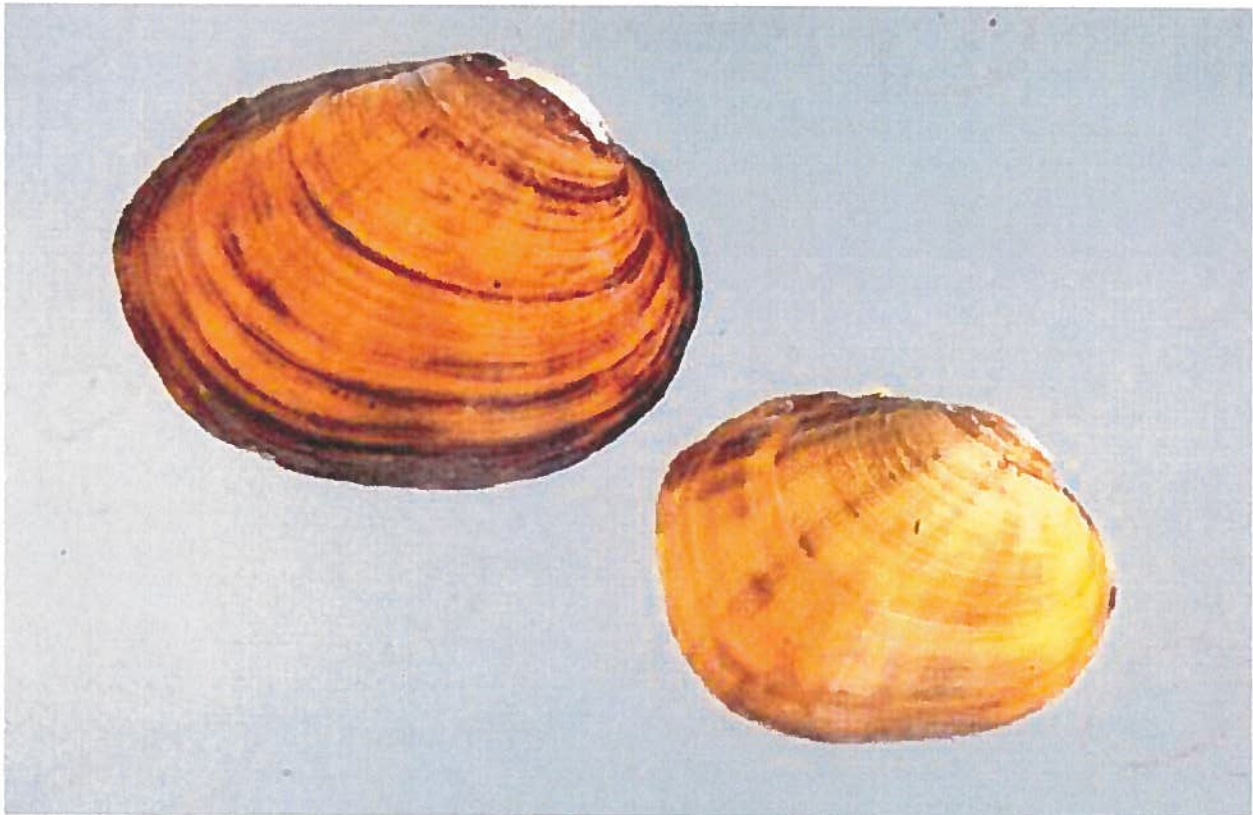


Pink Mucket
Lampsilis abrupta

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



**Male (left, specimen depicted as actual maximum size of 4.7 inches) and female (right);
courtesy Illinois Natural History Survey**

**U.S. Fish and Wildlife Service
Asheville, North Carolina, Field Office**

April 2018

5-YEAR REVIEW
Pink Mucket (*Lampsilis abrupta*)

I. GENERAL INFORMATION

A. Methodology Used to Complete the Review

Public notice was given in the Federal Register and a 60-day comment period was opened in 2008 (73 Federal Register 43947–43948). Pertinent status data was obtained from the Recovery Plan (U.S. Fish and Wildlife Service [FWS] 1985; hereafter not cited but referred to simply as “Recovery Plan”), published papers, unpublished reports, museum records, state natural resource agency imperiled species databases, and personal communications from governmental biologists, private consultants, and other experts on Pink Mucket. Once all known and pertinent data was gathered for this species, the status information was compiled and the review was completed in its entirety by the species’ recovery lead biologist in the Asheville, North Carolina, Field Office (FO). A draft of the 5-year review was peer reviewed by three experts familiar with the species (see Appendix A for a summary of the peer review). In addition, the draft was sent to FWS endangered species biologists throughout its historical range for their comments.

B. Reviewers

Lead Region – Region 4 (Southeast Region): Kelly Bibb, 404/679-7132

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I.C. Background

1. FR Notice citation announcing initiation of this review: July 29, 2008: 73 FR 43947–43948.

2. Species status: Stable

3. Recovery achieved: 1 (0–25%)

4. Listing history:

Original Listing

FR notice: 41 FR 24064–24069

Date listed: June 14, 1976

Entity listed: Species

Classification: Endangered

5. Associated rulemakings: 40 FR 44392–44333; September 26, 1975; CITES: Proposed Endangered Status for 216 Species on Convention Appendix I; 40 FR 44392–44333.

6. Review History: No status review(s), 5-year review(s), or other relevant reviews/documents have been previously completed on the Pink Mucket since the Recovery Plan was finalized in 1985, though the species' status was reviewed as part of the annual Recovery Data Call until 2011.

7. Species' Recovery Priority Number at start of review: 5, indicating a species with a high degree of threat and a low recovery potential.

8. Recovery Plan or Outline:

Name of plan: Recovery Plan [for the] Pink Mucket Pearly Mussel *Lampsilis orbiculata* [=abrupta]

Date issued: January 24, 1985

II. REVIEW ANALYSIS

II.A. Application of the 1996 Distinct Population Segment (DPS) Policy

1. **Is the species under review listed as a DPS?** No
2. **Is there relevant new information that would lead you to consider listing this species as a DPS in accordance with the 1996 policy?** No. The species is an invertebrate and therefore, does not meet DPS eligibility requirements.

II.B. Recovery Criteria

1. Does the species have a final, approved recovery plan containing objective, measurable criteria? Yes

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? No

The recovery criteria do not reflect the best available and most up-to-date information on the biology of the species and its habitat for two general reasons: 1) fish hosts have been determined in addition to many other aspects of its life history, and 2) nearly twice as many populations are now considered extant since the time the 1985 Recovery Plan was written.

b. Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria (and is there no new information to consider regarding existing or new threats)? No

There are four recovery criteria addressed in the Recovery Plan. They are addressed below. Factor 3, Disease and Predation, is not addressed in the Recovery Plan.

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.

1. "When two additional viable populations of [Pink Mucket] are found in any two rivers except the Tennessee, Cumberland, and Meramec Rivers. Both of these rivers will contain viable populations that are distributed such that a single event would be unlikely to eliminate [Pink Mucket] from the river system. Survey data must show at least five viable populations with each population having a minimum of two year-classes between 4 and 10 years of age as evidence of reproduction."

The Recovery Plan defines a *viable population* as "a reproducing population that is large enough to maintain sufficient genetic variation to enable it to evolve and respond to natural habitat changes". Determining the number of individuals needed to meet this definition is one of the recovery tasks.

