1989). Biologists have reported it from depths up to 3 m (Scammon 1906, Murray and Leonard 1962, Parmalee 1967). Bottom substrates generally include a mixture of sand and gravel (Parmalee and Bogan 1998, Fobian 2007). Strayer (1999a) demonstrated in field trials that within streams and rivers, mussels occur mainly in flow refuges, which are shallow areas with reduced water velocity that display little movement of substrate during flood events e.g., areas along banks and next to riffles and runs. Other researchers also have demonstrated that mussel beds occur in areas where shear stresses are low and sediments remain stable during flooding (Layzer and Madison 1995, Hastie et al. 2001). Because adults do not typically burrow into sediment but rather lies horizontally on the surface (Watters 1988; Fobian 2007), flow refuges may decrease the likelihood of displacement into unsuitable habitat. However, in higher energy habitats where flow refuges are not available along the lower Buffalo River, Tennessee, biologists have observed the Rabbitsfoot in relatively high concentrations burrowing completely into banks composed of sandy silt (T. Amacker, TVA, pers. comm., 2016).

## **2. 5-Factor Analysis (threats, conservation measures, and regulatory mechanisms)**

**a. Present or threatened destruction, modification or curtailment of its habitat or range**

*Impoundments*

Dams eliminate and alter river flow within impounded areas, trap silt leading to increased sediment deposition, alter water quality, change hydrology and channel geomorphology, decrease habitat heterogeneity, affect normal flood patterns, and block upstream and downstream movement of mussels and their fish hosts (Layzer et al. 1993, Neves et al. 1997, Watters 2000). Within impounded waters, decline of mussels has been attributed to direct loss of supporting habitat, sedimentation, decreased dissolved oxygen and temperature levels, and alteration in resident fish populations (Neves et al. 1997, Pringle et al. 2000, Watters 2000). Downstream of dams, mussel declines are associated with changes and fluctuation in flow regime, channel scouring and bank erosion, reduced dissolved oxygen levels and water temperatures, and changes in resident fish assemblages (Williams et al. 1992, Layzer et al. 1993, Neves et al. 1997, Watters 2000, Pringle et al. 2000). Dams that are low to the water surface, or have water passing over them (small low head or mill dams) can have some of these same effects on mussels and their fish hosts (Watters 2000, Dean et al. 2002). Obermeyer et al. (1997b) attributed the decline of mussels within the Arkansas River Basin to construction of numerous impoundments

Impoundments have contributed more to losses of populations of the Rabbitsfoot than any other factor (e.g. Tennessee and Ohio River basins). Impoundments have fragmented riverine habitat throughout the range of the Rabbitsfoot often resulting in short isolated patches of habitat, where fish hosts necessary for reproduction and dispersal may not be available. Because these isolated populations are unable to naturally recolonize suitable habitat upstream/downstream they become more prone to extirpation from stochastic events, such as severe drought, chemical spills, or unauthorized discharges (Layzer et al. 1993, Cope et al. 1997, Neves et al. 1997, Watters 2000, Pringle et al. 2000, Miller and Payne 2001, Watters and Flaute 2010).

*Sedimentation*

Excessive sediments adversely affect riverine mussel populations that require clean, stable streams (Ellis 1936; Brim-Box and Mossa 1999). Sedimentation remains a threat to the Rabbitsfoot. Specific biological effects include reduced feeding and respiratory efficiency from clogged gills, disrupted metabolic processes, reduced growth rates, limited burrowing activity, physical smothering, and disrupted host fish attraction mechanisms (Ellis 1936, Marking and Bills 1979, Vannote and Minshall 1982, Waters 1995, Hartfield and Hartfield 1996). Additionally, mussels may be indirectly affected if high turbidity levels significantly reduce the amount of light available for photosynthesis, and thus, the production of certain food items (Kanehl and Lyons 1992).

Studies indicate the primary effects of excess sediment levels on mussels are generally sublethal, with detrimental effects not immediately apparent (Brim-Box and Mossa 1999). The physical effects of sediment on mussel habitat include changes in suspended and bed material load, bed sediment composition associated with increased sediment production and runoff in the watershed, channel changes in form, position, and degree of stability, changes in depth or the width and depth ratio that affects light penetration and flow regime, actively aggrading (filling) or degrading (scouring) channels, and changes in channel position. These effects to habitat may dislodge, transport downstream, or leave mussels stranded (Vannote and Minshall 1982, Kanehl and Lyons 1992, Brim-Box and Mossa 1999). For example, many Kansas streams such as the Verdigris River have become increasingly sedimented over the past century, reducing habitat for the Rabbitsfoot (Obermeyer et al. 1997a). At least 43 streams within the Duck River watershed, Tennessee, comprising 300 RMs, are listed as impaired (303(d) list) due to loss of biological integrity and excessive sediment (USACE 2018).

Increased sedimentation may explain in part why the Rabbitsfoot is experiencing recruitment failure in some streams. Interstitial spaces in the substrate provide crucial shelter and nutrient uptake for juvenile mussel survival (Watters 2007). When interstitial spaces are clogged, interstitial flow rates and spaces are reduced (Brim-Box and Mossa 1999), and this decreases habitat for juvenile mussels. Geist and Auerswald (2007) found that sites with good recruitment of juvenile Freshwater Pearl Mussels had coarser and better sorted substrata with significantly lower quantities of fines whereas sites lacking recruitment of juveniles had a more variable and higher penetration resistance indicating clogging of the interstitial macropore system by the deposition of mud and compaction of the stream bed. Furthermore, sediment may act as a vector for delivering contaminants, such as nutrients and pesticides, to streams, and juvenile mussels may ingest contaminants and silt particles during normal feeding activities.

Increased turbidity levels due to siltation can be a limiting factor that impedes the ability of sight-feeding fishes to forage. This turbidity may impair an attempt of a brooding female to attract necessary fish hosts. In addition, sediment can eliminate or reduce the recruitment of juvenile mussels, interfere with feeding activity, and act as a vector in delivering contaminants to streams. Because the Rabbitsfoot is a filter-feeder that inhabits the bottom of streams, it is exposed to these contaminants contained within suspended particles and deposited in bottom substrates. High total suspended solids can interfere with fertilization by reducing the chance of females encountering suspended sperm during filter feeding, or an increase in pseudofeces production could bind sperm in mucus and lead to its egestion before fertilization. Suspended sediment is a potential mechanism to explain the lack of mussel recruitment in many locations (Gascho Landis et al. 2013).

### *Chemical Contaminants*

Chemical contaminants are ubiquitous in the environment and a major threat in the decline of mussel species (Richter et al. 1997, Strayer et al. 2004, Wang et al. 2007a, Cope et al. 2008). Chemicals enter rivers through point and nonpoint discharges including spills, industrial and municipal effluents, and residential and agricultural runoff. These sources contribute organic compounds, heavy metals, nutrients, pesticides, and a wide variety of newly emerging contaminants such as pharmaceuticals to the aquatic environment. As a result, water and sediment quality can degrade to an extent resulting in adverse effects to mussel populations. Cope et al. (2008) evaluated the pathways of exposure to environmental pollutants for freshwater mussel life stages (glochidia, juveniles, adults) and found that each life stage has both common and unique characteristics that contribute to observed differences in exposure and sensitivity.

