Species Biological Report

Neosho Mucket (*Lampsilis rafinesqueana*)


Cover photo: Dr. Chris Barnhart (Missouri State University)

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This species biological report informs the Final Recovery Plan for the Neosho Mucket (*Lampsilis rafinesqueana*) (U.S. Fish and Wildlife Service 2018). The Species Biological Report is a comprehensive biological status review by the U.S. Fish and Wildlife Service (Service) for the Neosho Mucket and provides an account of species overall viability. A Recovery Implementation Strategy, which provides the expanded narrative for the recovery activities and the implementation schedule, is available at https://www.fws.gov/arkansas-es/. The Recovery Implementation Strategy and Species Biological Report are finalized separately from the Recovery Plan and will be updated on a routine basis.

Executive Summary

The Neosho Mucket is a freshwater mussel endemic to the Illinois, Neosho, and Verdigris River basins in Arkansas, Kansas, Missouri, and Oklahoma. It is associated with shallow riffles and runs comprising gravel substrate and moderate to swift currents, but prefers near-shore areas or areas out of the main current in Shoal Creek and Illinois River. It does not occur in reservoirs lacking riverine characteristics. The life-history traits and habitat requirements of the Neosho Mucket make it extremely susceptible to environmental change (e.g., droughts, sedimentation, chemical contaminants). Mechanisms leading to the decline of Neosho Mucket 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 (interaction of two or more components) 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 Neosho Mucket populations.

To evaluate the biological status of the Neosho Mucket both currently and into the future, we consider the species' viability as characterized by resiliency, redundancy, and representation. The Neosho Mucket needs multiple resilient populations across its range to maintain its persistence into the future and to avoid extinction. Given the habitat deterioration, reduction of the range and small population size, Neosho Mucket has low resilience and low to moderate redundancy, making it more difficult for the species to withstand and recover from stochastic or catastrophic events. Further, the species is likely suffering genetic isolation and reduced adaptive capacity due to reservoir construction isolating populations from each other, resulting in lower representation. All these conditions combined contribute to decreased viability of the Neosho Mucket, and the decreased utility of its habitat if no recovery efforts are implemented for the species.

Introduction

The Species Biological Report is intended to be an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The biological report is intended to be an interim approach as we transition to using a species status assessment (SSA) as the standard format that the Service uses to analyze species as we make decisions under the Endangered Species Act. The intent is for the species biological report to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from candidate assessment to listing to consultations to recovery. Many species will have a Species Biological Report or SSA developed during the listing process. However, for species that are currently listed, such as the Neosho Mucket, a Species Biological Report or an SSA may be the first to be developed during the recovery process. As such, the Species Biological Report or SSA will be a living document. In this document, we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf et al. 2015).

- Resiliency is having sufficiently large populations for the species to withstand stochastic events (arising from random factors).

- Redundancy is having a sufficient number of populations for the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations).

- Representation is having the breadth of genetic makeup of the species to adapt to changing environmental conditions. Representation can be measured through the genetic diversity within and among populations and the ecological diversity of populations across the species' range.

Status of the Species

The Neosho Mucket was listed as endangered on September 17, 2013 (78 *Federal Register* 57076). Critical habitat was designated on April 30, 2015 (80 *Federal Register* 24691).

Taxonomy and Species Description

The Neosho Mucket (*Lampsilis rafinesqueana*) is a freshwater mussel in the family Unionidae. The species was originally described by Frierson (1927) from the Illinois River at Moody's, Cherokee County, Oklahoma (type locality) and in more detail by Oesch (1984) and McMurray *et al*. (2012). The shell is up to 18 cm (five inches) long. The periostracum (external covering of the shell) is olive–yellow to brown, becoming darker brown with age. Green rays are evident on younger shells but obscured as the shells darken with age. These rays are often discontinuous, and in many cases they form distinctive chevron shapes. The nacre (inner shell layer or mother of pearl) is bluish white to white. The species is sexually dimorphic as is typical of *Lampsilis*. The mantle lure of females, described below, is well developed in young females 2 – 5 years of age but may be less developed in older individuals (Oesch 1984; McMurray *et al*. 2012).

Life History

Neosho Mucket lives embedded in the bottom of rivers and streams. They siphon water into their shells and across four gills that are specialized for respiration and food collection. Food items for mussels include algae, bacteria, detritus (disintegrated organic debris), and microscopic animals (Strayer *et al.* 2004). It also has been surmised that dissolved organic matter may be a significant source of nutrition (Strayer *et al.* 2004). Adult mussels are filter feeders and generally orient themselves on or near the substrate surface to take in food and oxygen from the water column. Juveniles typically burrow completely beneath the substrate surface and are pedal (foot) feeders (bringing food particles inside the shell for ingestion that adhere to the foot while it is extended outside the shell) until the structures for filter feeding are more fully developed (Yeager *et al.* 1994; Gatenby *et al.* 1996).

Male mussels release sperm into the water column, which are drawn in by females through their siphons during feeding and respiration. Fertilization takes place inside the shell, and success is apparently influenced by mussel density and water flow conditions (Downing *et al.* 1993). The eggs are retained in the gills of the female until they develop into mature larvae called glochidia. The glochidia of most freshwater mussel species, including Neosho Mucket, have a parasitic stage during which they must attach to the gills, fins, or skin of a fish to transform into a juvenile mussel. Depending on the mussel species, females release glochidia either separately, in masses known as conglutinates (gelatinous or jelly–like), or in one large mass known as a super-conglutinate. The duration of the parasitic stage varies by mussel species, water temperature, and perhaps host fish species. When the transformation is complete, the juvenile mussels drop from their fish host and sink to the stream bottom where, given suitable conditions, they grow and mature into adults.

Neosho Mucket glochidia are an obligate parasite on Smallmouth Bass (*Micropterus dolomieu*), Largemouth Bass (*Micropterus salmoides*), and Spotted Bass (*Micropterus punctulatus*) (Barnhart and Roberts 1997; U.S. Fish and Wildlife Service 2005). Neosho Mucket spawns in late April and May, and female brooding occurs May through August. Barnhart (2003) reported an average fecundity to be approximately 1.3 million glochidia per female in the Spring River, Kansas. The female Neosho Mucket inflates and extends a pair of mantle flaps (actually an extension of the inner lobe of the mantle edge) that resembles a small fish. Each mantle flap in addition to its fish–like shape has pigmentation that resembles an eyespot as well as a fish's lateral line. Muscular contractions of the mantle flaps create an undulating or "swimming" motion that suffices to lure fish hosts (Obermeyer 2000).

Growth rates for mussels are highly variable among species, but overall, mussels tend to grow relatively rapidly for the first few years (Scruggs 1960; Negus 1966) then slow appreciably (Bruenderman and Neves 1993; Hove and Neves 1994). This reduction in growth rate is correlated to sexual maturity, probably as a result of energy being diverted from growth to gamete production (Baird 2000). Heavy–shelled species, such as Neosho Mucket, grow slowly relative to thin–shelled species (Coon *et al.* 1977; Hove and Neves 1994).

Habitat Requirements

Little is known about specific habitat requirements of the Neosho Mucket. The Neosho Mucket is associated with shallow riffles and runs comprising gravel substrate and moderate to swift currents. The species is most often found in areas with swift current, but in Shoal Creek and the Illinois River it prefers near-shore areas or areas out of the main current (Oesch 1984; Obermeyer 2000). Neosho Mucket does not occur in reservoirs lacking riverine characteristics (Obermeyer *et al*. 1997b).