[Listing factor 1]

The term *population* as used in this criterion refers to all Pink Mucket individuals in a specific stream (a *stream population*), whether we consider them *true populations* or *chance occurrences* in this document (see section II.C.1). Historically, occurrence of the species in the middle White River drainage—including in major tributaries such as Black and Spring rivers—was likely a single biological population with no barrier separating the species in the different rivers. However, for the purpose of this review, they are considered multiple *stream populations*.

At the time the 1985 Recovery Plan was written, 16 Pink Mucket stream populations were considered extant. Two of the populations considered extant in the Recovery Plan (Little Tennessee and Little Black rivers) have become extirpated in the intervening years. Currently, 29 stream populations are considered extant (see section II.C.1.a for status summaries of all extant populations). A number of these were discovered after the Recovery Plan was written in 1985.

The 29 extant stream populations, with few exceptions, are small and occur in relatively short river reaches despite the extent of seemingly suitable habitat in many streams. Over one-third of populations deemed extant are represented by only one or two individuals found over the past ~30 years (yrs) and 16 populations (55%) are individually restricted to ≤ 16 river miles (RMs). Subsequently, a majority of populations are essentially limited to discrete reaches making the species in these streams highly susceptible to extirpation from catastrophic stochastic events. Kanawha River represents one of the better populations rangewide but is particularly susceptible to a single stochastic event since it is limited to ~5 RMs.

In order to meet part of Recovery Criteria 1 language, Pink Mucket populations in Tennessee, Cumberland, and Meramec rivers must be widely distributed enough to prevent a single stochastic event from eliminating one of these populations. Current status suggests that the linear extent of these three populations meets this aspect of the criterion. In addition to these 3 populations, 11 other extant Pink Mucket populations (14 streams total, or 48% of extant streams) are probably distributed widely enough (>20 RMs) within individual rivers to preclude extirpation during a single stochastic event.

The Recovery Plan noted that “evidence of reproduction” was a key aspect of this recovery criterion. The more accurate term as it is used in this instance is “evidence of *recruitment*” and not just *reproduction*. *Reproduction* simply refers to the union of sperm with eggs in the formation of zygotes (and eventually glochidia), whereas *recruitment* refers to newly metamorphosed, free-living juveniles that have been recruited into and are now part of a population. Though successful reproduction—manifest in females gravid with mature glochidia—may be documented, recruitment is only evident when proof through sampling indicates the presence of juveniles or subadults in a population.

Most individuals observed during surveys tend to be large, older adult animals. Despite recent quantitative quadrat sampling in several streams, newly recruited individuals of an age approximating this recovery criterion’s 4-yr old minimum age standard are rarely found in populations. Recovery Criteria 1 stipulates the occurrence of two age cohorts between the ages of 4 and 10 yrs. This aspect of the criterion could probably be demonstrated in at least the lower Tennessee River, Tennessee, and Saline River, Arkansas, populations—deemed the two largest populations rangewide—and possibly elsewhere in relatively large populations if a quantitative sampling program was initiated specifically to find evidence of recent recruitment.

Though there is no empirical data to corroborate, a characteristically low rate of recruitment (see section II.C.1.a) may partially explain the typical absence of juveniles evident in most populations. It is possible that some extant populations have recruitment rates that are below

population maintenance levels while others may suffer from recruitment failure. Below population maintenance level means that a population is below the threshold of sustainability and may be inevitably—if not irreversibly—in decline. Unless this downward trend is arrested or reversed through active population management, the ultimate result will be population extirpation. Considering the advanced age Pink Mucket attains (36+ yrs, see section 2.C.1), non-recruiting populations may take decades to become extirpated. Consequently, we may not know for decades if most extant populations are truly viable.

In summary, given the overall rareness and limited linear extent of most stream populations and the absence of empirical evidence for recruitment in the vast majority of populations, we conclude that this recovery criterion has not been met at this time. However, with focused quantitative sampling regimes to determine the occurrence of multiple age classes from 4–10 yrs of age in some of the larger populations, this criterion could be met if those populations were also distributed such that a single stochastic event would be unlikely to eliminate the species from the river.

2. “Additional mussel sanctuaries are established or expanded in river systems which contain known concentrations of [Pink Mucket].”

[Listing factor 2]

Overutilization for commercial purposes was not specifically identified as a threat to Pink Mucket in the threat’s section of the Recovery Plan. However, Recovery Tasks were included in the narrative outline to reduce the incidence of harvest of this species.

As detailed in section II.C.2.b. of this review, commercial harvest is no longer considered a significant threat to the species globally, and at most, only a very minor threat locally in a few streams where legal harvest occurs for other target species of mussels. Concurrent with the reduced threat from harvest, additional mussel sanctuaries (state-designated river reaches where commercial harvest has been officially banned) have been established or expanded in various rivers since 1985, further protecting the species from any threat of harvest. The States of Kentucky and Tennessee have established numerous sanctuaries in at least portions of the Ohio, Green, Barren, Cumberland, Tennessee, and Clinch rivers (Recovery Plan; Cochran and Layzer 1993; Crowell and Kinman 1993; Todd 1993). Mussel sanctuaries have also been established in Arkansas in portions of the St. Francis, White, Black, Spring, Cache, and Ouachita rivers (C.L. Davidson, FWS, pers. comm., 2014). The States of Indiana, Missouri, Ohio, and West Virginia have closed commercial harvest of all species completely (Anderson et al. 1993; Fassler 1997; S.E. McMurray, MDC, pers. comm., 2014). Waters under ownership of the Ohio River Islands National Wildlife Refuge—which includes several islands in Kentucky, Ohio, and West Virginia—are also banned from commercial harvest (P.A. Morrison, FWS, pers. comm., 2009). Therefore, this Recovery Criterion has been met.

3. “An education program is established for the public with major emphasis towards commercial mussel fisherman.”

[Listing factor 2]

As clarified above, commercial harvest of Pink Mucket was tacitly considered a significant threat in the Recovery Plan, which prompted the major emphasis of this recovery criterion.

Commercial harvest continues to occur in portions of several streams with extant populations of Pink Mucket (e.g., Ohio, Cumberland, Tennessee, St. Francis, White, Black, Spring rivers). Since the Recovery Plan was written, the threat from commercial harvest is now virtually nonexistent (see section II.C.2.b). Relationships between shell buyers and natural resource managers have improved; meetings hosted by both groups have been mutually well-attended, participation and collaboration has been substantial, and outcomes have been positive (e.g., Baker 1993; Fassler 1997). Harvesters and buyers in the industry are better educated and have developed a greater appreciation for conservation of the resource, fully realizing that their livelihoods are based on sustainable mussel populations (Baker 1993). A series of events in the early 1990s (e.g., potential threat from Zebra Mussel, declining dominance of Japanese cultured pearl industry; see section II.C.2.b.) led to the formation of an advocacy group, Shell Exporters of America. Among their goals were to assist managers in the preservation and management of the mussel resource (Cohen 1994 in Fassler 1997).