In female mussels, the marsupial region of the gill may be physiologically isolated from respiratory functions, and this isolation may provide some level of protection from contaminant interference with the ability of a female to achieve fertilization or brood glochidia (Cope et al. 2008). A major exception to this assertion is with chemicals that act directly on the neuroendocrine pathways controlling reproduction (see discussion below). Nutritional and ionic exchange is possible between a brooding female and her glochidia, providing a route for chemicals (accumulated or waterborne) to disrupt biochemical and physiological pathways (such as maternal calcium transport for construction of the glochidial shell). Glochidia can be exposed to waterborne contaminants for up to 36 hours until encystment occurs; between 2 and 36 hours, and then from fish host tissue burdens (for example, atrazine), that last from weeks to months and this could affect metamorphosis of glochidia into juveniles (Ingersoll et al. 2007).

Studies have reported the juvenile freshwater mussels remain burrowed in the sediment for the first 2–4 years of life, employing a pedal feeding strategy to gather nutrition and dissolved oxygen primarily from interstitial water (Yeager et al. 1994, Strayer et al. 2004, Watters 2007). The relative importance of exposure of juvenile Rabbitsfoot to contaminants in overlying surface water, interstitial water, whole sediment, or food needs further assessment. Exposure to contaminants from each of these routes varies with certain periods and environmental conditions (Cope et al. 2008).

The primary routes of exposure to contaminants for adult Rabbitsfoot are surface water, sediment, interstitial (pore) water, and diet; adults can be exposed when either partially or completely burrowed in the substrate (Cope et al. 2008). Adult mussels detect toxicants in the water and close their valves to avoid exposure (Van Hassel and Farris 2007). Adult mussel toxicity and relative sensitivity (exposure and uptake of toxicants) may be reduced at high rather than low toxicant concentrations because uptake is affected by the

prolonged or periodic toxicant avoidance responses (when the avoidance behavior of keeping their valves closed can no longer be sustained for physiological reasons (respiration and ability to feed) (Cope et al. 2008). Cope et al. (2008) found similar toxicity results for adults based on low-level and estimates for glochidia and juveniles for some toxicants (for example, copper). The duration of any toxicant avoidance response by an adult mussel is likely to vary due to several variables, such as species, age, shell thickness and gape, properties of the toxicant, and water temperature. There is a lack of information on toxicant response(s) for the Rabbitsfoot but results of tests using glochidia and juveniles may be valuable for protecting adults (Cope et al. 2008).

Studies conducted in accordance with standard mussel testing methods demonstrated that mussels are among the most sensitive freshwater species to a variety of contaminants, including copper, nickel, chloride, sulfate, potassium, and ammonia (e.g. Wang et al. 2007a, b; 2010, 2013; Gillis 2011). Metals occur in industrial and wastewater effluents. Metals from mine water runoff (for example, Tri-State Mining Area in southwest Missouri) contributed to mussel declines in streams such as Shoal, Center, and Turkey creeks and Spring River in the Arkansas River basin (Angelo et al. 2007; EcoAnalysts, Inc. 2018), which are streams with historical and extant populations of the Rabbitsfoot. EcoAnalysts, Inc. (2018) found a negative correlation between mussel community metrics and sediment toxicity, suggesting sediment metal concentrations negatively affect the Spring River basin mussel community. Heavy metals can cause mortality and affect biological processes, for instance, disrupting enzyme efficiency, altering filtration rates, reducing growth, and changing behavior of freshwater mussels (Keller and Zam 1991, Naimo 1995, Jacobson et al. 1997, Valenti et al. 2005, Wang et al. 2007a, b, 2010). Low but chronic heavy metal and other toxicant inputs may reduce mussel recruitment (Yeager et al. 1994, Naimo 1995, Ahlstedt and Tuberville 1997). Newly transformed juveniles (age at 5 days) are more sensitive to acute toxicity than glochidia or older juveniles (age at 2 to 6 months) (Wang et al. 2010).

Mercury occurs in many aquatic environments as a product of municipal and industrial waste and atmospheric deposition from coal burning plants. One study on Rainbow Mussel (*Villosa iris*) concluded that glochidia were more sensitive to mercury than were juvenile mussels, with a median lethal concentration value of 14 µg/L for glochidia and 114 µg/L for juvenile mussels (Valenti et al. 2005). For this species, the chronic toxicity test showed that juveniles exposed to mercury greater than or equal to 8 µg/L exhibited reduced growth (Valenti et al. 2005). Mercury also affects oxygen consumption, byssal thread production, and filtration rates (Naimo 1995, Jacobsen et al. 1997, and Nelson and Calabrese 1988 in Valenti et al. 2005).

Polychlorinated biphenyls (PCBs) are ubiquitous contaminants in the environment due to their widespread use as insulating material in electric equipment, such as transformers and capacitors, as well as in heat transfer fluids and lubricants from the 1920s to 1970s. The inherent stability and toxicity of PCBs have resulted in them being a persistent environmental problem (Safe 1994 in Lehmann et al. 2007). PCBs adsorb easily to soil and sediment, and are present in the water column, making them available to bioaccumulate and induce negative effects in living organisms (Livingstone 2001 in Lehmann et al. 2007). Studies indicate increased PCB concentrations in native freshwater mussels (Ruessler et al. 2011), marine bivalves (Krishnakumar et al. 1994), and nonnative invasive mollusks such as Zebra Mussels (*Dreissena polymorpha*) and Asian Clams (*Corbicula* spp.) (Gossiaux et al. 1996, Lehmann et al. 2007). Oxidative stress (imbalance in the normal redox state of cells that causes toxic effects that damage all components of the cell, including proteins, lipids, and DNA) is a direct consequence of PCB exposure. Relevant changes, whether directly or indirectly due to oxidative stress, occurs at the organ and organism levels and likely results in mussel population-wide effects, including reduced fecundity and chronic maladies (Lehmann et al. 2007).

Agriculture, timber harvest, and lawn management practices utilize nutrients and pesticides. Nutrients, such as nitrogen and phosphorus, primarily occur in runoff from livestock farms, feedlots, heavily fertilized row crops and pastures (Peterjohn and Correll 1984), post timber management activities, and urban and suburban runoff, including leaking septic tanks, and residential lawns. Studies have demonstrated that excessive nitrogen concentrations can be lethal to the adult Freshwater Pearl Mussel (*Margaritifera margaritifera*) and reduce the life span and size of other mussel species (Bauer 1988, 1992). Nutrient enrichment can result in an increase in primary productivity, and the associated algae respiration depletes dissolved oxygen levels. This may be particularly detrimental to juvenile mussels that inhabit the interstitial spaces in the substrate where lower dissolved oxygen concentrations are more likely than on the sediment surface where adults tend to live (Sparks and Strayer 1998). Over-enriched conditions exacerbated by low flow conditions, such as those experienced during a typical summer season, may occur with greater frequency and severity due to climate change.

In the upper Big Sunflower River of Mississippi, most swamps and wetlands that provided dry season water storage have been drained or filled with agricultural sediments, and streams and bayous across the landscape have been channelized, drained, and are now intermittent. Agricultural irrigation along with the loss of floodplain storage, has disconnected river and tributary channels with the ground water table, severely reducing base flows (Yazoo Mississippi Delta Joint Water Management District 2006). Low river discharge is now dependent to a large degree upon irrigation runoff and late summer river flows are characterized by high turbidity and water temperature.

As a result, seasonal hypoxia (dissolved oxygen ~3 ppm), and fish kills due to hypoxia have become seasonal events (Pennington 1993, Shields and Knight 2012). While the adult mussel fauna appears to survive these events, juvenile mussel and recruitment, including the Rabbitsfoot, are believed to be negatively impacted (P. D. Hartfield, Service, pers. comm. 2020).