Strayer (1999a) demonstrated that mussels in streams occur chiefly in "flow refuges" (relatively stable areas that displayed little movement of substrate particles during flood events). Other researchers also concluded that mussel location and density are greatest in areas where shear stress (stream's ability to entrain and transport bed material created by the flow acting on the bed material) is low and sediments remain generally stable during flooding (Layzer and Madison 1995; Strayer 1999a; Hastie *et al.* 2001). These "flow refuges" conceivably allow relatively immobile mussels, such as the Neosho Mucket, to remain in the same general location throughout their life span. However, flow refuges are not created equally and other habitat variables are important, but poorly understood (Roberts 2008, pers. comm.).

The following description provides a general characterization of habitat requirements for Neosho Mucket:

1. Geomorphically stable river channels and banks (channels that maintain lateral dimensions, longitudinal profiles, and sinuosity patterns over time without an aggrading or degrading bed elevation) with habitats that support a diversity of freshwater mussel and native fish (such as stable riffles, runs, and mid-channel island habitats that provide flow refuges consisting of gravel and sand substrates with low to moderate amounts of fine sediment and attached filamentous algae).

2. A hydrologic flow regime (the severity, frequency, duration, and seasonality of discharge over time) necessary to maintain benthic habitats where the species are found and to maintain connectivity of rivers with the floodplain, allowing the exchange of nutrients and sediment for maintenance of the mussel's and fish host's habitat, food availability, spawning habitat for native fishes, and the ability for newly transformed juveniles to settle and become established in their habitats.

3. Water and sediment quality (including, but not limited to, conductivity, hardness, turbidity, temperature, pH, ammonia, heavy metals, and chemical constituents) necessary to sustain natural physiological processes for normal behavior, growth, and viability of all life stages.

Very little is known of the microhabitat characteristics/preferences of Neosho Mucket.

Species Distribution and Abundance

Neosho Mucket historically occurred in at least 17 streams within the Illinois, Neosho, and Verdigris River basins covering four states (Arkansas, Kansas, Oklahoma, and Missouri; Table 1; Figure 1). It is endemic to the Arkansas River system (Gordon 1981; Harris and Gordon 1987; Obermeyer 1996; Vaughn 1996; Mather 1990; Obermeyer *et al.* 1997a; Harris *et al.* 2009). Based on historical and current data, Neosho Mucket has been extirpated from approximately 1,342 km (834 mi) of its historical range (62 percent). Most of this extirpation has occurred within the Oklahoma and Kansas portions of its range. Extant populations are disjunct (not contiguous) in approximately 819 km (509 mi) of its range.

A viable population is defined as a wild, naturally reproducing population that is able to persist and maintain sufficient genetic variation to evolve and respond to natural changes and stochastic events without further human intervention. Viable populations are expected to be large and genetically diverse, include multiple age classes, and recruit at sufficient rates to maintain or increase population size. Subpopulations are defined here as significant concentrations of mussels sufficiently isolated from one another as to be unlikely to be simultaneously reduced by a toxic spill or other catastrophic event. Populations are referred to herein as rivers/streams since

insufficient population genetic information exists to more precisely define populations and subpopulations. A study at Miami (OH) University is ongoing (2018) to estimate within river and among river genetic variation for extant populations of Neosho Mucket. Based on these results, we will be able to identify genomic regions showing significant variation among individuals and among populations and identify geographic locations that contain unique variation. The latter will allow us to infer the existence of management units within the species. Knowledge of management units will contribute to the design of optimal strategies for creating captive populations that can be sources of individuals for reintroductions and population augmentations. Knowledge of historic and contemporary gene flow will inform conservation strategies that might serve to link populations (with human assistance) that are currently isolated from one another.

FIGURE 1. Neosho Mucket current and historical distribution.

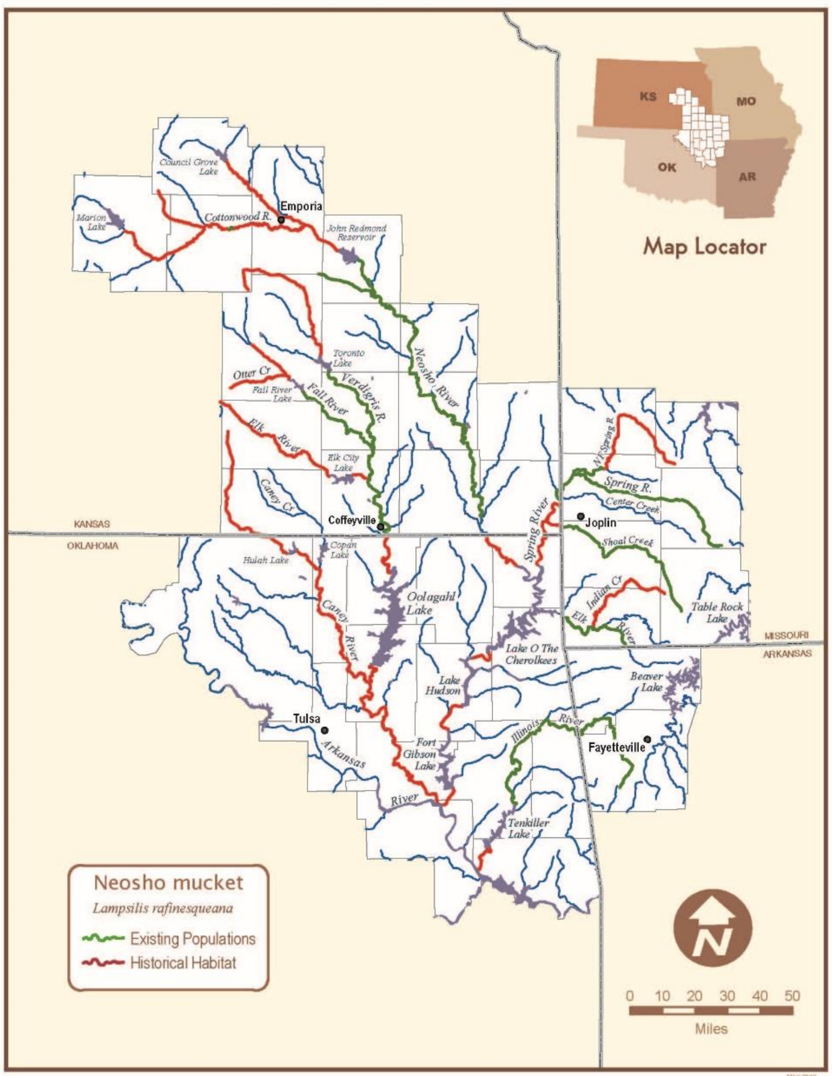

TABLE 1. Neosho Mucket river and creek occurrences and current population status

River Basin	River/Creek	State(s)	Current Status	Date of Last Observation
Neosho River	Neosho River	KS, OK	Declining	2014
	Cottonwood River	KS	Reintroduction	2015
	South Fork Cottonwood River	KS	Extirpated	Pre-1979
	Spring River	KS, MO, OK	Stable	2015
	North Fork Spring River	MO	Declining	2015
	Cow Creek	KS	Unknown	2006
	Center Creek	KS, MO	Extirpated	1995
	Shoal Creek	KS, MO	Declining	2015
	Elk River	MO, OK	Increasing	2016
	Indian Creek	MO	Extirpated	Pre-1980
	Little Sugar Creek	MO	Extirpated	Pre-1980
Illinois River	Illinois River	AR, OK	Declining	AR – 2008 OK - 1995
Verdigris River	Verdigris River	KS, OK	Declining	2015
	Otter Creek	KS	Extirpated	Pre-1993
	Fall River	KS	Declining	2004
	Elk River	KS	Extirpated	Pre-1979
	Caney River	KS, OK	Extirpated	Pre-1979

Neosho River Basin

Neosho River: The Neosho River drains southeast through Kansas and Oklahoma. Historical data of Neosho Mucket densities for the Neosho River are not available prior to the late 1970s (Obermeyer *et al.* 1997b). Mussel harvest records from the early 1900s provide useful insight on the abundance of mussels in the river. From 1911 through 1912, the Neosho River provided 17 percent or approximately 85 million mussels used in the nation's pearl button industry. Many of the 30 tons of mussel shells processed weekly in 1918 at a shell blank factory in Iola, Kansas, came from the Neosho River near LeRoy, Kansas (Obermeyer *et al.* 1997b).