Over the past ~15 yrs many FWS offices within the range of Pink Mucket have added fulltime education outreach biologists. The FWS outreach staff routinely conducts environmental education programs targeted for various sectors of the population (e.g., secondary school teachers and students, local governmental agencies, landowners, special interest groups). Activities include presentations, workshops, distribution of outreach materials, annual awareness campaigns, and news releases. Federally listed mussels are the focus of many of these programs and Pink Mucket is one of many imperiled species that have been addressed. Therefore, at least indirectly, this recovery criterion has largely been met.

4. “The species and its habitat are protected from present and foreseeable human-related and natural threats that may interfere with the survival of any of the populations.”

[Listing factors 1, 4, and 5]

Pink Mucket is generally intolerant of the profound altered habitat conditions of reservoirs, though sporadic individuals may persist in areas transitional between lentic and lotic habitats. Large hydropeaking and flood control dams contributed directly to extirpation of populations in certain streams (e.g., Obey River, Caney Fork, Little Tennessee River, Limestone Creek) and has resulted in highly fragmented habitats and isolated populations currently characteristic of the species. Typical flow characteristics of many large dam tailwaters (e.g., low temperatures, depressed oxygen levels, lack of minimum flows, bank failures and substrate instability from hydropeaking) continue to negatively affect Pink Mucket habitat in some tailwaters (Barnhart 2003; A.D. Roberts, FWS, pers. comm., 2004) and have contributed to river reaches having reduced populations (e.g., Osage, Cumberland, Clinch, White, Black, Ouachita, Little Missouri rivers). Several extant populations continue to be affected by these dams due to their close proximity downstream from these facilities (e.g., Osage, Sac, Licking, Cumberland, Holston, French Broad, Ouachita rivers) and the lack of stream miles necessary to overcome the negative effects of large impoundments on mussel populations (Vaughn and Taylor 1999). What remains of other stream populations may persist far enough downstream from hydro and flood control dams to be relatively unaffected by tailwater conditions (e.g., Kanawha, Elk, Green, Barren, White, Black, Little Missouri rivers).

Unless tailwater conditions are modified to improve Pink Mucket habitat, many populations downstream of hydro dams will continue to be threatened by their operations. In addition to threats from dam operations, the U.S. Army Corps of Engineers (Corps) has determined that the two largest dams (Wolf Creek, Cumberland River; and Center Hill, Caney Fork) in the middle Cumberland River drainage are at high risk for failure (<https://www.usace.army.mil/Missions/Civil-Works/Dam-Safety-Program/Program-Activities/>). The Pink Mucket population in Cumberland River is therefore at risk from the catastrophic habitat alterations that would result from a major dam failure.

Though most dam operations adversely affect Pink Mucket populations, there are means for improving dam discharges at hydro facilities. For instance, Tennessee Valley Authority (TVA) is improving tailwater conditions downstream of certain dams in the Tennessee River drainage that may benefit Pink Mucket by increasing temperatures through multiport releases, increasing oxygenation with aerators, establishing minimum flow schedules, and reducing or eliminating hydropneaking (e.g., Layzer and Scott 2006). TVA has also changed operations at Wilson Dam on the Tennessee River, Alabama, during summer months to provide flushing flows in the Pink Mucket reach of its tailwaters by pulsing at least one turbine for an hour every four hours (S. Chance, FWS, pers. comm., 2009). Partners are collaborating with Federal Energy Regulatory Commission (FERC), Corps, and power companies to upgrade discharges and improve mussel habitat in tailwaters. For instance, FERC relicensing of the privately owned Bagnell Dam on the Osage River, Missouri, and meetings with the Corps on Cumberland River drainage dam discharges are providing opportunities to improve habitat to two of the most significant Pink Mucket populations in the Osage and Cumberland rivers. At Sutton Dam on Elk River, West Virginia, constructed in 1961, the Corps switched to multiport release in 1980 (Clayton 1994) thus ameliorating some of the effects of operational discharges on downstream Pink Mucket habitat.

Despite its general intolerance to larger reservoir environments, Pink Mucket can persist in run-of-the-river impoundments that retain some riverine characteristics, as well as in certain tailwaters downstream of navigation dams (Haag 2009a). Run-of-the-river reservoirs typically have a riverine zone in their upper reaches that approximates pre-impoundment conditions by having rocky substrates swept free of excessive fine sediment deposits by oxygenated currents and a lentic zone in their lower reaches characterized by more slackwater, low oxygen, and heavy silt depositional conditions (Tippit et al. 1997). The species therefore continues to occupy riverine zones of larger regulated rivers that have been modified to facilitate barge navigation (e.g., Ohio, Cumberland, Tennessee, White, Ouachita rivers). However, its occurrence in transitional areas between tailwaters and reservoirs behind navigational dams is highly sporadic and the species is extremely rare at best in these habitats.

Populations in navigational waters will invariably be susceptible to channel maintenance (e.g., dredging, spoil deposition) and other activities associated with navigation (e.g., mooring facility construction). Stochastic events associated with navigation (e.g., chemical spills from barges) or other sources (e.g., chemical releases from industrial facilities or transportation arteries) are ever-present uncontrollable threats that routinely occur in Pink Mucket habitat (see section II.C.2.e). For example, in the same general Pink Mucket reach of upper Ohio River, two major

catastrophic events within the past 15 yrs resulted in the death of huge numbers of mussels. A chemical release from an Ohio industrial facility at ~RM 177 in the Belleville Lock and Dam Pool wiped out millions of mussels in an ~20 RM reach in 1999 (Ecological Specialists, Inc. [ESI] 2002). Though no dead Pink Mucket were found during mortality assessments at five sites in the core kill reach (~15 RMs long), the rare species was known from the immediate area in recent times and individuals were assumed to have died in unknown numbers from the event (P.A. Morrison, FWS, pers. comm., 2009). In winter 2005 breakaway barges collided with Belleville Lock and Dam resulting in partial dewatering of the pool and the stranding and/or freezing of an estimated 84,000 mussels (P.A. Morrison, FWS, pers. comm., 2009). Though no Pink Mucket were found in the affected reach, individuals may have been affected by the event. Recently, the natural gas extraction industry proposed barging drilling wastewaters down the Ohio River from the Marcellus Shale region of New York, Ohio, Pennsylvania, and West Virginia. If allowed to do so, the probability for spills would increase dramatically given the huge volumes of wastewater potentially involved. Zebra Mussel numbers have also been shown to negatively impact native mussel populations and are a major threat especially in navigational channels such as the Ohio River (see section II.C.2.e). Two of the best Pink Mucket populations occur in the regulated channels of the Cumberland and Tennessee rivers. For these reasons, the complete elimination of these threats is virtually impossible. The threats can, however, be reduced and minimized through use of best management practices and careful planning and prevention.

All Pink Mucket populations may be impacted by activities that fail to maintain riparian buffers and allow sedimentation and pollutants to enter stream habitat. The species may benefit from activities that improve riparian and instream habitat conditions. Various governmental agencies, non-governmental organizations, corporate and private landowners, and other partners are collaborating to protect water and habitat quality in various streams with extant Pink Mucket populations. As an example, The Nature Conservancy and partners have ongoing projects in several streams (e.g., Licking, Green, Clinch, Paint Rock Rivers) intended to repair and restore stream banks, riparian areas, and instream habitats.