Ammonia is particularly toxic to early life stages of mussels, and accumulating data on the sensitivity of bivalves and snails to ammonia resulted in revision of the U. S. Environmental Protection Agency (USEPA) water quality criteria for ammonia in 2013 (USEPA 2013). Sources of ammonia include agricultural wastes (animal feedlots and nitrogenous fertilizers), municipal wastewater treatment plants, and industrial waste (Augspurger et al. 2007) as well as precipitation and natural processes (decomposition of organic nitrogen) (Goudreau et al. 1993, Hickey and Martin 1999, Augspurger et al. 2007, Newton 2003). Ammonia is considered a limiting factor for survival and recovery of some mussel species due to its ubiquity in aquatic environments and high level of toxicity, and because the highest concentrations typically occur in mussel microhabitats (Augspurger et al. 2007). Studies have demonstrated that ammonia concentrations increase with increasing temperature, pH, and low flow conditions (Cherry et al. 2005, Cooper et al. 2005, Wang et al. 2007a) and may cause ammonia (unionized and ionized) to become more problematic for juvenile mussels (Wang et al. 2007a). Sublethal effects include, but may not be limited to, reduced time the valves are open for respiration and feeding, impaired secretion of the byssal thread (used for substrate attachment), reduced ciliary action impairing feeding, depleted lipid, glycogen, and other carbohydrate stores, and altered metabolism (Goudreau et al. 1993, Augspurger et al. 2007, Mummert et al. 2003).

Elevated concentrations of pesticide frequently occur in streams due to residential or commercial pesticide runoff, overspray application to row crops, and lack of adequate riparian buffers. Agricultural pesticide applications often coincide with the reproductive and early life stages of mussels, and these effects may increase during critical times (Bringolf et al. 2007a). Recent studies tested the toxicity of glyphosate, its formulations, and a surfactant (MON 0818) used in several glyphosate formulations, to early life stages of the Fatmucket (*Lampsilis siliquoidea*) (Bringolf et al. 2007a). Studies conducted with juvenile mussels and glochidia determined that the surfactant (MON 0818) was the most toxic of the compounds tested and that glochidia of Fatmucket were the most sensitive organism tested to date (Bringolf et al. 2007a). Roundup®, technical grade glyphosate isopropylamine salt, and isopropylamine were also acutely toxic to juveniles and glochidia (Bringolf et al. 2007a). The study of other pesticides, including atrazine, chlorpyrifos, and permethrin, on glochidia and juvenile life stages determined that chlorpyrifos was toxic to glochidia and juveniles of Fatmucket (Bringolf et al. 2007b).

There are instances where chemical spills have resulted in the loss of high numbers of mussels (Jones et al. 2001, Brown et al. 2005, Schmerfeld 2006) and are considered a serious threat to mussel species. Chemical spills threaten the Rabbitsfoot because they can occur anywhere that highways with tanker trucks, industries, or mines overlap with their distribution.

Pharmaceutical chemicals used in commonly consumed drugs increasingly occur in surface waters. Kolpin et al. (2002) detected the presence of numerous pharmaceuticals, hormones, and other organic waste products in nationwide sampling of 139 stream sites in 30 states downstream from urban development and livestock production areas. Another study in northwestern Arkansas found pharmaceuticals or other organic wastewater constituents at 16 of 17 sites in seven streams surveyed in 2004 (Galloway et al. 2005). Toxic levels of exposure to chemicals that act directly on the neuroendocrine pathways controlling reproduction can cause premature release of viable or nonviable glochidia. For example, the active ingredient in many human prescription antidepressant drugs belonging to the class of selective serotonin reuptake inhibitors may exert negative reproductive effects on mussels because of the drug's action on serotonin and other neuroendocrine pathways (Cope et al. 2008). Pharmaceuticals or organic wastewater constituents are generally greater downstream of wastewater treatment facilities (Galloway et al. 2005). Pharmaceuticals that alter mussel behavior and influence successful attachment of glochidia on fish hosts may have population-level implications for the Rabbitsfoot.

### *Mining*

Gravel and metal mining are activities negatively affecting water quality in habitat for the Rabbitsfoot. Results of studies have implicated instream and alluvial gravel mining in the destruction of mussel populations (Hartfield 1993, Brim-Box and Mossa 1999). Negative effects associated with gravel mining include stream channel modifications (altered habitat, disrupted flow patterns, sediment transport), water quality modifications (increased turbidity, reduced light penetration, increased temperature), macroinvertebrate population changes (elimination), and changes in fish populations, resulting from adverse effects to spawning and nursery habitat and food web disruptions (Kanehl and Lyons 1992).

Metal mining (lead, cadmium, and zinc) in the Tri-State Mining Area (15,022 km<sup>2</sup> in Kansas, Missouri, and Oklahoma) has adversely affected Center and Shoal creeks and the Spring River (Obermeyer et al. 1997b; EcoAnalysts, Inc. 2018). A study by the Kansas Department of Health and Environment documented a strong negative correlation between the distribution and abundance of native mussels, including the Rabbitsfoot, and sediment concentrations of lead, zinc and cadmium in the Spring River system (Angelo et al. 2007). Sediment and water quality samples exceeded the EPA 2006 threshold effect concentrations for cadmium, lead, and zinc at numerous

sampling locations within the Tri-State Mining Area (T. Gunter 2007, pers. comm.).

**b. Overutilization for commercial, recreational, scientific, or educational purposes**

There is no evidence to suggest overutilization for commercial, recreational, scientific, or educational purposes is a current threat to the Rabbitsfoot in any portion of its range.

**c. Disease or predation**

We know little about disease in mussels or its effects on the Rabbitsfoot. Studies indicate that in some localized areas disease and predation may have negative effects on mussel populations. While the intensity of disease or predation may increase in the future, we have no evidence to suggest that disease and predation are threats to the Rabbitsfoot.

**d. Inadequacy of existing regulatory mechanisms**

*Clean Water Act*

The objective of the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act (CWA) (33 U.S.C. 1251 *et seq.*), is to restore and maintain the chemical, physical, and biological integrity of the nation's waters by preventing point and nonpoint pollution sources. States are responsible for setting and implementing water quality standards that align with the requirements of the CWA. Overall, implementation of the CWA could benefit the Rabbitsfoot through the point and nonpoint programs.

Unlike pollution from industrial and sewage treatment plants, nonpoint source pollution comes from many diffuse sources. The runoff transports natural and human-made pollutants (nonpoint source). States report that nonpoint source pollution is the leading remaining cause of water quality problems. Nonpoint source pollution within the watersheds occupied by the Rabbitsfoot include timber clear-cutting, clearing of riparian vegetation, urbanization, road construction, and other practices that allow sediment to enter streams. For example, streams labeled as impaired in the Duck River watershed (300 RMs) are losing 5–55% more soil per year than streams not labeled as impaired (USACE 2011). Currently, the CWA may not adequately protect the Rabbitsfoot habitat from nonpoint source pollution. There is no information concerning the implementation of the CWA regarding nonpoint source pollution specific to protection of the Rabbitsfoot. However, insufficient implementation of it could threaten this mussel species.