Since the 1990s, extant populations have been found downstream of John Redmond Reservoir Dam to near Parsons, Kansas, in Allen, Coffey, Labette, and Neosho Counties, Kansas. In addition, fresh dead or relict (shell shows no sign of recent mortality, such as tissue inside shell or outer shell material (periostracum) is weathered) shells were collected at 11 sites extending to near the Kansas–Oklahoma state line in Cherokee County, Kansas (Obermeyer *et al.* 1997a; Obermeyer 2000). In 1994, Obermeyer *et al.* (1995) collected 32 live Neosho Mucket specimens (relative abundance = 0.6 percent) at 7 of 19 sites in Kansas. Surveys conducted by the Peoria Tribe of Indians of Oklahoma from 2006 – 2007 yielded six relict shells from Gravel Bars 4, 7 and 8 (Peoria Tribe of Indians 2011). In 2008, approximately 516,400 Neosho Mucket juveniles were released at Stepps Ford Bridge, Ottawa County, Oklahoma. In 2014, one live and one relict Neosho Mucket was collected at this location, and subsequently relocated due to bridge construction (Downs 2015, pers. comm.). The Neosho Mucket is becoming increasingly rare in the Oklahoma segment of the river (Tabor 2015, pers. comm.).

Cottonwood River: The Cottonwood River drains easterly through eastern Kansas. There are few historical records of Neosho Mucket from the Cottonwood River prior to the late 1970s. Obemeyer *et al.* (1997a) collected 59 live mussels from 6 sites surveyed from 1993 – 1995, but only found weathered dead shells of Neosho Mucket. Kansas Department of Wildlife, Parks, and Tourism (KDWPT) reintroduced approximately 2,725 mature male and brooding female Neosho Mucket individuals at two sites east of Cottonwood Falls, Chase County, Kansas, in 2011 and 2013 – 2015 (Tabor 2015, pers. comm.). KDWPT sampled a 100 x 10 m run at the stocking site in 2018. They found 4 Neosho Mucket (one from each of the 4 restocking efforts, 2011, 2013, 2014, and 2015) (Miller 2018, pers. comm.).

Spring River: The Spring River drains southwesterly through southwest Missouri, southeast Kansas, and eastern Oklahoma. The Spring River Neosho Mucket population is the only viable population. There are few historical records of Neosho Mucket from the Spring River prior to the late 1970s. Obermeyer (1996) provides the most comprehensive status assessment of Neosho Mucket in the Spring River. He collected 1,104 live Neosho Mucket specimens from 13 of 20 sites extending from Missouri Highway 97 downstream to near the Turkey Creek confluence in Kansas.

Miscellaneous records from 1979 – 2010 report 11 localities yielding 566 live Neosho Mucket specimens between Missouri Highway 97 near Stott City, Lawrence County, Missouri, and the Missouri and Kansas state line (McMurray 2011, pers. comm.). From 2014 – 2015, live Neosho Mucket were collected at seven of 16 sites in this same reach (Faiman 2015, pers. comm.). From 1993 – 2007, 30 live Neosho Mucket (number not available) were collected from four Kansas sites upstream of Empire Lake. Cope (1985) collected 424 live Neosho Mucket specimens out of 993 live mussels collected in 79 x 1 m^2 quadrat samples from three Kansas sites upstream of Empire Lake.

The KDWPT surveyed a site approximately 0.5 to 0.8 km downstream of the Kansas and Missouri state line in 2003 and collected 201 live Neosho Mucket specimens (approximately 30 percent of live mussels collected). In 2006, KDWPT collected 141 live Neosho Mucket specimens (approximately 30 percent of live mussels collected) at a site just upstream of the Kansas and Missouri Highway YY (Miller 2011). Eight to 10 percent of live Neosho Mucket specimens collected at the 2006 site were quantitatively aged at less than 5 years (Tabor 2008, pers. comm.). In 2011, a site downstream of Kansas and Missouri Highway YY yielded 114 live Neosho Mucket (36% of community) with at least 5 different age classes, including a four to five year-old age class (Miller 2018, pers. comm.). A 2010 survey, 6 km east of Crestline, Kansas, found 400 live mussel specimens, of which approximately half were Neosho Mucket (Tabor 2011, pers. comm.). The same site was resurveyed in 2014. A total of 176 Neosho Mucket individuals were collected during 436 person minutes. A recent gravel bar shift (presumably due to flooding) placed the majority of this site in a backwater area during normal flow conditions and may compromise the long-term viability of this site.

North Fork Spring River: The North Fork Spring River is a tributary of the Spring River in Missouri. There are no historical records for Neosho Mucket in the North Fork Spring River prior to 1980. Neosho Mucket distribution is limited to a few sites downstream of the Dry Fork confluence southwest of Jasper, Jasper County, Missouri. Three sites yielded 136 live Neosho Mucket specimens in the mid-1990s (Obermeyer *et al.* 1997a; McMurray 2011, pers. comm.). Fourteen live Neosho Mucket were collected at three sites in 2014 – 2015 (Faiman 2015, pers. comm.). In 2018, 16 live Neosho Mucket were collected from four sites near Missouri County Road 210 and the Buck Creek confluence (Faiman 2018, pers. comm.).

Shoal Creek: Shoal Creek is a southern tributary of the Spring River draining portions of southwest Missouri and southeast Kansas. There are few historical records for Neosho Mucket in Shoal Creek prior to 1979. Surveys of Shoal Creek conducted from 1979 to 2001 from Missouri Highway W near Ritchey, Missouri, to Empire Lake, Cherokee County, Kansas, yielded 75 live Neosho Mucket specimens from 11 sites (Obermeyer *et al.* 1995; McMurray 2011, pers. comm.). No specimens were found in the Kansas portion of Shoal Creek. Sixteen live individuals were collected at four of six sites surveyed from 2011 – 2015 (Faiman 2015, pers. comm.). Twenty-two live Neosho Mucket were collected from a single location in Shoal Creek approximately 3.6 km southeast of Tipton Ford and approximately 7.2 km east of Spurgeon, Newton County, Missouri, in 2018. (Faiman 2018, pers. comm.).

Elk River: The Elk River, a tributary of the Spring River, drains southwestern Missouri and northeastern Oklahoma. The Oklahoma reach downstream of Buffalo Creek just west of the Missouri and Oklahoma state line is inundated by Grand Lake O' the Cherokees, resulting in the loss of Neosho Mucket habitat. Live Neosho Mucket individuals have been collected from two sites in Missouri, 18 individuals in 1978 and five individuals in 1995, and the species is rare from Noel, Missouri, to the Kansas and Missouri state line (McMurray 2011, pers. comm.). Brooding Neosho Mucket females and juveniles also were reported in this reach at two sites in 1992 and 1998 (Barnhart 2008, pers. comm.). In 2016 – 2017, 45 live Neosho Mucket were collected from 4 locations in the vicinity of Noel and Hwy DD, McDonald County, Missouri (Faiman 2018, pers. comm.).

Cow Creek: Cow Creek is a tributary of the Spring River draining portions of Crawford and Cherokee counties in southeastern Kansas. One recently deceased male Neosho Mucket was collected in Cow Creek, Cherokee County, Kansas, approximately one mile west of Lawton, Kansas (KS Mussel Database 2011; Angelo *et al*. 2007). Historical and current status for Neosho Mucket in Cow Creek is unknown.