The occurrence of fossil fuel and mineral resources in the watersheds of certain Pink Mucket populations adds a threat to the species' persistence. Metals mining takes place in the headwaters of several streams in southeastern Missouri and northeastern Arkansas (e.g., Big, Black, St. Francis rivers). Instream gravel and sand (aggregate) mining affects populations in at least Meramec, Osage, Gasconade, Elk, Tennessee, White, and Ouachita rivers. Take from this activity is a perpetual concern for individuals in Pink Mucket populations in these streams despite regulatory oversight (see section II.C.2.d). Portions of the Ohio River, Ohio and West Virginia; Kanawha and Elk rivers, West Virginia; and Clinch River, Virginia, upstream of their extant Pink Mucket populations represent considerable areas of coal, oil, and natural gas resource extraction activities. The West Virginia and Southwestern Virginia FWS FOs, various agencies, and other partners are working collaboratively to better protect the biota of these rivers from fossil fuel extraction.

In summary, several remaining Pink Mucket populations are significantly threatened by tailwater conditions downstream of hydropeaking dams, activities associated with navigation, and mining activities, while all populations are susceptible to stochastic events.

II.C. Updated Information and Current Species Status

1. Biology and Habitat:

Since the Recovery Plan was written, additional biological studies on Pink Mucket have been completed and ecological information synthesized. Relevant biological information that was not included in the Recovery Plan is provided here. Units of measure are presented as English units except for glochidial dimensions.

Glochidium Description

The Recovery Plan presented a very brief description of a Pink Mucket glochidium without giving dimensions. A subsequent study provides a more detailed description (Hoggarth 1999). The glochidium is 207–214 μm long by 251–259 μm high, without styliform hooks, subspatulate in outline and with straight dorsal margin, broadly rounded ventral margin, and convex anterior and posterior margins. As noted in the Recovery Plan, Ortmann (1912) found two sizes of glochidia for Pink Mucket. However, the Recovery Plan failed to emphasize that he did not find intergrades and could not rule out cross contamination of his sample with glochidia from another species.

Period of Gravidity

The Recovery Plan indicated that the species became gravid in August and September with glochidia overwintering and being released the following June. Subsequent information reports Pink Mucket as gravid in October, November, and January as well (Gordon and Layzer 1989, and citations therein).

Fish Hosts

Host fishes identified through laboratory induced infections include Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieu*), Spotted Bass (*Micropterus punctulatus*), and Walleye (*Sander vitreus*) (Barnhart et al. 1997) as well as White Crappie (*Pomoxis annularis*) and Sauger (*Sander canadensis*) (J.B. Layzer, retired, and L.M. Madison, USGS, pers. comm., in Williams et al. 2008). The use of large piscivorous fishes for hosts is consistent with the presence of a fish-like mantle lure in Pink Mucket (Barnhart et al. 1997). Freshwater drum (*Aplodinotus grunniens*) was erroneously cited as a host by Fuller (1974) (Williams et al. 2008) and Schulz and Marbain (1998) (probably based on Fuller 1974). Dispersal by their large, vagile, habitat generalist host fishes—commonly found in reservoir, tailwater, and riverine habitats alike—may account for the sporadic and sometimes highly disjunct occurrences of Pink Mucket individuals in non-riverine conditions and in streams long distances from known populations.

Sporadic Occurrences in Reservoirs

Pink Mucket often inhabit regulated rivers, particularly those navigational waters modified by locks and dams. Though not reservoir tolerant per se, it is found sporadically in transitional areas between the lentic and lotic habitats of reservoir/tailwater systems in large navigational rivers (e.g., Tennessee River). Typical

reservoir conditions are not conducive for reproduction, recruitment, sustainability, and survival of the species.

True Population or Chance Occurrence?

The mobility of its hosts and host fish tolerance for habitats unsuitable for Pink Mucket may account for the sporadic occurrence of individuals in streams like Bourbeuse, Licking, Paint Rock, Current, and Eleven Point rivers and Bear Creek, as well as in transitional areas between lentic and lotic habitats in large navigational rivers (see previous heading). It is possible that some of these sporadic records—many in otherwise well-sampled streams—do not actually represent true populations but are merely chance occurrences of low-probability events (e.g., a highly mobile host fish conveys Pink Mucket glochidia spawned from adjacent source populations into suitable habitats). Without a source population in relative close proximity (Meramec River for Bourbeuse River; Ohio River for Licking River; Tennessee River, Gunter'sville Dam tailwaters for Paint Rock River; Tennessee River, Wilson Dam tailwaters for Bear Creek; Black River for Current River; and Spring River for Eleven Point River), records for Pink Mucket would probably not exist in several of these streams. Accordingly, relative close proximity of a source population in no way guarantees that these chance occurrences are capable of becoming sustainable “true populations” over time.

It is important but potentially difficult to distinguish between chance occurrences and true populations that are very small and localized due to threats. Though threatened by various factors, Pink Mucket in Paint Rock River and Bear Creek probably represent chance occurrences given the proximity of source Pink Mucket populations and apparent suitable habitat. These two streams, Paint Rock River in particular, may be too small in size to sustain populations of a large river mussel such as Pink Mucket. Pink Mucket in the Bourbeuse River may actually represent a true population, albeit one where the species is very rare due to past and possibly ongoing threats. The upstream extent of range of its parent population in the Meramec River has decreased from ~RM 55 to ~RM 38, which now puts the species ~30 RMs downstream of the mouth of Bourbeuse River. Shrinking range in its parent stream makes population sustainability less likely in Bourbeuse River, especially if it depends on a putative source population in Meramec River for sustainability. Similarly, Pink Mucket in the Licking River may represent a true population that is very small, highly localized, and now disjunct by several hundred river miles to the nearest Pink Mucket population in the upper Ohio River.

For these reasons, it is imperative that ample thought and consideration be given to habitat conditions and Pink Mucket population characteristics in streams before population restoration activities are initiated. In general, population restoration efforts should be focused on putative adjacent source populations, but only if conditions warrant.

Age.

Pink Mucket appears to have a lifespan of at least 36 yrs based on the growth ring method (qualitative age estimations from external shell growth-rest ring counts, Neves and Moyer 1988) from 36 individuals examined from Osage River, Missouri (ESI 2003). It is highly probable the species lives many years longer considering that the growth ring

method typically underestimates age compared to quantitative age determinations (thin sectioning shells to count growth rests), particularly in older specimens (Neves and Moyer 1988). Unfortunately, no empirical age data exists from thin sectioning Pink Mucket shells.

Feeding Ecology and Diet

Neither mussel feeding ecology nor diets were mentioned in the Recovery Plan. Though specific dietary components of Pink Mucket remain unknown, our knowledge of mussel feeding ecology and their foods has increased substantially in recent decades. Mussels in general are suspension feeders (Strayer et al. 2004). They are also capable of deposit feeding—taking organic substances in sediments through their shell gape along ciliated tracts—thus being able to access both planktonic and benthic food supplies (Nichols et al. 2005). Patterns of food availability and hydrodynamic conditions in rivers potentially result in spatial or seasonal shifts between suspension- and deposit-feeding strategies (Ostrovsky et al. 1993; Vaughn and Hakenkamp 2001). Food components typically include detritus, phytoplankton, zooplankton, protozoans, fungal spores, and bacteria (Strayer 2008; Vaughn et al. 2008). Large river species like Pink Mucket have been demonstrated to feed almost exclusively on phytoplankton while suspension feeding (Thorp et al. 1998), but probably deposit feed as well. Juvenile mussels are pedal feeders, using their foot to sweep food particles from sediments into their shells (Reid et al. 1992; Yeager et al. 1994).