Despite some reductions in point source discharges, the CWA may not provide adequate protection for filter-feeding organisms that are sensitive to extremely low levels of contaminants (see Chemical Contaminants discussion). There is no specific information known about the sensitivity of the Rabbitsfoot to common point source pollutants like industrial and

municipal pollutants and very little information on other freshwater mussels. Because there is very little information known about water quality parameters necessary to protect freshwater mussels, it is difficult to determine whether the CWA is adequately addressing threats to the Rabbitsfoot.

#### *State and Federal Water Quality Programs*

Current State regulations regarding pollutants are protective of aquatic organisms. However, freshwater mussels may be more susceptible to some pollutants than the test organisms commonly used in bioassays. Additionally, water quality criteria may not incorporate data available for freshwater mussels (March et al. 2007). A multitude of bioassays conducted on mussel species (Augspurger et al. 2007, Wang et al. 2007a, b; 2010) show that freshwater mussels are more sensitive to some chemical pollutants, including chlorine, ammonia, certain metals, fungicides, and herbicide surfactants. Gibson (2015) found that nickel and chlorine were toxic to another federally threatened mussel species at levels below the current criteria. The study also found mussels are sensitive to sodium dodecyl sulfate, a surfactant commonly used in household detergents, for which water quality criteria do not currently exist. Several studies have demonstrated that the criteria for ammonia developed by EPA in 1999 were not protective of freshwater mussels (Augspurger et al. 2007, Newton et al. 2003, Mummert et al. 2003). However, in 2013 EPA revised its recommended criteria for ammonia. The new criteria are more stringent and reflect new toxicity data on sensitive freshwater mollusks (78 FR 52192, August 22, 2013; p. 2). However, all states within the range of the Rabbitsfoot have not yet adopted the new ammonia criteria.

In summary, despite existing authorities such as the CWA, pollutants continue to impair the water quality throughout the current range of the Rabbitsfoot. While State and Federal regulatory mechanisms have helped reduce the negative effects of point source discharges since the 1970s, these regulations are difficult to implement and regulate. While new water quality criteria that take freshwater mussels into account are being developed, most criteria currently do not. We expect that it will take several years to implement new water quality criteria throughout the range.

#### **e. Other natural or manmade factors affecting its continued existence**

##### *Population Fragmentation and Isolation*

Population fragmentation and isolation prohibit the natural interchange of genetic material between populations. Most of the remaining the Rabbitsfoot populations are small and geographically isolated, and, thus, are susceptible to genetic drift, inbreeding depression, and stochastic changes to the environment, such as toxic chemical spills (Smith 1990, Watters and Dunn 1995, Avise and Hamrick 1996). Inbreeding depression can result in early mortality, decreased fertility, smaller body size, loss of vigor, reduced fitness, and various chromosome abnormalities (Smith 1990). A species'

vulnerability to extinction increases with patchy distribution due to habitat loss and degradation (Noss and Cooperrider 1994, Thomas 1994). Although changes in the environment may cause populations to fluctuate naturally, small and low-density populations are more likely to fluctuate below a minimum viable population size, which is the minimum or threshold number of individuals needed in a population to persist in a viable state for a given interval (Shaffer 1981, Shaffer and Samson 1985, Gilpin and Soulé 1986). Furthermore, this level of isolation makes natural repopulation of any extirpated population unlikely without human intervention. Population isolation prohibits the natural interchange of genetic material between populations, and small population size reduces the reservoir of genetic diversity within populations, which can lead to inbreeding depression (Avisé and Hambrick 1996). Genetic inbreeding and loss of heterozygosity, low fecundity, decreased reproductive success and recruitment are all factors that could lead to isolated populations experiencing the Allee effect, a decline in individual fitness at low population size or density, that may result in a minimum population size below which they are not able to recover (Courchamp et al. 1999). For many populations of the Rabbitsfoot, we do not have data to examine how population size and isolation affects genetic diversity.

Because of the restricted distribution of the Rabbitsfoot and the number of populations represented by a few individuals, the probability that some populations of this mussel species are below effective population size (EPS), the number of individuals in a population contributing offspring to the next generation, is great. Achieving EPS is necessary for a population to adapt to environmental change and maintain long-term viability (Soulé 1980). Biologists reported evidence of recruitment for 13 of the 63 (21%) extant populations of the Rabbitsfoot, making recruitment reduction or outright failure suspect. These populations may be experiencing the bottleneck effect of small populations and fragmentation. Small, isolated, less than EPS–threshold populations of short-lived species (i.e. most fish hosts) theoretically die out within a decade (Tilman et al. 1994). Even in the absence of existing or new anthropogenic threats, low EPS may reduce population viability and presents conservation challenges.

#### *Invasive Nonindigenous Species*

The nonnative, invasive species that poses the most significant threat to the Rabbitsfoot is the Zebra Mussel. The fouling effects of the Zebra Mussel to native mussels include impeding locomotion (both laterally and vertically), interfering with normal valve movements, deforming valve margins, and locally depleting food resources and increasing waste products. Heavy infestations of the Zebra Mussel on native mussels may stress them by reducing energy stores. They also may reduce food concentrations to levels too low to support reproduction or even survival in extreme cases. The Zebra Mussel also filter and remove native mussel sperm and possibly glochidia

from the water column, thus reducing reproductive potential (Strayer 1999b). Large deposits of pseudofeces of the Zebra Mussel (undigested waste material passed out of the excurrent siphon) may degrade habitat for native mussels (Vaughn 1997c).

The Zebra Mussel occurs in several rivers with the Rabbitsfoot (Ohio, Tennessee, White, Allegheny, and Neosho rivers). Populations of the Zebra Mussel occur primarily in streams with barge navigation (Stoeckel et al. 2003). Biologists have reported that native freshwater mussel populations are able to survive when the Zebra Mussel abundance is low (Butler 2005, B. E. Fisher, IN DNR, pers. comm., 2009), which tends to be the case for rivers with no barge traffic and warmer water temperatures.

Asian Clams have spread throughout the range of the Rabbitsfoot since its introduction in the early twentieth century. It competes with native mussels, particularly juveniles, for resources such as food, nutrients, and space (Neves and Widlak 1987, Leff et al. 1990) and may ingest sperm, glochidia, and newly metamorphosed juveniles of native mussels (Strayer 1999b, Yeager et al. 2000). Periodic die-offs of Asian Clams may produce enough ammonia and consume enough dissolved oxygen to kill native mussels (Strayer 1999b, Cherry et al. 2005, Cooper et al. 2005). Yeager et al. (2000) determined high densities of Asian Clams negatively affect the survival and growth of newly metamorphosed juvenile mussels and thus reduce recruitment. Dense populations of Asian Clams actively disturb sediments that may reduce habitat for native juvenile mussels (Strayer 1999b). Ferreira-Rodríguez et al. (2018) conducted field and laboratory experiments to assess the effects of the Asian Clam (*Corbicula fluminea*, Müller 1774) on the growth, physiological condition, and locomotor activity of *Unio delphinus* (Spendgler 1783). They found *U. delphinus* exhibited lower growth and physiological condition and greater locomotor activity at high densities of *Corbicula fluminea*. Although they were not able to establish the main mechanism(s) responsible for these results, they hypothesized competition for food resources, and/or and abiotic changes in microhabitat features as a result of bioturbation activities, and production of feces and pseudofeces by *Corbicula fluminea* may be involved in the negative impacts on growth, physiological condition, and locomotor activity.