Illinois River Basin

Illinois River: The Illinois River drains portions of northwest Arkansas and northeast Oklahoma. There are few historical records of Neosho Mucket from the Illinois River prior to the late 1970s. In 1978, Gordon *et al.* (1979) surveyed 16 sites between Hogeye and Siloam Springs, Arkansas, but only report Neosho Mucket as part of the mussel fauna. Eighteen live Neosho Mucket specimens were reported from four Arkansas locations in the early 1990s, including the only specimen ever collected from the Muddy Fork Illinois River (Harris 1991; Environmental and Gas Consulting, Inc. 1994). Harris (1998) conducted a Neosho Mucket status survey and found live specimens at 19 of 22 sites in the 48 km reach, Washington and Benton Counties, Arkansas. Neosho Mucket was the third most abundant species collected, but there was little evidence of recent recruitment (Harris 1998).

In 2005, 92 live Neosho Mucket specimens were collected from two Benton County, Arkansas, sites (Robinson Road Bridge and 800 m (2,624 feet) downstream of Chambers Spring Road, Benton County, Arkansas (Posey 2005, pers. comm.). In 2008, the Arkansas Game and Fish Commission (AGFC) and the Service conducted a comprehensive Neosho Mucket status survey in the Arkansas portion of the Illinois River. Live specimens of Neosho Mucket were collected at 9 of 15 survey sites. There was a 53 percent decline in number of extant (still in existence) locations inhabited by live Neosho Mucket specimens, respectively, versus the Harris (1998) status survey. Sixty-seven percent of locations with Neosho Mucket present were represented by three or fewer live specimens. Neosho Mucket was the fourth most abundant species in this portion of the river, but 3 locations accounted for 85 percent of live Neosho Mucket specimens (52 individuals) collected during this survey. Of the 15 survey locations, only two appear stable with the rest in decline, indicating imminent extirpation. No mussels were collected in 2008 at locations sampled by AGFC in 2005, further documenting the precipitous decline of mussels in the Arkansas portion of the Illinois River (Davidson 2011, pers. comm.).

Neosho Mucket was locally common prior to the late 1990s in approximately 89 rkm (55 rmi) of the Illinois River from the Oklahoma and Arkansas state line downstream to Lake Tenkiller, Cherokee County, Oklahoma (Mather 1990). The population within the survey reach was estimated at more than 1,200 individuals in 1990. In 1995, Vaughn (1995, 1997) estimated the Neosho Mucket population in the same reach surveyed by Mather in 1990 at between 500 and 1,000 individuals and locally common at 8 of 10 sites with live mussels. Although some evidence of reproductive potential was observed during 1990 and 1995 (for example, gravid females displaying mantle lures), there was little evidence of recruitment. Neosho Mucket specimens were not found in or downstream of Lake Tenkiller.

Verdigris River Basin

Fall River: The Fall River is a southern tributary of the Verdigris River in southeast Kansas. There are few historical records from the Fall River prior to the mid-1990s (Obermeyer *et al.* 1995). In 1994, Obermeyer *et al.* (1995) found 34 live specimens (relative abundance = 1.7 percent) from 5 sites in the Fall River, with little evidence of recruitment into the population. In

2004, two sites were resurveyed and Neosho Mucket composed 1.0 and 0.5 percent of mussels detected in qualitative and quantitative surveys, respectively (Tabor 2008, pers. comm.). All specimens were found downstream of Fall River Lake in Greenwood, Elk, and Wilson Counties (Obermeyer *et al.* 1995). In 2017, 14 live Neosho Mucket were found upstream of bridge replacement site over the Fall River (Miller 2018, pers. comm.).

Verdigris River: The Verdigris River flows through southeast Kansas and northeast Oklahoma until it reaches the Arkansas River in Oklahoma. There are few historical records from the Verdigris River in either State prior to the 1990s. Obermeyer *et al.* (1997a, 1997b) collected five Neosho Mucket specimens from 4 of 14 sites from 1993 to 1995, representing 0.2 percent of the total sample from the Verdigris River between Altoona, Wilson County, Kansas, and Sycamore, Montgomery County, Kansas. The KDWPT surveys eight sites between the Fall and Verdigris River and Elk and Verdigris River confluences at six year intervals from 1991 – 2010. Six live Neosho Mucket specimens were collected from two of these sites in, seven live specimens from four sites in 2010. Sixteen live specimens were recovered from one site (Dan Small site) in 2015. Newly metamorphosed juveniles were stocked at this site in 2000 and 2002 (Barnhart 2002). Fourteen of 16 adults recovered in 2015 appear to derive from these stocking events, and the other two were 5 – 6 years old and potential offspring of the stocked cohorts. Overall relative abundance of Neosho Mucket in the Verdigris River in Kansas has ranged between 0.1 to 0.3 percent in the years from 1993 to 2015 (Miller 2011; Miller 2015, pers. comm.).

The majority of the Oklahoma reach of the Verdigris has been inundated (Oologah Lake) and channelized as part of the McClellan–Kerr Arkansas River Navigation System. In 1996 and 1997, searches in the Verdigris in Oklahoma found no live Neosho Mucket specimens at 32 sites. However, relict Neosho Mucket shells confirmed the historical presence of the species (Vaughn 1996, 1997). In 2008, researchers confirmed it is still extirpated from the Oklahoma reach (Boeckman 2008, pers. comm.).

Critical Habitat

Critical habitat was designated for Neosho Mucket on April 30, 2015 (80 *Federal Register* 24691) and includes the following units:

- Unit NM1 includes 146.1 km (90.8 mi) of the Illinois River from the Muddy Fork Illinois River confluence with the Illinois River south of Savoy, Washington County, Arkansas, downstream to the Baron Creek confluence southeast of Tahlequah, Cherokee County, Oklahoma.

- Unit NM2 includes a total of 20.3 km (12.6 mi) of the Elk River from Missouri Highway 59 at Noel, McDonald County, Missouri, to the confluence of Buffalo Creek immediately downstream of the Oklahoma and Missouri State line, Delaware County, Oklahoma.

- Unit NM3 includes approximately 75.8 km (47.1 mi) of Shoal Creek from Missouri Highway W near Ritchey, Newton County, Missouri, to Empire Lake where inundation begins in Cherokee County, Kansas.

- Unit NM4 includes 102.3 km (63.6 mi) of the Spring River from Missouri Highway 97 north of Stotts City, Lawrence County, Missouri, downstream to the confluence of Turkey Creek north of Empire, Cherokee County, Kansas.

- Unit NM5 includes 16.4 km (10.2 mi) of the North Fork Spring River from the confluence of Buck Branch southwest of Jasper, Missouri, downstream to its confluence with the Spring River near Purcell, Jasper County, Missouri.

- Unit NM6 includes a total of 171.1 km (106.3 mi), including 90.4 km (56.2 mi) of the Fall River from Fall River Lake dam northwest of Fall River, Greenwood County, Kansas, downstream to its confluence with the Verdigris River near Neodesha, Wilson County, Kansas.

- Unit NM7 includes 244.5 km (151.9 mi) of the Neosho River from Kansas Highway 58 west of LeRoy, Coffey County, Kansas, downstream to the Kansas and Oklahoma State line, Cherokee County, Kansas.