Growth and Sexual Maturity

An experimental pond propagation study that took place in early 2006 using Pink Mucket stock from Pickwick Landing tailwaters (Tennessee River, Tennessee) shed light on early life history aspects (D.W. Hubbs, Tennessee Wildlife Resources Agency [TWRA], pers. comm., 2009). Host fish (Largemouth Bass) were infested with mature glochidia teased from a gravid female Pink Mucket and contained in a small pond enclosure. By late summer 2006, six juvenile individuals were found in the pond enclosure and subsequently released to a tailwater enclosure to monitor survival, growth, and sexual activity. After ~20 months, they had all survived and grown from ~0.9 inches (in) length at time of translocation to a range of 2.2–2.7 in, and were beginning to develop sexually dimorphic shell characters. During reassessment in March 2009 when the mussels were approaching 3 yrs of age, the investigator reported 100% survival and that there were four females and two males. All females had charged gills (whether with unfertilized eggs, zygotes, or mature glochidia was unknown) and had grown to a length range of 2.4–2.8 in, while males were longer at 3.1 and 3.2 in.

From this age and growth data it appears that female Pink Mucket reach sexual maturity at 2+ yrs of age. Growth is very rapid for the first few years, especially in males. In general, mussel growth slows considerably after the first few years, presumably when individuals become fully mature, with energy shifting to gamete production and development (Baird 2000).

a. Abundance, population trends (e.g. increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate), or demographic trends:

Pink Mucket has apparently always been an uncommon or rare species (Ortmann 1919; Johnson 1980; Recovery Plan). A similar rarity during archeological times has been documented across much of its historical range (Casey 1986; Bogan 1990; Hughes and Parmalee 1999; Peacock and Chapman 2001). Rarity in these collections could at least partially be attributable to its being a large river species that is generally found in deeper waters, making it difficult for early collectors or Native Americans to effectively procure individuals from these habitats in any appreciable numbers.

Most literature and museum records report very low population numbers for Pink Mucket. The holdings at Ohio State University Museum of Biological Diversity (OSUM, accessed through their web site) represent Pink Mucket collections rangewide over a period covering more than a century. Only 11 of 232 Pink Mucket lots at OSUM, which houses the largest mussel collection in the country, contained more than 10 specimens. All 11 of the largest OSUM lots represented collections made circa (ca.) 1980 from commercial sheller's cull piles in the lower Tennessee and middle Cumberland rivers, Tennessee (L.M. Koch, FWS, pers. comm., 2009). Pink Mucket was similarly reported from harvestors' cull piles on the upper Ohio River (Ortmann 1919).

Recruitment rates may play a considerable role in shaping relative population size and demographic structure (Haag 2012). Current Pink Mucket recruitment rates appear very low given the scant evidence available for presence of juveniles in many populations despite considerable effort in search of small young animals. Considering the species' longevity and the fact that it has always appeared to be rare, it is conceivable that recruitment rates are naturally low for Pink Mucket (e.g., Roff 2002).

Thousands of miles of Pink Mucket former range has been lost over the past century (see section II.C.1.d). Considering the huge range loss, it is likely the current total population size of Pink Mucket represents a small proportion of its historical abundance. Unfortunately, very little quantifiable information is available for estimating population size for this species either historically or currently.

The Recovery Plan noted 16 extant stream populations: Meramec, Big, Osage, Gasconade, Ohio, Kanawha, Green, Cumberland, Tennessee, Clinch, Little Tennessee, Paint Rock, Black, Current, Little Black, and Spring rivers. The lower Little Tennessee River, Tennessee, was inundated by Tellico Reservoir (as stated in the Recovery Plan). Currently, all habitat in the lower river reach in Tennessee is now inundated or adversely affected by cold tailwaters, likely rendering the species extirpated. Pink Mucket is also considered extirpated from Little Black River, Missouri, having not been found live or fresh dead since ca. 1980, despite concerted sampling efforts (Bruenderman et al. 2001a).

The following is an annotated summary of Pink Mucket status in each of the 29 streams considered to have extant populations. For the purposes of this document, stream populations are referenced when addressing extant and historical streams of occurrence. A stream population simply implies that Pink Mucket occupies specific streams but does not connote the genetic definition of the term (see section II.C.1.b for discussion of Pink

Mucket genetic populations). Populations are generally considered extant if live individuals or fresh dead specimens have been observed since ca. 1980. These populations are divided into upper and lower Mississippi River basins, then into their major river drainages. Distribution and relative abundance within particular streams are described in terms outlined by Smith (1965): “generally distributed” implies that suitable habitat should be expected to yield individuals with a reasonably thorough search, “occasional” implies that suitable-appearing habitat may or may not yield individuals even after prolonged search, and “sporadic” implies that encountering individuals cannot be predicted at all. No connotation of abundance is intended with this terminology. When live and fresh dead Pink Mucket are expressed in numerical terms, the abbreviations L and FD are used, respectively. Recent recruitment is noted where known and age estimates represent the external growth ring method. Overall status of each population is generally assessed as improving, stable, declining, or unknown.

Upper Mississippi River basin

Meramec River, Missouri: The Meramec River is a western tributary of the Mississippi River draining east-central Missouri. Pink Mucket is occasional in distribution and rare to uncommon over ~30 RMs (RM 38–7) but may be fairly common and generally distributed in very localized beds. The Meramec River was sampled in 1977–1978 at 66 sites, yielding 19 L Pink Mucket at 9 sites and fresh dead shells at another site from RMs 55.0–4.9 (Buchanan 1980). A follow-up study in 1997 sampled most of the same sites from the Buchanan (1980) survey (Roberts and Bruenderman 2000). The two similar studies allow Pink Mucket status trend comparisons over a 20-year period at 28 sites. At shared sites Pink Mucket comprised a consistent 0.2% of all individuals recovered in Meramec River in both the 1977–1978 (15 L individuals of 7886 total mussels) and 1997 (7 of 3,969) surveys. The species was found live at 7 of the 28 resurveyed sites in 1977–1978 but only at 4 sites in 1997. Pink Mucket occurred over ~50 RMs (~RMs 55–5) during the former survey (19 L/FD at 10 sites) but was reduced by one third to ~33 RMs (~RMs 38–5) during the latter survey (16 L at 7 sites). The 19 individuals ranged in age from 4–15 yrs in the former study and three individuals estimated to be 4–5 yrs old were found at two sites in the latter survey. As part of mitigation at an interstate bridge construction site at RM 6.9, seven live individuals (among 4,514 total mussels) were relocated to a site where six survived one year later (Dunn and Sietman 1997). A juvenile ~3 yrs old was among five live Pink Mucket sampled in 2003 at RM 25.6 (MDC database, S.E. McMurray, pers. comm., 2009). Three visits to the same site during 2003 yielded 11 live individuals while expending 38 total hours of effort (1/3.5 hrs) (N. Eckert, FWS, pers. comm., 2009).