Densities of Asian Clams vary widely in the absence of native mussels or in patches with sparse mussel concentrations, but their density is never high in dense mussel beds, indicating that it is unable to successfully invade small-scale habitat patches with high unionid biomass (Vaughn and Spooner 2006). The invading clam appears to invade sites where mussels are already in decline (Strayer 1999b, Vaughn and Spooner 2006) and does not appear to be a causative factor in the decline of mussels in dense beds. However, a population of Asian Clams that thrives in previously stressed, sparse mussel populations might exacerbate mussel decline through competition and by

impeding expansion of a mussel population (Vaughn and Spooner 2006). Haag (2019) stated that in his opinion *Corbicula fluminea* is the most compelling single explanation for enigmatic mussel declines, and there is a need for more research to test hypotheses that invoke *Corbicula fluminea* as a mechanism for enigmatic declines in native mussel species.

The introduced Black Carp (*Mylopharyngodon piceus*), a molluscivore (mollusk eater), is a potential threat to the Rabbitsfoot (Strayer 1999b). It has been proposed for widespread use by aquaculturists to control snails, the intermediate host of a trematode (flatworm) parasite that affects catfish in ponds in the Southeast and lower Midwest. The Black Carp feeds on various mollusks, including mussels and snails, in China. They are the largest of the Asiatic carp species, reaching more than 1.2 m in length (Nico and Williams 1996). Foraging rates for a four year old fish average 1.4 – 1.8 kg a day, indicating that a single individual could consume 9,072 kg of native mollusks during its lifetime (Mississippi Interstate Cooperative Resource Association [MICRA] 2005; <https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=573>).

The Round Goby (*Neogobius melanostomus*) is another nonnative, invasive fish species released in the 1980s that is well established and likely to spread through the Mississippi River system (Strayer 1999b). This species is an aggressive competitor of similar-sized benthic fishes (sculpins and darters), as well as a voracious carnivore, despite its size (<25.4 cm in length), preying on a variety of foods, including small mussels and fishes that could serve as glochidial hosts for freshwater mussel species (Strayer 1999b, Janssen and Jude 2001). Therefore, the Round Goby may pose a threat to the Rabbitsfoot reproduction.

#### *Temperature*

Impoundments, tail water releases from dams, industrial and municipal effluents, changes in riparian habitat, and droughts may alter natural temperature regimes. Exact critical thermal limits for survival and normal physiological functions of the Rabbitsfoot are unknown, but closely related species are classified as thermally sensitive e.g., the Pimpleback (*Cyclonaias pustulosa*) (Spooner and Vaughn 2008). However, high temperatures can reduce dissolved oxygen concentrations in the water, which slows growth, reduces glycogen stores, impairs respiration, and may inhibit reproduction (Fuller 1974). Low temperatures can significantly delay or prevent metamorphosis (Watters and O'Dee 2000). Increases in water temperature decrease the period of glochidial encystment, reduce righting speed (various reflexes that tend to bring the body into normal position in space and resist forces acting to displace it out of normal position), increase oxygen consumption, and slow burrowing and movement responses (Fuller 1974, Bartsch et al. 2000, Watters et al. 2001, Schwalb and Pusch 2007, Ganser et al. 2015). Several studies have documented the influence of temperature on

the timing aspects of mussel reproduction (Gray et al. 2002, Allen et al. 2007, Steingraeber et al. 2007). Peak glochidial releases are associated with water temperature thresholds that can be thermal minimums or maximums, depending on the species (Watters and O'Dee 2001). Results of Payton et al. (2016) strongly support the prediction by an Intergovernmental Panel on Climate Change (IPCC) that a thermal increase of 2–3°C for the southeastern United States by 2100 is sufficient to cause negative responses in mussel physiology, tissue biochemistry, and gene expression in thermally intolerant species. In general, Payton et al. (2016) found the thermally tolerant, Spectaclecase (*Villosa lienosa*), responded better without utilizing critical resources necessary to maintain other cellular, metabolic, and physiological processes. Whereas, the thermally sensitive, Alabama Rainbow (*Villosa nebulosi*), utilized resources in response to thermal stress and ultimately was unable to maintain physiological performance and suffered significant mortality.

### *Climate Change*

In its Fifth Assessment Report, the IPCC concluded that warming of the climate system is unequivocal (IPCC 2014). Numerous long-term climate changes have been observed including changes in arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves, and the intensity of tropical cyclones (IPCC 2014). Species that are dependent on specialized habitat types, limited in distribution, or at the extreme periphery of their range may be most susceptible to the impacts of climate change (see 75 FR 48911, August 12, 2010); however, while continued change is certain, the magnitude and rate of change is unknown in many cases.

To the extent possible, we use “downscaled” climate projections which provide higher resolution information that is more relevant to the spatial scales used to assess effects to a given species (see Glick et al. 2011 for a discussion of downscaling). Downscaled projections of climate change are available within the range of the Rabbitsfoot but projecting precise effects on the species from downscaled models is difficult because of the large inhabited geographic area. However, projections for the change in annual mean and maximum air temperature by the year 2074 for the range of the Rabbitsfoot are a decrease of 13–15°C (National Climate Change Viewer, <https://www2.usgs.gov/landresources/lcs/nccv/viewer.asp>).

Mussel species that are classified as thermally sensitive or thermally tolerant, according to their response to warm summer water temperatures >35 °C (Spooner and Vaughn 2008). Although we do not have physiological data on the Rabbitsfoot, a closely related species, *C. pustulosa*, is thermally sensitive (Spooner and Vaughn 2008). Data for the Kiamichi River in Oklahoma suggest that as water and air temperatures increased over a 17-year period,

mussel beds once dominated by thermally sensitive species transitioned to dominance by thermally tolerant species (Galbraith et al. 2010, Spooner and Vaughn 2008). Ficke et al. (2005; 2007) described the general potential effects of climate change on freshwater fish populations worldwide. Overall, they expect the distribution of fish species to change, including range shifts and local extirpations. Because freshwater mussels are entirely dependent upon a fish host for successful reproduction and dispersal, any changes in local fish populations also would affect freshwater mussel populations. Therefore, mussel populations will reflect local extirpations or decreases in abundance of fish species.

Climate change has the potential to increase the vulnerability of the Rabbitsfoot to random catastrophic events (McLaughlin *et al.* 2002, Thomas et al. 2004). We expect an increase in both severity and variation in climate patterns, with extreme floods, strong storms, and droughts becoming more common (Cook et al. 2004, Ford et al. 2011, IPCC 2014). Thomas et al. (2004) reported that frequency, duration, and intensity of droughts are likely to increase due to global climate change.

#### *Cumulative Effects of Threats (Factors A, D, E)*

The life-history traits and habitat requirements of the Rabbitsfoot, and other freshwater mussels in general, make them extremely susceptible to environmental change. Unlike other aquatic organisms (e.g., aquatic insects and fish), mussels have limited refugia from stream disturbances (e.g., droughts, sedimentation, chemical contaminants). Mechanisms leading to the decline of the Rabbitsfoot, as discussed above, range from local (e.g., riparian clearing, chemical contaminants, etc.), to regional influences (e.g., altered flow regimes, channelization, etc.), to global climate change. The synergistic effects of threats are often complex in aquatic environments, making it difficult to predict changes in mussel and fish host(s) distribution, abundance, and habitat availability that may result from these effects. While these stressors may act in isolation, it is more probable that many stressors are acting simultaneously or in combination on populations of the Rabbitsfoot (Galbraith et al. 2010).