Summary of current resiliency, redundancy, and representation

Two Neosho Mucket populations persist within the Verdigris River basin, one population within the Illinois River basin, and five populations within the Neosho River basin, while its persistence in Cow Creek is unknown and Cottonwood River is questionable due to its recent (2015) reintroduction (Neosho River basin). Reservoir construction isolated each river basin and most populations within the river basin from each other. The Spring and North Fork Spring river populations are the only extant populations connected without barriers (e.g., dams) in the Neosho River basin. Both extant stream populations in the Verdigris River basin are connected without barriers. Neosho Mucket individuals are widely scattered in isolated concentrations with low abundance within each population (river), except the Spring River where relatively high abundance still occurs at extant sites. The Neosho Mucket faces a variety of threats from declines in water quality, altered hydrology, riparian habitat fragmentation, and deterioration of instream habitat. These threats, which are expected to be exacerbated by urbanization within portions of the range and climate change, are important factors affecting future viability of Neosho Mucket. If population declines continue, captive propagation may be needed to increase resiliency. Reintroduction of the species may be necessary to achieve sufficient redundancy. Due to the restricted range, geographic isolation of most extant populations, and small population size, the 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. In summary, through expert elicitation of the recovery team using a qualitative process resiliency was determined to be low in all Neosho Mucket populations except the Spring River. Redundancy was determined to be moderate and representation low to moderate for Neosho Mucket.

Reasons for Listing/Threats Assessment

Below, we present a summary of threats affecting the Neosho Mucket and its habitat. A detailed evaluation of factors affecting the species at the time of listing can be found in the listing determination (78 *Federal Register* 57076). Primary concerns for Neosho Mucket are related to curtailment of habitat and range, small population sizes, and their resulting vulnerability to natural or human induced events.

<u>Factor A: Present or threatened destruction, modification, or curtailment of its habitat or range</u>

Impoundments (Factor A)

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, 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). The decline of mussels within the Arkansas River basin has been directly attributed to construction of numerous impoundments (Obermeyer *et al.* 1997b). Population losses due to impoundments have likely contributed more to the Neosho Mucket decline than any other factor. River habitat throughout the Neosho Mucket range has been impounded, leaving short isolated patches of suitable habitat that sometimes lacks suitable presence and abundance of fish hosts necessary for recruitment. These isolated populations are unable to naturally recolonize suitable habitat upstream/downstream and 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; Miller and Payne 2001; Pringle *et al.* 2000; Watters and Flaute 2010).

Impoundments have eliminated a large portion of the Neosho Mucket population and habitat in the Arkansas River basin. For example, mussel habitat in the Neosho River in Kansas has been adversely affected by at least 15 city dams and 2 Federal dams, both with regulated flows. Almost the entire length of the river in Oklahoma is now impounded or adversely affected by tail water releases from three major dams (Matthews *et al.* 2005). Several reservoirs and numerous small watershed lakes have eliminated suitable mussel habitat in several larger Neosho River tributaries in Kansas and Missouri (Spring, Elk and Cottonwood Rivers and Shoal Creek). The Verdigris River (Kansas and Oklahoma) has two large reservoirs with regulated flows, and the lower section has been channelized as part of the McClellan–Kerr Arkansas River Navigation System. All the major Verdigris River tributaries in Kansas and Oklahoma have been partially inundated by reservoirs with regulated flows and numerous flood control watershed lakes (Obermeyer *et al.* 1995). Construction of Lake Tenkiller eliminated Neosho Mucket populations and habitat in the lower portion of the Illinois River, Oklahoma (Mather 1990).

Sedimentation (Factor A)

Excessive sediments adversely affect riverine mussel populations requiring clean, stable streams (Ellis 1936; Brim Box and Mossa 1999). Adverse effects resulting from sediments have been noted for many components of aquatic communities. Potential sediment sources within a watershed include virtually all activities that disturb the land surface. Most localities occupied by Neosho Mucket are currently being affected to varying degrees by sedimentation.

Sedimentation has been implicated in the decline of mussel populations nationwide, and remains a threat to Neosho Mucket (Ellis 1936; Vannote and Minshall 1982; Dennis 1984; Brim Box and Mosa 1999; Fraley and Ahlstedt 2000; Poole and Downing 2004). 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). In addition, 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 appear to be multifold, and 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 Verdigris and Neosho Rivers) supporting mussels have become increasingly sedimented in over the past century, reducing habitat for the Neosho Mucket (Obermeyer *et al.* 1997a).

Increased sedimentation may explain in part why Neosho Mucket is experiencing recruitment failure in some streams. Interstitial spaces in the substrate provide crucial habitat (shelter and nutrient uptake) for juvenile mussel survival. When interstitial spaces are clogged, interstitial flow rates and spaces are reduced (Brim Box and Mossa 1999), and this decreases habitat for juvenile mussels. Furthermore, sediment may act as a vector for delivering contaminants, such as nutrients and pesticides, to streams, and juvenile mussels may ingest contaminants adsorbed to 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 a brooding Neosho Mucket female’s attempt 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 Neosho Mucket is a filter-feeder and may bury itself in the substrate, 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. High TSS is a potential mechanism to explain the lack of mussel recruitment in many locations (Gascho Landis *et al*. 2013)

Chemical Contaminants (Factor A)

Chemical contaminants are ubiquitous in the environment and are considered 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 be degraded to an extent resulting in adverse effects to mussel populations.

Cope *et al.* (2008) evaluated the pathways of exposure to environmental pollutants for freshwater mollusk 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. Almost nothing is known of the potential mechanisms and consequences of waterborne toxicants on sperm viability. In the female mollusk, the marsupial region of the gill is thought to be physiologically isolated from respiratory functions, and this isolation may provide some level of protection from contaminant interference with a female's ability 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 transformation success of glochidia into juveniles (Ingersoll *et al.* 2007).

Juvenile mussels typically remain burrowed beneath the sediment surface for 2 to 4 years. Residence beneath the sediment surface necessitates deposit (pedal) feeding and a reliance on interstitial water for dissolved oxygen (Watters 2007). The relative importance of juvenile Neosho Mucket exposure to contaminants in overlying surface water, interstitial water, whole sediment, or food has not been adequately assessed. 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 Neosho Mucket 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 have the ability to 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 at 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). Toxicity results based on low–level exposure of adults are similar to 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 Neosho Mucket, 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 and are often a result of atmospheric deposition from industrial processes and incinerators, but metals also are associated with mine water runoff (for example, Tri–State Mining Area in southwest Missouri) and have been attributed to mussel declines in streams such as Shoal, Center, and Turkey Creeks and Spring River in the Arkansas River basin (Angelo *et al.* 2007), which are streams with historical and extant Neosho Mucket populations. 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.* 2007b; Wang *et al.* 2007c; Wang *et al.* 2010). Mussel recruitment may be reduced in habitats with low but chronic heavy metal and other toxicant inputs (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 is another heavy metal that has the potential to negatively affect mussel populations. Mercury has been detected throughout 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 *u*g/L for glochidia and 114 *u*g/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 *u*g/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 from the 1920s to 1970s as insulating material in electric equipment, such as transformers and capacitors, as well as in heat transfer fluids and in lubricants. Polychlorinated biphenyls have also been used in a wide range of products, such as plasticizers, surface coatings, inks, adhesives, flame retardants, paints, and carbonless duplicating paper. Polychlorinated biphenyls were still being introduced into the environment at many sites (such as landfills and incinerators) until the 1990s. The inherent stability and toxicity of PCBs have resulted in them being a persistent environmental problem (Safe 1994 *in* Lehmann *et al*. 2007). Polychlorinated biphenyls are lipophilic (affinity to combine with fats or lipids), adsorb easily to soil and sediment, and are present in the sediment and water column in aquatic environments, making them available to bioaccumulate and induce negative effects in living organisms (Livingstone 2001 *in* Lehmann *et al*. 2007). Studies have demonstrated increased PCB concentrations in native freshwater mussels (Ruessler *et al*. 2011), marine bivalves (Krishnakumar *et al*. 1994), and nonnative, invasive mollusks (zebra mussels and Asian clams) (Gossiaux *et al*. 1996; Lehmann *et al.* 2007) in areas with high levels of PCBs. 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 exposure to PCBs. Relevant changes, whether directly or indirectly due to oxidative stress, may occur at the organ and organism levels and will likely result in mussel population-wide effects, including reduced fecundity and chronic maladies due to PCB exposure (Lehmann *et al*. 2007).