The Meramec River Pink Mucket population represented one of the best populations according to the Recovery Plan. The decline over the 20-year period in total mussel abundance by half and Pink Mucket range by nearly one-third are obvious points of concern for the entire Meramec River mussel fauna (Hinck et al. 2012). Further, species diversity also declined markedly downstream from RM 21.5 (Roberts and Bruenderman 2000). Threats were summarized by Hinck et al. 2011). Habitat loss from channel and bank degradation was cited as the reason for the Pink Mucket decline over the 20-year

period. Encroachment of the St. Louis metropolitan area into the lower Meramec and resultant increase in impervious surfaces is a likely cause of instream habitat instability. General water quality issues from both point and nonpoint sources are a concern due to the high level of urbanization in this reach. Extensive instream aggregate mining (the Corps issued 230 mining permits in the entire Meramec watershed from 1994–1998) and an increasing loss of riparian vegetation was also noted throughout the watershed (Roberts and Bruenderman 2000). The upstream-most extent of Pink Mucket in Meramec River has recently been ~RM 50. Sediments contaminated with cadmium and lead from heavy metals mining in the upper Big River watershed appear to be moving downstream and have the potential to ultimately impact much of the Meramec River population of the species (A.D. Roberts, FWS, pers. comm., 2009). Further, Zebra Mussels have also invaded the Meramec River and warrant close monitoring.

A Pink Mucket propagation and population augmentation program was initiated in 2003 to boost its status in the Meramec River. Several hundred thousand cultured juveniles were released during 2003–2005 at several sites (A.D. Roberts, FWS, pers. comm., 2014). Realizing high mortality rates for newly-metamorphosed mussels, the program switched to rearing individuals to a taggable (subadult) size. A total of ~400 subadults were released in 2007 and 2010 at two sites (A.D. Roberts and B. Simmons, FWS, pers. comm., 2014). Though still recruiting at some level since 1997, Pink Mucket status in the Meramec River is clearly in decline (Hinck et al. 2012).

Bourbeuse River, Missouri: The Bourbeuse River is a large northern tributary of the Meramec River entering at ~RM 68 and draining a portion of east-central Missouri. The Pink Mucket population was discovered since the Recovery Plan was written and was documented with a single live individual observed in 2002 while diving in a middle reach of the stream (MDC database, S.E. McMurray, pers. comm., 2009). Surveys in 1977–1978 (37 sites, Buchanan 1980) and 1997 (26 sites, Roberts and Bruenderman 2000) failed to detect even relic shells of Pink Mucket. A relic shell was subsequently found in 2008 (A.D. Roberts, FWS, pers. comm., 2009). Threats were summarized by Hinck et al. (2011). It is debatable but possible that these two records represent a true population that depends upon the source population in the Meramec River for sustainability (see section II.C.1). Its current status in the Bourbeuse River is unknown.

Big River, Missouri: The Big River is a large southern tributary of the Meramec River at ~RM 38, draining a portion of east-central Missouri. Pink Mucket is known from a single site in recent years where it is occasional in distribution and uncommon in abundance. Relic shells were found at RM 4.8 during a survey in 1977–1978 consisting of 41 main stem sites (Buchanan 1980). A single live Pink Mucket was found at RM 1.3 among six lower river sites surveyed in 1997 (Roberts and Bruenderman 2000). All nine live individuals (no more than two per sample) observed in the Big River since 1978 have come from the same site (MDC database, S.E. McMurray, pers. comm., 2009). Nineteen sites were sampled in 2008 but only a single relic specimen was found at RM 1.3 (A.D. Roberts, FWS, pers. comm., 2009). Historically, Pink Mucket occurred at least in the lower ~70 RMs (MDC database, S.E. McMurray, pers. comm., 2009). Threats were summarized by Hinck et al. (2011). The species may continue to be affected by metals

mining wastes in the watershed. In fact, a 2009 study found an inverse relationship between mussel diversity and abundance and sediment concentrations of lead and cadmium in the Big River (Roberts et al. 2009). The contaminated sediment slug has apparently reached the lowermost river. The Big River population, which is probably dependent upon Meramec River for sustainability, appears to be declining and in imminent danger of extirpation. The level of Pink Mucket imperilment in the Big River is likely exacerbated from the shrinking status of the species in the parent stream.

Missouri River drainage

Osage River, Missouri: The Osage River is a large southern tributary of the lower Missouri River draining a considerable portion of west-central Missouri and east-central Kansas. Pink Mucket occurrences are sporadic and the species rare between RM 72.5–41.0, more occasional in distribution and uncommon in abundance downstream, while approaching generally distributed and common locally (e.g., ~RM 13.5). During 1981 Pink Mucket were found live at 8 of ~25 sites ranging from RMs 66.0–13.6 (Grace and Buchanan 1981, in ESI 2003). During 2001 sampling downstream of Bagnell Dam (RM 81.7), 36 L individuals were found at 8 of 25 sites ranging from RMs 72.5–13.5, including 13 L at the lowermost site (ESI 2003). Seven and 18 L individuals were also found at RM 13.5 in 2009 and 2010, respectively (Missouri Department of Conservation [MDC] database, S.E. McMurray, pers. comm., 2014). Relic shells were found at several sites further upstream to just downstream of the dam during the 2001 sampling (ESI 2003). The species had a relative abundance of 0.45%, or 36 of 7994 total mussels recorded. The youngest individuals were estimated to be 8 and 9 yrs old over the two studies, respectively (Grace and Buchanan 1981, in ESI 2003; ESI 2003). Despite some quantitative sampling during the study by ESI (2003), no younger individuals were found. These data indicated that recruitment has remained limited over the 20-year period. Generally, fewer species were found per site when comparing the 1981 and 2001 surveys, though a direct comparison of mussel densities between the two studies was deemed difficult. However, both species abundance and diversity are depressed downstream of the dam and increase with distance from the dam, a situation reported in other dam tailwaters as well (e.g., Vaughn and Taylor 1999).

Based on collection records and its larger stream habitats with multiple large tributaries, Pink Mucket likely occurred over extensive big river reaches in this sizable drainage. Conservatively, the species has been eliminated from at least the Sac River confluence to downstream of Bagnell Dam (~160 RMs). Two impoundments—Lake of the Ozarks (completed in 1930) and Harry S. Truman Reservoir (1978)—have drastically restricted the species' distribution in the river and contributed to destruction of its habitat in much of the main stem. Though no pre-impoundment records are available, it potentially occurred much further up the Osage River and possibly into the lower reaches of several large tributaries (e.g., South Grand, Pomme de Terre, Niangua rivers) the downstream-most reaches of which are now inundated by these impoundments. An old lock and dam also occurs at ~RM 12 (ESI 2003). Pink Mucket in the Osage River is now limited to ~60 RMs of the lower main stem.

The physical effects of hydropeaking flow fluctuations are probably largely responsible for a general lack of recruitment and continuing decline of mussels in the lower Osage River (Barnhart 2003; ESI 2003). Its overall status in the river appears to be declining due largely to operation of Bagnell Dam (A.D. Roberts, FWS, pers. comm., 2004). Localized aggregate mining also takes place in the river (A.D. Roberts, FWS, pers. comm., 2009). Over the past several years modifications from the operation of Bagnell Dam include improvements in dissolved oxygen and flow regime. A Pink Mucket propagation and population augmentation program has been initiated with FERC relicensing funding to boost its numbers in the river. During 2012–2013 about 14,400 subadult individuals have been propagated, tagged, and released to two sites in the lower river (RM 27 and RM 72) (B. Simmons, FWS, pers. comm., 2014). The Osage River continues to rank as one of the larger populations rangewide despite its generally uncommon abundance, current declining status, and overall lack of recruitment. If successful, the ambitious augmentation program may soon reverse its conservation status in this river.