## **D. Synthesis**

We considered populations of the Rabbitsfoot extant in 63 of 148 (43%) rivers or creeks. Fourteen of these populations (24%) are stable or improving and 7 declining (11%). The status of 41 (65%) extant populations is unknown due to no new information since publication of the proposed listing rule (Table 1). Reservoir construction isolated most populations within river basins from each other. These results demonstrate a need to conduct more surveys to assess status of populations of the Rabbitsfoot. Individuals are widely scattered in isolated concentrations with low abundance in many extant populations with few exceptions (e.g. Green River, Little River).

The Rabbitsfoot faces a variety of threats from declines in water quality, altered hydrology, riparian habitat fragmentation, and deterioration of instream habitat. These threats, which urbanization may exacerbate within portions of the range coupled with climate change, are important factors affecting future viability of the Rabbitsfoot. Captive propagation, augmentation, and reintroduction may be necessary to increase resiliency and achieve sufficient redundancy in the future. Due to the restricted range of the Rabbitsfoot, geographic isolation of most extant populations, and small population size, this mussel species is likely suffering genetic isolation and reduced adaptive capacity throughout much of its range, resulting in lower representation. Given current and expected future decreases in resiliency, populations become more vulnerable to extirpation from stochastic events resulting in concurrent losses in representation and redundancy.

### III. RESULTS

The current status of the Rabbitsfoot is similar to its status at time of listing with widely scattered individuals in isolated populations with low abundance (see section II.C.1.a). Since publication of the proposed listing rule, biologists have reported records of occurrence for the Rabbitsfoot from 10 additional rivers or creeks, some of which pre-date listing (Table 1). The status of 7 of these population is unknown and the other 3 are extirpated. Results of surveys conducted since listing found that 5 populations whose status biologists determined as extirpated still persist. However, few extant populations (22%) are stable or improving. Threats associated with impoundments, sedimentation, chemical contaminants, mining, inadequacy of State and Federal water quality programs, population fragmentation, climate change, and invasive species continue at levels similar to at the time of listing and continue to threaten extant populations (see section II.C.2.a-e). Given sustained threats and that biologists consider the status of 50% of populations as declining (current declining status coupled with declining status at listing for currently unknown status populations) and few populations as stable or increasing, we conclude that the Rabbitsfoot is still likely to become endangered throughout all or a significant portion of its range; and therefore, we recommend no change in status (threatened).

### IV. RECOMMENDATIONS FOR FUTURE ACTIONS

We arranged the following recommendations for future conservation actions by general priority.

1. Conduct a genetics study to evaluate the taxonomic validity of *Theliderma cylindrica* to determine whether the Service moves forward with recovery planning and implementation for 1 (*Theliderma cylindrica*) or more ( e.g., *Quadrula cylindrica cylindrica* and *Quadrula cylindrica strigillata*) mussel species.
2. Complete a recovery plan.
3. Restore degraded habitat with a focus on areas designated as critical habitat.
4. Implement watershed habitat improvement and protection of critical habitat.

5. Fund and implement a rangewide genomics project to inform propagation and reintroduction efforts.
6. Develop and implement a plan for propagation and reintroduction.
7. Conduct priority research once identified in the recovery plan.
8. Develop and implement a monitoring protocol to assess status rangewide at an appropriate interval or as necessary to accomplish management needs.
9. Implement and enforce programs to minimize spread of invasive or non-native mussel and fish species that compete with native freshwater mussels

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**U.S. FISH AND WILDLIFE SERVICE**  
**5-YEAR REVIEW**  
**Rabbitsfoot (*Quadrula cylindrica cylindrica*)**

**Current Classification:** Endangered

Recommendation resulting from the 5-Year Review

- Downlist to Threatened**
- Uplist to Endangered**
- Delist**
- No change is needed**

**Review Conducted By:** Chris Davidson, U. S. Fish and Wildlife Service, Arkansas Field Office

**FIELD OFFICE APPROVAL:**

**Lead Field Supervisor, U. S. Fish and Wildlife Service**

Approve: \_\_\_\_\_ Date 6/17/2020

**OTHER REGIONAL OFFICE APPROVAL:**

We e-mailed this 5-year review to the following regional and/or field offices for their concurrence prior to finalizing the document: Great Lakes, Missouri Basin, Arkansas-Rio Grande-Texas Gulf, and North Atlantic-Appalachian regions. We will retain any comments that we received, as well as verification of concurrence from other regions, in the administrative record for this 5-year review.

## Appendix A

### Peer Review

**A. Peer Review Method:** Jessica Miller in the Service's Kentucky Field Office solicited 8 individuals for peer review. She sent a draft of the 5-year status review, cover letter, and conflict of interest form to them as attachments to an e-mail. She gave peer reviewers 30 days to complete the review.

Additionally, we solicited staff in the Service's Alabama, Illinois, Indiana, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Ohio, Oklahoma, Pennsylvania, and Tennessee field office's with knowledge and expertise with the Rabbitsfoot or mussels like it for internal reviews. Staff from Illinois, Indiana, Kansas, Louisiana, Mississippi, Missouri, Ohio, Pennsylvania, and Tennessee/Kentucky responded to this request.

**B. Peer Reviewers:** The peer review request included personnel from the following institutions:

1. Dr. Chris Barnhart, Southeast Missouri State University
2. Mr. John Harris, Arkansas State University
3. Mr. Todd Fobian, Alabama Department of Conservation and Natural Resources
4. Mr. Jeremy Tiemann, Illinois Natural History Survey
5. Mr. Kevin Cummings, Illinois Natural History Survey
6. Dr. Tom Watters, The Ohio State University
7. Dr. Michael Hoggarth, Otterbein University
8. Mr. Todd Amacker, Tennessee Valley Authority

**C. Peer Review Charge:** The cover letter explained that the Service was soliciting them for peer review of this draft document because they provided data used to review the status of the Rabbitsfoot and are knowledgeable about it or mussels like it. We asked peer reviewers to conduct a scientific review of technical information. Specifically, we asked for comments that address the following questions:

- Have we assembled the best available scientific and commercial information?
- Is our analysis of this information correct and properly applied? And,
- Can you identify any additional new information on the Rabbitsfoot that has not been considered in this review?

We did not request reviewers to review the legal status determination. We asked that they complete the conflict of interest form and return it with their review.

**D. Summary of Peer Review Comments and Our Response:**

Todd Amacker provided additional information on abundance, population trends, demographic features, or demographic trends for the Elk River since publication of the

proposed listing rule. The data included records of live individuals, fresh dead specimens, and evidence of recruitment, and determined the current status as stable for this population. He also provided additional information about habitat. I incorporated all the additional information into the document.

John Harris provided editorial comments and recommendations that greatly improved the flow, clarity, and accuracy of the review. I incorporated all the edits and recommendations into the document. In addition to these comments, he provided a copy of an unpublished report that summarized results of surveys in War Eagle Creek and the Strawberry and White rivers.

Bouldin, J., W. R. Posey, II, and J. L. Harris. 2013a. Status assessment survey for *Leptodea leptodon* (Rafinesque 1820), the scaleshell, in Arkansas. Department of Biological Sciences, Arkansas State University, Jonesboro, Arkansas. Final report. 24 pp.

This report included survey results for the Rabbitsfoot that were not yet included in the review, so I added them to it.

Chris Barnhart commented on the thorough job the preparer did in compiling the information. He also provided a correction for a sentence that summarized the results of Barnhart (2017). I made the correction.