Agriculture, timber harvest, and lawn management practices utilize nutrients and pesticides. These are two broad categories of chemical contaminants that have the potential to adversely affect mussel species. 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 shown 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; Bauer 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 are exacerbated by low flow conditions, such as those experienced during a typical summer season and that may occur with greater frequency and severity as a result of climate change.

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 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.* 2003; 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.* 2003). Studies have shown 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 held 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 (Goodreau *et al.* 1993; Augspurger *et al.* 2003; 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 effects to mussels may be increased during a critical time period (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

L. siliquoidea glochidia 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 both *L. siliquoidea* glochidia and juveniles (Bringolf *et al.* 2007b). The above results indicate the potential toxicity of commonly applied pesticides and the threat to mussel species as a result of the widespread use of these pesticides.

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. The Neosho Mucket is especially threatened by chemical spills because these spills can occur anywhere that highways with tanker trucks, industries, or mines overlap with their distribution.

Pharmaceutical chemicals used in commonly consumed drugs are increasingly found in surface waters. A recent nationwide study sampling 139 stream sites in 30 States detected the presence of numerous pharmaceuticals, hormones, and other organic wastewater contaminants downstream from urban development and livestock production areas (Kolpin *et al*. 2002). 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 Neosho Mucket.

Mining (Factor A)

Gravel and metal mining are activities negatively affecting water quality in Neosho Mucket habitat. Instream and alluvial gravel mining has been implicated 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 (15,000 km^2; 5,800 mi^2 in Kansas, Missouri, and Oklahoma) has adversely affected Center and Shoal Creeks and the Spring River. It has been implicated in the loss of Neosho Mucket from portions of these streams (Obermeyer *et al*. 1997b). A study by Kansas Department of Health and Environment documented a strong negative correlation between the distribution and abundance of native mussels, including Neosho Mucket, and sediment concentrations of lead, zinc and cadmium in the Spring River system (Angelo *et al.* 2007). Sediment and water quality samples exceeded

EPA 2006 threshold effect concentrations for cadmium, lead, and zinc at numerous sampling locations within the Tri–State Mining Area (Gunter 2007, pers. comm.).

Factor B: Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Though it is possible that the intensity of inadvertent or illegal harvest may increase in the future, we have no evidence that this stressor is currently increasing in severity. Overutilization for commercial, recreational, scientific, or educational purposes is not a current threat to the Neosho Mucket in any portion of its range at this time nor is it likely to become so in the future.

Factor C. Disease or Predation

Disease in mussels is poorly known and not currently considered a threat rising to a level such that it would have an effect on the Neosho Mucket as a whole. Studies indicate that, in some localized areas, disease and predation may have negative effects on mussel populations. Though it is possible that the intensity of disease or predation may increase in the future, we have no evidence that this stressor is currently increasing in severity. Disease and predation is not a current threat to the Neosho Mucket in any portion of its range at this time nor is likely to become so in the future.

Factor D: The Inadequacy of Existing Regulatory Mechanisms

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 Neosho Mucket through the point and nonpoint programs.

Nonpoint source (NPS) pollution comes from many diffuse sources, unlike pollution from industrial and sewage treatment plants. Nonpoint source pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it transports natural and human-made pollutants. While some pollutants may be "deposited", some may remain in suspension (dissolved) as they are transported through various waterbodies. States report that nonpoint source pollution is the leading remaining cause of water quality problems. The effects of nonpoint source pollutants on specific waters vary and may not always be fully assessed.

Sources of NPS pollution within the watersheds occupied by Neosho Mucket include timber clear-cutting, clearing of riparian vegetation, urbanization, road construction, and other practices that allow bare earth to enter streams. Currently, the CWA may not adequately protect Neosho Mucket habitat from NPS pollution. There is no information concerning the implementation of the CWA regarding NPS pollution specific to protection of Neosho Mucket. However, insufficient implementation could threaten Neosho Mucket.

Point-source discharges within the range of the Neosho Mucket have been reduced since the enactment of the CWA. Despite some reductions in point source discharges, adequate protection may not be provided by the CWA for filter-feeding organisms that can be affected by extremely low levels of contaminants (see *Chemical Contaminants* discussion). There is no specific information known about the sensitivity of the Neosho Mucket 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 fully protect freshwater mussels, it is difficult to determine whether the CWA is adequately addressing threats to Neosho Mucket.

Factor E. Other Natural or Manmade Factors Affecting Its Continued Existence

Population Fragmentation and Isolation (Factor E)
Population fragmentation and isolation prohibit the natural interchange of genetic material between populations. Most of the remaining Neosho Mucket 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 is increased when they are patchily distributed 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 (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 (Avise and Hambrick 1996).

Neosho Mucket was once widespread throughout its range with few natural barriers to prevent migration (via fish host species) among suitable habitats. However, construction of dams extirpated many Neosho Mucket populations and isolated others. Recruitment reduction or failure is a potential problem for many small Neosho Mucket populations, a potential condition exacerbated by its reduced range, increasingly small populations, and increasingly isolated populations.

The likelihood is high that some Neosho Mucket populations are below the effective population size (EPS– the number of individuals in a population contributing offspring to the next generation), based on restricted distribution and populations only represented by a few individuals. Achieving the EPS is necessary for a population to adapt to environmental change and maintain long-term viability. Isolated populations eventually are extirpated when population size drops below the EPS or threshold level of sustainability (Soulé 1980). Evidence of recruitment in many Neosho Mucket populations is scant, making recruitment reduction or outright failure suspect. These populations may be experiencing the bottleneck effect of not attaining the EPS. Small, isolated, less than EPS–threshold populations of short-lived species (most fish hosts) theoretically die out within a decade. Without genetic interchange, small, isolated populations could be slowly expiring (Tilman *et al.* 1994). Even given the absence of existing or new anthropogenic threats, disjunct populations may be lost as a result of current below-threshold effective population size.

Invasive Nonindigenous Species (Factor E)
Various invasive or nonnative species of aquatic organisms are firmly established in the range of Neosho Mucket. The nonnative, invasive species that poses the most significant threat is the Zebra Mussel, *Dreissena polymorpha*, introduced from Europe. Zebra Mussel fouling effects 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 Zebra Mussels 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. Zebra Mussels also filter and remove native mussel sperm and possibly glochidia from the water column, thus reducing reproductive potential (Strayer 1999b). Habitat for native mussels also may be degraded by large deposits of Zebra Mussel pseudofeces (undigested waste material passed out of the incurrent siphon) (Vaughan 1997).

Overlapping much of the current range of the Neosho Mucket, Zebra Mussels have been detected or are established in two Neosho Mucket streams (Neosho and Verdigris Rivers). Zebra Mussel populations occur primarily in streams with barge navigation (Stoeckel *et al.* 2003). The Zebra Mussel threat to native mussels may be minimized by the lack of barge traffic in rivers with extant Neosho Mucket populations. Native freshwater mussel populations are able to survive when Zebra Mussel abundance is low (Butler 2005; Fisher 2009, pers. comm.), which tends to be the case for rivers with no barge traffic and warmer water temperatures.

The Asian Clam (*Corbicula fluminea*) has spread throughout the range of Neosho Mucket 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 reduced recruitment. Dense Asian Clam populations actively disturb sediments that may reduce habitat for native juvenile mussels (Strayer 1999b).