Sac River, Missouri: The Sac River is a large southern tributary of the upper Osage River in southwestern Missouri. The Pink Mucket population in the Sac River was considered historical at the time the Recovery Plan was written. Pink Mucket is very sporadically distributed and very rare in the river. During 2001–2002, Hutson and Barnhart (2004) surveyed 32 sites over RMs 53.5–11.3 downstream of Stockton Dam (completed in 1970), yielding a single live female Pink Mucket at RM 21.0. Pink Mucket had a relative abundance of 0.01% (1 of 9124 total mussels recorded). Another live female was found in 2003 at RM 36.7 (Hutson and Barnhart 2004). There appears to be very little recruitment of mussels in general in the river. Historically, this species may have occurred to ~RM 60 (near the confluence of Sac and Little Sac rivers, now inundated by Stockton Dam). During hydropeaking the level of flows released is excessive for the size of river channel which has resulted in much bank sloughing and overall channel instability. These conditions have likely contributed to reduction in mussel recruitment levels. Overall status of Pink Mucket in the Sac River appears to be very rare and declining, being affected by operation of Stockton Dam (A.D. Roberts, FWS, pers. comm., 2004). Little else is known regarding this marginal Pink Mucket population, which is considered in danger of extirpation (Hutson and Barnhart 2004).

Gasconade River, Missouri: The Gasconade River is a southern tributary of lower Missouri River draining south-central Missouri. Pink Mucket is occasionally distributed and generally rare to locally uncommon in abundance in the lower main stem. A 1994 survey of 24 sites downstream of RM 83 produced 11 L individuals from 5 of 10 sites between RMs 6.7–62.5 (Buchanan 1994; MDC database, S.E. McMurray, pers. comm., 2009). Pink Mucket comprised 0.2% of all individuals recovered in lower Gasconade River in 1994 (Buchanan 1994, in Barnhart 2003). Live individuals were found at separate sites in 2004 (3 L, RM 46.5) and 2007 (6 L, ~RM 11), while a fresh dead specimen was found at RM 12.3 in 2006 (MDC database, S.E. McMurray, pers. comm., 2009). A 1.7 in male found in 2004 was estimated to be 3 yrs old. In 2012, sampling at two sites yielded 19 L individuals at RM 8.3 and 7 L at RM 12.3 (MDC database, S.E. McMurray, pers. comm., 2009). Pink Mucket is known from an ~60 RM reach in the

lower river (MDC database, S.E. McMurray, pers. comm., 2009) but is apparently absent from the upper river (Bruenderman et al. 2001b). Its historical range in the river is unknown but it may have occurred considerably upstream of present to near the Big Piney River confluence, the first major tributary upstream of the Pink Mucket reach. Threats to Pink Mucket include channel instability from past landuse practices, wastewater effluents from several municipal and industrial sources, and aggregate mining (Bruenderman et al. 2001b). Pink Mucket appears to be recruiting at some level, as are most species in at least upper Gasconade River (Bruenderman et al. 2001b). The species was considered in decline from loss of habitat in 2004 (A.D. Roberts, FWS, pers. comm., 2004), but 2012 sampling in a four-mile reach of the lower main stem indicates the species appears to be increasing in abundance there.

Ohio River drainage

Ohio River, Ohio, West Virginia, Kentucky, and Illinois: The Ohio River is the largest eastern tributary of the Mississippi River, draining portions of 13 states. All known Pink Mucket populations east of the Mississippi River are from this drainage. Historically, records indicate that the species occurred throughout the 981-mile long main stem Ohio River in all six states that share the river. Over the past several decades, two “subpopulations” persist: one in the upstream river between Ohio and West Virginia and the other near its mouth between Illinois and Kentucky. The species has not been collected in the middle reaches of the Ohio River for many decades with a single exception (see below).

The upstream river subpopulation occurs sporadically and is very rare in three lock and dam pools. Records for eight live individuals are known since 1989 from Belleville (~RMs 175–204), Byrd (~RMs 254–255), and Greenup (~RMs 282–297) pools, but none have been found since 1995 (ESI 2000; West Virginia Department of Natural Resources [WVDNR] database, J.L. Clayton, pers. comm., 2009). In the broad sense, Pink Mucket habitat is confined to approximately the upstream half of these pools where tailwater habitat is more riverine in nature, but actual records for the species are much more restricted than the ~75 RMs of potential habitat collectively in these three pools. The 1989 record of a single live individual from ~RM 443 (Kentucky State Nature Preserves Commission [KSNPC] database, R.R. Evans, pers. comm., 2007) is treated here as a chance occurrence, and not part of the upstream Ohio River Pink Mucket subpopulation. In the downstream subpopulation, recent records of Pink Mucket also appear to be very sporadic in distribution, the species being very rare and limited to the reach in the vicinity of Metropolis, Illinois (~RM 940) downstream ~15 RMs. Appropriate habitat for this subpopulation, however, probably occurs from downstream of Smithland Lock and Dam at RM 918.7 downstream to near the confluence with the Mississippi River, this ~50 RM reach essentially being free-flowing (L.M. Koch, FWS, pers. comm., 2009). Few post-1980 records are recorded in the KSNPC database (1980 RM 940.7, 1 FD; 1980 RM 944.2, 2 FD; 2001 RM 948.4 1L/1FD) (R.R. Evans, pers. comm., 2007). In 1997, Pink Mucket was considered extirpated from the downstream Ohio River (Cummings and Mayer 1997), but the 2001 record proves its continued existence in this reach.

Currently, the collective population in this large river's two subpopulations is very sporadically distributed over a total of ~125 RMs of habitat. Considering its total linear extent, Pink Mucket in the Ohio River may represent one of the longest reaches considered inhabited rangewide, but individual records may be several hundred miles apart, corroborating its rarity and sporadic distribution in both inhabited reaches. It is also highly threatened, as recent history has demonstrated, by navigational activities, industrial pollution, and stochastic events, examples of which were specifically described previously (see section II.B.3 Recovery Criterion 4). The upstream subpopulation cluster is considered in decline due to Zebra Mussel impacts (mostly ca. 2000) and particularly the chemical discharge in 1999. Numerous industrial facilities including several chemical plants located in the Pink Mucket reach are an on-going threat (P.A. Morrison, FWS, pers. comm., 2004, 2009). As part of the mussel population restoration program being implemented following the 1999 chemical discharge, 5000 cultured juvenile Pink Mucket have been released in the Belleville pool. The downstream subpopulation was also considerably affected by Zebra Mussels (Chaffee 1997, see section II.C.2.e.). The last and downstream-most high-wall lock and dam on the river at RM 964.5 is nearing completion. The influence that Olmsted Lock and Dam may have on Pink Mucket in this reach is unknown, but potential habitat will likely be compromised for several miles upstream from the dam, similar to conditions upstream of the other high-wall locks and dams throughout the river. Kentucky has designated limited portions of the river harvest-free mussel sanctuaries (Crowell and Kinman 1993). The upstream subpopulation was considered rare and non-recruiting by ESI (2000), while the downstream subpopulation was considered sporadic and rare (Cicerello et al. 1991; Cicerello and Schuster 2003). Viability of the downstream subpopulation is unknown. Overall, Pink Mucket in the Ohio River appears to be in decline. It is possible that the Zebra Mussel invasion in 1991 was at least partially responsible for its decline since (Chaffee 1997; P.A. Morrison, FWS, pers. comm., 2004; see section II.C.2.e.). However, its absence during a 1982 trail survey along the entire 664 RM northern boundary of Kentucky attested to its extreme rarity 10-yr's earlier (Williams and Schuster 1989).