Jeremy Tiemann provided editorial comments and recommendations that greatly improved the flow and clarity of the review. I incorporated all the edits and recommendations into the document. He also provided a copy of an unpublished report that summarized results of surveys from the North Fork Vermilion River.

Stodola, A. P., S. A. Bales, and D. K. Shasteen. 2013. Freshwater mussels of the Vermilion and Little Vermilion Rivers of the Wabash River in Illinois. Illinois Natural History Survey Technical Report 2013 (27). Champaign, Illinois. 26 pp.

It did not provide any additional information, but replaced a pers. comm reference. He provided information about when it is appropriate to reference *Corbicula* spp. vs. *Corbicula fluminea*. I incorporated the information into the document.

Finally, he stated that with the Williams et al. (2017) publication the Freshwater Mollusk Conservation Society will adopt *Theliderma cylindrica* as the “official” scientific name and asked why the Service is not doing the same. I added results of Lopes-Lima et al. (2019) to the taxonomic classification or changes in nomenclature section of the review to illustrate the need for further studies using multiple genetic markers and appropriate sample sizes of individuals to assess the taxonomic validity of reassignment of the Rabbitsfoot and the Rough Rabbitsfoot as *Theliderma cylindrica* as well as other reassignments from Williams et al. (2017).

Lopes-Lima, M. L. Burlakova, A. Karatayev, A. Gomes-dos-Santos, A. Zieritz, E. Froufe, and A. E. Bogan. 2019. Revisiting the North American freshwater mussel genus

*Quadrula sensu lato* (Bivalvia Unionidae): phylogeny, taxonomy and species delineation. *Zoologica Scripta* 48:313–336.

Todd Fobian provided editorial comments and recommendations that greatly improved the flow, clarity, and accuracy of the review. I incorporated all the edits and recommendations into the document. He also asked about why the Service was not adopting the reassignment of the Rabbitsfoot as *Theliderma cylindrica* from Williams et al. (2017). See summary of response provided above. Finally, he recommended inclusion of results from two publications in the 5-Factors Analysis section of the review:

Geist, J. and K. Auerswald. 2007. Physiochemical stream bed characteristics and recruitment of the freshwater pearl mussel. *Freshwater Biology* 52: 2299–2316.

Haag, W. R. 2019. Reassessing enigmatic mussel declines in the United States. *Freshwater Mollusk Biology and Conservation*. 22: 43–60.

I incorporated the information into the document.

We did not receive peer review comments from the other reviewers.

Table 1. Occurrence, status at time of listing, year of last observation of live and/or fresh dead specimen(s), and current status for the Rabbitsfoot within 8 river basins. Stable, improving, declining, and unknown represent categories of extant populations.

<b>RiverBasin</b>	<b>River/Creek</b>	<b>States</b>	<b>Status at time of listing</b>	<b>Year of last observation</b>	<b>Current Status</b>
<b>Lower Great Lakes</b>	Maumee River	IN, OH	Extirpated	1927	Extirpated
	St. Joseph River	IN, OH	Extirpated	1967	Extirpated
	Fish Creek	IN, OH	Declining	2012	Declining
	Feeder Canal	IN	Extirpated	1908	Extirpated
	St. Mary's River	IN	Extirpated	~1920	Extirpated
	Auglaize River	OH	Extirpated	1900s	Extirpated
<b>Ohio River</b>	Ohio River	IL, IN, KY, OH, PA, WV	Stable	2018	Stable <sup>a</sup>
	Allegheny River	PA	Declining	2007	Unknown
	French Creek	PA	Stable	2017	Stable
	Le Boeuf Creek	PA	Unknown	2006	Unknown
	Conneautee Creek	PA	Unknown	2006	Unknown
	Muddy Creek	PA	Declining	2003	Unknown
	Monongahela River	PA	Extirpated	~1890	Extirpated
	West Fork River	WV	Extirpated	<1913	Extirpated
	Beaver River	PA	Extirpated	1898	Extirpated
	Shenango River	PA	Unknown	2009	Unknown
	Pymatuning Creek	PA	Extirpated	1909	Extirpated

<b>RiverBasin</b>	<b>River/Creek</b>	<b>States</b>	<b>Status at time of listing</b>	<b>Year of last observation</b>	<b>Current Status</b>
<b>Ohio River</b>	Muskingum River	OH	Declining	2007	Unknown
	Mahoning River	OH, PA	Extirpated	<1957	Extirpated
	Tuscarawas River	OH	Extirpated	1997	Extirpated
	Walhonding River	OH	Declining	2019	Improving
	Killbuck Creek	OH	Extirpated	<1990	Extirpated
	Mohican River	OH	Extirpated	2019	Unknown
	Black Fork Mohican River	OH	Extirpated	<1990	Extirpated
	Little Kanawha River	WV	Extirpated	~1900	Extirpated
	Elk River	WV	Extirpated	Unknown	Extirpated
	Big Sandy River	KY	Extirpated	~1800	Extirpated
	Levisa Fork	KY	Extirpated	1909	Extirpated
	Scioto River	OH	Extirpated	1962	Extirpated
	Olentangy River	OH	Extirpated	2016	Unknown
	Whetstone Creek	OH	Extirpated	<1930	Extirpated
	Big Walnut Creek	OH	Extirpated	1961	Extirpated
	Alum Creek	OH	Extirpated	1961	Extirpated
	Walnut Creek	OH	Extirpated	<1990	Extirpated
	Big Darby Creek	OH	Declining	2001	Unknown
Little Darby Creek	OH	Declining	2006	Unknown	
Deer Creek	OH	Extirpated	<1980	Extirpated	

<b>RiverBasin</b>	<b>River/Creek</b>	<b>States</b>	<b>Status at time of listing</b>	<b>Year of last observation</b>	<b>Current Status</b>
<b>Ohio River</b>	Ohio Brush Creek	OH	Extirpated	1970	Extirpated
	Little Miami River	OH	Extirpated	~1900	Extirpated
	Licking River	KY	Extirpated	1963	Extirpated
	South Fork Licking River	KY	Extirpated	<1980	Extirpated
	Kentucky River	KY	Extirpated	~1922	Extirpated
	South Fork Kentucky River	KY	Declining	2009	Unknown
	Salt River	KY	Extirpated	<1980	Extirpated
	Green River	KY	Improving	2015	Stable
	Russell Creek	KY	Extirpated	1908	Extirpated
	Nolin River	KY	Extirpated	2013	Unknown
	Barren River	KY	Declining	2008	Unknown
	Drakes Creek	KY	Extirpated	1926	Extirpated
	West Fork Drakes Creek	KY	Extirpated	1927	Extirpated
	Rough River	KY	Declining	2012	Unknown
	Wabash River	IL, IN	Declining	1988	Unknown
	Mississinewa River	IN	Extirpated	<1990	Extirpated
	Eel River	IN	Declining	2017	Declining <sup>a</sup>
	Tippecanoe River	IN	Stable	2017	Stable <sup>a</sup>
	Vermilion River	IL, IN	Extirpated	<1990	Extirpated
North Fork Vermilion River	IL	Declining	2011	Unknown	