Asian Clam densities vary widely in the absence of native mussels or in patches with sparse mussel concentrations, but Asian Clam 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 therefore appears to preferentially 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, an Asian Clam population that thrives in previously stressed, sparse mussel populations might exacerbate mussel decline through competition and by impeding mussel population expansion (Vaughn and Spooner 2006).

The introduced Black Carp (*Mylopharyngodon piceus*), a molluscivore (mollusk eater), is a potential threat to Neosho Mucket (Strayer 1999b). It has been proposed for widespread use by aquaculturists to control snails, the intermediate host of a trematode (flatworm) parasite affecting catfish in ponds in the southeast and lower midwest. They are known to feed on various mollusks, including mussels and snails, in China. They are the largest of the Asiatic carp species, reaching more than 1.2 m (4 ft) in length (Nico and Williams 1996). Foraging rates for a four year old fish average 1.4 – 1.8 kg (3 or 4 pounds) a day, indicating that a single individual could consume 9,072 kg (10 tons) of native mollusks during its lifetime (MICRA 2005). In 1994, 30 Black Carp escaped from an aquaculture facility in Missouri during a flood. Recent captures of young fish in the Mississippi river near Cape Girardeau, Missouri suggest that a reproductive population has been established (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 (less than 25.4 cm (10 in.) in length), preying on a variety of foods, including small mussels and fishes that could serve as glochidial hosts (Strayer 1999b; Janssen and Jude 2001). Round Goby may, therefore, pose a threat to Neosho Mucket reproduction.

Temperature (Factor E)
Natural temperature regimes can be altered by impoundments, tail water releases from dams, industrial and municipal effluents, changes in riparian habitat, and droughts. Exact critical thermal limits for Neosho Mucket survival and normal physiological functions are unknown, but closely related species are classified as thermally sensitive (e.g., *Lampsilis cardium* and *Lampsilis teres*; 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 1999). Water temperature increases have been documented to shorten 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). 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 2000).

Climate Change (Factor E)
Our analyses under the Act include consideration of ongoing and projected changes in climate. The terms ‘‘climate’’ and ‘‘climate change’’ are defined by the Intergovernmental Panel on Climate Change (IPCC). ‘‘Climate’’ refers to the mean and variability of different types of weather conditions over time, with 30 years being a typical period for such measurements, although shorter or longer periods also may be used (IPCC 2007). The term ‘‘climate change’’ thus refers to a change in the mean or variability of one or more measures of climate (e.g., temperature or precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both (IPCC 2007).

Various types of changes in climate can have direct or indirect effects on species. These effects may be positive, neutral, or negative and they may change over time, depending on the species and other relevant considerations, such as the effects of interactions of climate with other variables (e.g., habitat fragmentation) (IPCC 2007). In our analyses, we use our expert judgment to weigh relevant information, including uncertainty, in our consideration of various aspects of climate change. Projected changes in climate and related effects can vary substantially across and within different regions of the world (e.g., IPCC 2007 projections are informative and in some cases are the only or the best scientific information available), 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). With regard to Neosho Mucket, downscaled projections of climate change are available, 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 air temperature by the year 2080 for the Neosho Mucket ranges between an increase of 7 to 8 degrees Fahrenheit (°F) in annual air temperature (Maura *et al.* 2007, as displayed on *http://www.climatewizard.org/# 2012*).

Mussels can be placed into thermal guilds, thermally sensitive and thermally tolerant species, according to their response to warm summer water temperatures greater than 35 °C (95 °F) (Spooner and Vaughn 2008). Although we do not have physiological data on Neosho Mucket, a closely related species, *L. cardium*, is thermally sensitive (Spooner and Vaughn 2008). Data for the Kiamichi River in Oklahoma suggests that over a 17-year period as water and air temperatures increased, mussel beds once dominated by thermally sensitive species are now dominated by thermally tolerant species (Galbraith *et al.* 2010; Spooner and Vaughn 2008). As temperature increases due to climate change throughout the range of Neosho Mucket, it may experience population declines as warmer rivers are more suitable for thermally tolerant species. Ficke *et al. (*2005; 2007) described the general potential effects of climate change on freshwater fish populations worldwide. Overall, the distribution of fish species is expected 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 would also affect freshwater mussel populations. Therefore, mussel populations will reflect local extirpations or decreases in abundance of fish species.

<u>Cumulative Effects of Threats (Factors A, D, E)</u>

The life-history traits and habitat requirements of the Neosho Mucket, 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 Neosho Mucket, 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 (interaction of two or more components) 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) (Galbraith *et al.* 2010) on Neosho Mucket populations.

Ongoing Conservation Efforts

During the past decade, numerous conservation partners in state and federal agencies, academia, tribes, and non-governmental organizations have dedicated resources to a variety of Neosho Mucket conservation efforts. These efforts are best categorized into population monitoring, propagation/augmentation/reintroduction, research, and habitat and water quality improvements.

Population Monitoring

The States of Arkansas, Kansas, Missouri, and Oklahoma with assistance from academia, tribes, and the Service conduct periodic status assessments. The AGFC surveys the Illinois River at a seven-year interval. The KDWPT has eight long-term monitoring sites for Neosho Mucket surveyed at six-year intervals for the past 30 years in the Verdigris River. The MDC revisited many of Obermeyer's sites, proposed lake sites, and other opportunistic sites in 2014 – 2015. Additional population monitoring will be essential to the recovery of Neosho Mucket.

Propagation, Augmentation, and Reintroduction

Culture technology has been devised and implemented for the laboratory culture of Neosho Mucket (Barnhart 2003; Barnhart 2006). The Service and its partners have propagated Neosho Mucket with good success. From 1999 – 2008, approximately 2.3 million Neosho Mucket individuals (age zero month or freshly transformed juveniles) were released in Kansas, Missouri, and Oklahoma. Very limited survivorship occurred at a Verdigris River mussel refuge site in Kansas. In 2007, the Peoria Tribe with assistance from academia and the Service reintroduced approximately 200,000 Neosho Mucket juveniles to 2 sites in the Spring River under tribal jurisdiction. In 2008, approximately 516,400 Neosho Mucket juveniles were released at Stepps Ford Bridge, Ottawa County, Oklahoma. In 2014, one live and one relict Neosho Mucket was collected at this location, and subsequently relocated due to bridge construction (Downs 2015, pers. comm.). In 2011 – 2015, the KDWPT reintroduced 2,725 marked mussels from three cohorts comprised of mature males and brooding females (ages 2 – 3+) at two sites in the Cottonwood River. Mortality related to extended drought conditions during summers of 2011 and 2012 allowed sampling of a small number of dead (predated) shells, which had grown substantially. Quantitative sampling of the reintroduction sites occurred in 2017 and was previously discussed in the Cottonwood River section.

Research

The U.S. Geological Survey Columbia Environmental Research Center is conducting research to assess the sensitivity of mussels inhabiting the Ozarks to acute and chronic effects of lead, zinc, and cadmium in water and sediment exposures. Prior to listing, Neosho Mucket was a test organism in this research effort. This information is expected to aid regulatory agencies in establishing water quality criteria protective of Neosho Mucket and other mussel species.

Habitat and Water Quality Improvement

State agencies and the Service review projects potentially affecting Neosho Mucket and make recommendations to minimize and mitigate for adverse effects. The Illinois River Watershed Partnership (IRWP), formed in 2005, is a membership-based organization working to protect and restore the Illinois River and its tributaries. The organization is working together to improve water quality and to educate and encourage others to enjoy and positively affect the Illinois River Watershed. In 2008 and 2009, the IRWP sponsored The Riparian Project, with volunteers planting thousands of trees along stream banks on tributaries to the Illinois River. While efforts similar to IRWP's conservation initiative have been initiated, such as U.S.D.A. Farm Bill programs and state stream team initiatives in Arkansas and Missouri, a coordinated watershed-level approach to conservation is needed to recover Neosho Mucket populations.