<b>RiverBasin</b>	<b>River/Creek</b>	<b>States</b>	<b>Status at time of listing</b>	<b>Year of last observation</b>	<b>Current Status</b>
<b>Ohio River</b>	Jordan Creek	IL	Unknown	2010	Unknown
	Middle Branch North Fork Vermilion River	IL	Declining	2014	Declining
	Middle Fork Vermilion River	IL	Extirpated	1918	Extirpated
	Salt Fork Vermilion River	IL	Extirpated	~1920	Extirpated
	Sugar Creek (Wabash River)	IN	Extirpated	1932	Extirpated
	Embarras River	IL	Extirpated	1986	Extirpated
	White River	IN	Extirpated	~1960	Extirpated
	East Fork White River	IN	Extirpated	1964	Extirpated
	Driftwood River	IN	Extirpated	<1944	Extirpated
	Big Blue River	IN	Extirpated	<1900	Extirpated
	Brandywine Creek	IN	Extirpated	<1900	Extirpated
	Flatrock River	IN	Extirpated	2012	Unknown
	West Fork White River	IN	Extirpated	<1990	Extirpated
	Black Creek	IN	Extirpated	Unknown	Extirpated
	Sugar Creek (East Fork White River)	IN	Unknown	2012	Unknown
	Big Monon Creek	IN	Unknown	Unknown	Extirpated
Pipe Creek	IN	Unknown	Unknown	Extirpated	
Salamonie River	IN	Unknown	Unknown	Extirpated	

<b>RiverBasin</b>	<b>River/Creek</b>	<b>States</b>	<b>Status at time of listing</b>	<b>Year of last observation</b>	<b>Current Status</b>
<b>Ohio River</b>	Patoka River	IN	Extirpated	1998	Extirpated
<b>Cumberland River</b>	Cumberland River	KY, TN	Extirpated	1979	Extirpated
	Rockcastle River	KY	Extirpated	1911	Extirpated
	Big South Fork Cumberland River	KY	Extirpated	1911	Extirpated
	Beaver Creek	KY	Extirpated	1948	Extirpated
	Obey River	TN	Extirpated	1939	Extirpated
	East Fork Obey River	TN	Extirpated	1929	Extirpated
	Caney Fork	TN	Extirpated	1961	Extirpated
	Stones River	TN	Extirpated	1964	Extirpated
	East Fork Stones River	TN	Declining	2002	Unknown
	West Fork Stones River	TN	Extirpated	1966	Extirpated
	Harpeth River	TN	Extirpated	<1886	Extirpated
	Red River	KY, TN	Declining	1992	Unknown
	Whippoorwill Creek	KY	Extirpated	<1980	Extirpated
<b>Tennessee River</b>	Tennessee River	AL, KY, MS, TN	Stable	2018	Stable <sup>a</sup>
	Holston River	TN	Extirpated	1915	Extirpated
	French Broad River	TN	Extirpated	Unknown	Extirpated
	Little Pigeon River	TN	Extirpated	Unknown	Extirpated

<b>RiverBasin</b>	<b>River/Creek</b>	<b>States</b>	<b>Status at time of listing</b>	<b>Year of last observation</b>	<b>Current Status</b>
<b>Tennessee River</b>	Little Tennessee River	TN	Extirpated	Unknown	Extirpated
	Clinch River	TN	Extirpated	1935	Extirpated
	Lookout Creek	GA	Extirpated	1972	Extirpated
	Sequatchie River	TN	Extirpated	<1925	Extirpated
	Paint Rock River	AL	Improving	2018	Improving
	Hurricane Creek	AL	Extirpated	1991	Extirpated
	Estill Fork Paint Rock River	AL	Extirpated	1970	Extirpated
	Larkin Fork Paint Rock River	AL	Extirpated	1966	Extirpated
	Flint River	AL	Extirpated	1955	Extirpated
	Elk River	TN	Declining	2018	Stable <sup>a</sup>
	Shoal Creek	AL, TN	Extirpated	<1990	Extirpated
	Bear Creek	AL, MS	Declining	2019	Improving <sup>a</sup>
	Duck River	TN	Improving	2015	Improving
	Big Rock Creek	TN	Extirpated	<1990	Extirpated
	Buffalo River	TN	Extirpated	2013	Unknown <sup>a</sup>
<b>Lower Mississippi River</b>	St. Francis River	AR, MO	Declining	2016	Declining <sup>a</sup>
	Big Creek	MO	Extirpated	1976	Extirpated
	Yazoo River	MS	Extirpated	Unknown	Extirpated
	Big Sunflower River	MS	Declining	2017	Declining <sup>a</sup>

<b>RiverBasin</b>	<b>River/Creek</b>	<b>States</b>	<b>Status at time of listing</b>	<b>Year of last observation</b>	<b>Current Status</b>
<b>Lower Mississippi River</b>	Big Black River	MS	Declining	2000	Unknown
	Hatchie River	TN	Unknown	2008	Unknown
<b>White River</b>	White River	AR	Stable	1999	Unknown
	War Eagle Creek	AR	Unknown	2013	Improving
	Buffalo River	AR	Declining	2011	Unknown
	North Fork White River	AR	Extirpated	1914	Extirpated
	Black River	AR, MO	Declining	2014	Declining
	Current River	AR	Declining	1984	Unknown
	Spring River	AR	Declining	2018	Declining
	South Fork Spring River	AR	Declining	2006	Unknown
	Strawberry River	AR	Unknown	2018	Improving <sup>a</sup>
	Little Red River	AR	Extirpated	<1986	Extirpated
	Middle Fork Little Red River	AR	Stable	2016	Declining
Reeses Fork Cache River	AR	Extirpated	1980	Extirpated	
<b>Arkansas River</b>	Verdigris River	KS, OK	Unknown	2018	Unknown <sup>a</sup>
	Fall River	KS	Extirpated	~1900	Extirpated
	Neosho River	KS, OK	Declining	1999	Unknown

<b>RiverBasin</b>	<b>River/Creek</b>	<b>States</b>	<b>Status at time of listing</b>	<b>Year of last observation</b>	<b>Current Status</b>
<b>Arkansas River</b>	Cottonwood River	KS	Extirpated	<1990	Extirpated
	Spring River	KS, MO	Declining	2017	Declining
	North Fork Spring River	MO	Unknown	1995	Unknown
	Center Creek	MO	Extirpated	~1920	Extirpated
	Shoal Creek	MO	Extirpated	<1920	Extirpated
	Illinois River	AR, OK	Declining	2017	Declining
<b>Red River</b>	Blue River	OK	Extirpated	~1900	Extirpated
	Little River	AR, OK	Stable	2018	Stable
	Glover River	OK	Declining	1996	Unknown
	Mountain Fork Little River	OK	Extirpated	1968	Extirpated
	Rolling Fork Little River	AR	Unknown	2013	Unknown
	Cossatot River	AR	Declining	2013	Declining <sup>a</sup>
	Ouachita River	AR, LA	Stable	2013	Stable
	Caddo River	AR	Extirpated	<1986	Extirpated
	Little Missouri River	AR	Declining	1996	Unknown
	Saline River (Ouachita River)	AR	Declining	2015	Stable
	North Fork Saline River	AR	Extirpated	<1986	Extirpated
	Bayou Bartholomew	LA	Declining	2017	Improving <sup>a</sup>
Bayou D'Arbonne	LA	Unknown	2017	Unknown	

<b>RiverBasin</b>	<b>River/Creek</b>	<b>States</b>	<b>Status at time of listing</b>	<b>Year of last observation</b>	<b>Current Status</b>
<b>Red River</b>	Saline River (Little River)	AR	Unknown	2013	Unknown

<sup>a</sup> denotes 1 of the 13 rivers or creeks where biologists reported evidence of recruitment since publication of the proposed listing rule in 2012.