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APPENDIX A
Threats Assessment

The following assessment describes the relative importance of various threats to the Neosho Mucket. Threats are categorized under each listing factor and characterized according to the process or event by which they cause (1) a negative effect (the stressor), (2) a change in behavior, reproductive capacity, or survival due to a specific stressor (response), and (3) the geographic extent of the stressor and its related effects (scope). Each threat is assigned an overall threat level. This assessment also identifies potential management actions that can be employed to alleviate the listed threats.

Listing Factors

A = The present or threatened destruction, modification, or curtailment of its habitat or range.
B = Overutilization for commercial, recreational, scientific, or educational purposes.
C = Disease and predation.
D = The inadequacy of existing regulatory mechanisms.
E = Other natural or manmade factors affecting its continued existence.

Scope

Widespread = multiple watersheds, but not present at all sites
Pervasive/omnipresent = all rivers, all sites
Uncertain = scope unknown

Threat Level

High = Stressor is seriously degrading habitat or health of mussels and is widespread across many locations within one or more watersheds; existing circumstances are expected to continue for more than 10 years.

Medium = Threat is likely localized and affects mussels and their habitat at a limited portion of localities; existing circumstances are expected to continue for the next 5 – 10 years.

Low = Stressor is localized in its scope (affects mussels and their habitat at a limited portion of localities); existing circumstances are expected to continue for less than 5 years.

Management Potential

High = Stressor does not require changes to existing infrastructure, funding less than $500,000; affects require localized management and can be accomplished in less than 10 years.

Moderate = Stressor requires minor infrastructure modifications; funding requirements are between $500,000 and $1 million; affects require sustained management across multiple watersheds.

Low = Stressor requires substantive regulatory changes and infrastructure modifications; funding requirements exceed $1 million; affects may not be reversible.

Listing Factor	Threat	Stressor	Response	Geographic Scope	Overall Threat Level	Management Potential	Comments
A	Impoundments	Changes and fluctuation in flow regime, channel scouring and bank erosion	Displacement, desiccation, reduced feeding and respiratory efficiency, disrupted metabolic processes, reduced growth, disrupted fish host attraction	Widespread	High	Low	Dam modifications may be necessary
		Reduced dissolved oxygen levels	Reduced rate of oxygen consumption, slower growth, higher mortallity		Low/Medium	Moderate/Low	Ability to regulate oxygen depends on degree of hypoxia normally experienced; dam modifications required at some sites
		Altered thermal regimes	*Adults and juveniles*: slower growth, reduced glycogen levels, impaired respiration, impaired reproduction, reduced righting speed, slower movement *Glochidia:* shorten encystment period, delayed or no metamorphosis		Medium	Moderate	Dam modifications may be necessary
		Changes in resident fish assemblages	Inhibit encystment, reduce recruitment		Low	Low	
		Population isolation	Prohibit genetic interchange, inbreeding depression		High	Moderate	Propagation and augmentation may be necessary to maintain genetic diversity
A	Gravel Mining	Stream channel modification (altered habitat, flow patterns,	Displacement, desiccation, reduced feeding and respiratory efficiency,	Widespread, but dispersed	Medium	Low	Requires state law and enforcement

Listing Factor	Threat	Stressor	Response	Geographic Scope	Overall Threat Level	Management Potential	Comments
	Gravel Mining (continued)	thermal regime, sediment transport)	disrupted metabolic processes, reduced growth, disrupted fish host attraction				
		Water quality modifications (increased turbidity and temperature, reduced light penetration)	*Adults and juveniles*: slows growth, reduces glycogen, impairs respiration, inhibit reproduction, reduce righting speed, slow movement, oxygen efficiency *Glochidia:* shorten encystment, delay or prevent metamorphosis		Medium	Moderate	
		Fish and macroinvertebrate community changes (fish spawning and nursery and food web disruptions)	Reduces fitness, recruitment and dispersal		Low	Moderate	
A	Tri-State Mining (Lead, Cadmium, Zinc, Copper, Selenium)	Sediment quality	Mortality, disrupting enzyme efficiency, altering filtration rates, reduced growth, behavioral changes, reduced recruitment	Spring River and tributaries; Neosho River; Elm and Tar Creeks	High	Low	Last active mine closed in 1970. Hundreds of mines operated for ~150 years. NRDA ongoing.
		Water quality					
A	Industrial and Municipal Wastewater Treatment	Chemical contaminants	Mortality, disrupting enzyme efficiency, altering filtration rates, reduced growth, behavioral changes, reduced recruitment	Omnipresent	Medium	Low	

Listing Factor	Threat	Stressor	Response	Geographic Scope	Overall Threat Level	Management Potential	Comments
A	Agricultural Practices	Nutrients	Impaired respiration and secretion of byssal thread, reduced ciliary action impairing feeding, depleted lipid, glycogen and other carbohydrates, altered metabolism	Omnipresent	Medium	Moderate	
		Chemical contaminants	See industrial/municipal wastewater treatment	Omnipresent	Medium	Moderate	Add CAFOs
		Riparian clearing	See altered thermal regime and stream channel modification	Omnipresent	High	Moderate	Tributaries, KS mostly row crop encroachment; MO mostly due to CAFOs: AR pasture and urban development; OK mostly for pasture and CAFOs
		Sediment	Reduced feeding and respiratory efficiency, disrupted metabolic processes, reduced growth, disrupted fish host attraction, displacement, mortality	Omnipresent	High	Moderate	Vector for delivering chemical contaminants
A	Unpaved Roads	Sediment	See agricultural practices	Omnipresent	High	Moderate	2015 legislation enacting AR Unpaved Roads Program with direct tie to endangered species and improving water quality

Listing Factor	Threat	Stressor	Response	Geographic Scope	Overall Threat Level	Management Potential	Comments
A	Development (houses, industry, recreational)	Sediment	See Unpaved Roads	Illinois and Spring Rivers, Shoal Creek	High	Moderate	
		Chemical contaminants	See industrial/municipal wastewater treatment		Medium	Moderate	
		Changes and fluctuation in flow regime	See impoundments		High	Low	Impervious surfaces increasing rapidly
A	Recreational Over Use	Habitat disturbance (trampling, dragging boats, snag removal)	Mortality, injury, displacement of individuals	Illinois and Elk Rivers	Locally High	Moderate	Merits additional study to quantify scope of effects
A	Water Diversion	Changes and fluctuation in flow regime	See impoundments	Widespread, but dispersed	Medium	Moderate	
A	Road crossings (bridges, low water pads, fords)	Sediment		Omnipresent	Medium	High	See impoundments
D	Inadequacy of Existing Regulatory Mechanisms	Chemical contaminants	See industrial/municipal wastewater treatment	Omnipresent	Medium	Moderate	Also includes CAFOs
		Sediment	See agricultural practices and gravel mining	Omnipresent	High	Moderate	Agriculture practices are practically exempt from CWA

Listing Factor	Threat	Stressor	Response	Geographic Scope	Overall Threat Level	Management Potential	Comments
E	Climate Change	Water Temperature	See impoundments	Omnipresent	Unknown	Unknown	
		Changes and fluctuation in flow regime					
E	Invasive Nonindigenous Species	Fouling (zebra mussel)	Impede locomotion, interfere with valve movement, shell deformity, reduce recruitment	Omnipresent	Low	High	
		Food availability	Reduce energy stores		Medium	Medium	
		Chemical contaminants from waste products and die-offs (zebra mussel and Asian clam)	See nutrients		Low	High	
		Reduced dissolved oxygen levels	See impoundments		Low	High	
		Predation	Mortality, reduced recruitment and reproduction		Medium	High	