Kanawha River, West Virginia: The Kanawha River is a large southern tributary of the upper Ohio River with its headwaters in portions of north-central North Carolina, southwestern Virginia, and southern West Virginia. Several studies since ca. 1980 have reported Pink Mucket to be occasional in distribution but generally distributed locally in a ~5 RM reach (RMs 95.5–90.6) downstream of Kanawha Falls where it is uncommon (Stansbery 1980; Clarke 1982; Taylor 1983). For example, 10 and 14 L individuals were reported in this reach in 1982 (Taylor 1983) and 1990–1991 (Clarke 1991), respectively. In 1999, six live/fresh dead Pink Mucket were found at five sites; sampling efforts included both channel diving and bank snorkeling (Douglas ca. 1999). Relative abundance for Pink Mucket was 0.7% (6 of 843). One individual was estimated to be 9–12 yrs old (Douglas ca. 1999). A single site in 2005 produced 14 L Pink Mucket over two sampling dates (WVDNR database, J.L. Clayton, pers. comm., 2009).

Historically, Pink Mucket likely occurred throughout the 95 RM Kanawha River reach downstream of Kanawha Falls. Three locks and dams were constructed in this reach and habitat conditions were further compromised due to heavy industrialization of the middle

main stem floodplain and general coal mining in the watershed. Railroad lines that frequently transport coal and chemicals parallel both banks of the Kanawha River the entire length of the Pink Mucket reach. In addition to a major federal highway (US 60) that also parallels the reach, numerous railroad and highway bridges span the river. The limited extent of the population to a ~5 RM reach and its location in a major transportation network therefore makes it particularly susceptible to stochastic events. Fossil fuel extraction activities are also an ongoing threat. The lower Kanawha River impounded reaches effectively isolate the three extant Pink Mucket populations (along with Ohio and Elk rivers) known from West Virginia. Its status is probably stable (B. Douglas, FWS, pers. comm., 2004), having appeared to be recruiting at least in 1999 (Douglas ca. 1999). Though very reach-limited and uncommon in abundance, it is considered one of the more significant population's rangewide.

Elk River, West Virginia: The Elk River is an eastern tributary of the lower Kanawha River draining the east-central portion of West Virginia. The Pink Mucket population in Elk River was considered historical at the time the Recovery Plan was finalized. Recent survey work indicates the status of the population to be sporadic in distribution and rare in a ~50 RM reach downstream of Sutton Dam (~RM 99) but occasional in a localized reach in the lower river. The species was not found during a 1978–1979 survey of 15 sites (Taylor and Hughart 1981). During a 1991–1992 survey, a single live Pink Mucket was found at the lowermost site among 21 sites sampled downstream of Sutton Dam (Clayton 1994). The species was also reported live in 1991 from a site (RM 15.6) further downstream (ESI 1991, in ESI 2009). During a 2002–2008 survey of the river downstream of Sutton Dam (~RM 99), eight live Pink Mucket were observed at 4 of 110 shoals and 2 of 102 pools sampled; fresh dead specimens were collected at another site (ESI 2009). Relative abundance of the 17,803 live mussels recorded in the reach was 0.04%. Seven of the individuals reported by ESI (2009) were estimated to be 12–14 yrs of age (B. Douglas, FWS, pers. comm., 2004). Pink Mucket records (7 of 8 L + FD) were concentrated in a ~5 RM reach downstream of ~RM 29 in Kanawha County but a live individual was also found upstream in Clay County (~RM 77). Coupled with a 2006 record of two large (~4 in length) live and presumably old individuals from ~RM 32 in Clay County in a separate study (Dinkins Biological Consulting 2006), Pink Mucket appears occasional in distribution and uncommon from ~RM 32–24.

Threats were detailed by ESI (2009) and include coal mining (including abandoned mines), oil and natural gas exploration and production, industrial and wastewater treatment plant discharges, riparian zone development, excessive sedimentation from several tributaries, and localized aggregate mining. Stochastic spills from the railway that parallels the river for the entire length of the Pink Mucket reach, numerous highway bridges, and several pipeline crossings are a constant threat. Pink Mucket have not been found in decades downstream of Big Sandy Creek, whose mouth is 1 RM downstream of the lowermost record (ESI 2009). Heavy sedimentation emanates from this tributary, and the main stem is considered impaired from metals downstream from the creek (ESI 2009). Despite the lack of concerted effort to search for juveniles in the stream (no quadrats were sampled; ESI 2009), Pink Mucket is considered non-recruiting (H.L. Dunn, ESI, pers. comm., 2009), as is most of the mussel fauna (ESI 2009).

Licking River, Kentucky: The Licking River is a southern tributary of the middle Ohio River draining a portion of northeastern Kentucky. Pink Mucket was discovered in the Licking River after the Recovery Plan was written. The species is very sporadically distributed and extremely rare (Cicerello and Schuster 2003). A single large individual was found live in 1994 at the well-collected Moores Ferry site, located ~22 RMs downstream of Cave Run Dam (KSNPC database, R.R. Evans, pers. comm., 2007). Other than a relic shell in 1999 from ~20 RMs upstream from the mouth (>100 RMs downstream from Moores Ferry), no other records are known from the stream. It is debatable but possible that these records represent a true population that depended on a source population in its parent Ohio River for sustainability (see section II.C.1). The range of its potential source population in the Ohio River has decreased and is now several hundred miles away making sustainability of Pink Mucket in the Licking River virtually impossible without active management through population augmentation. Current Pink Mucket status is unknown in the river. The species has been propagated to augment the species in Licking River, which began in 2013 and included a few hundred individuals cultured from Tennessee River broodstock (M. McGregor, Kentucky Department of Fish and Wildlife Resources [KDFWR], pers. comm., 2013).

Green River, Kentucky: The Green River is a large westerly-flowing southern tributary of the lower Ohio River draining west-central Kentucky. Pink Mucket occurs occasionally but is uncommon from Lock and Dam 5 (~RM 168) downstream ~8 RMs. Pink Mucket is very sporadic and extremely rare upstream of RM 198, being known only from a fresh dead specimen observed in 1987 from ~RM 214 (Cicerello et al. 1991; Cicerello and Schuster 2003; KSNPC database, R.R. Evans, pers. comm., 2007). The species is presumably absent from the pools of locks and dams 5 and 6 (~RMs 182–168 and 198–182, respectively) downstream from and in the western portion of Mammoth Cave National Park (MCNP). Were it not for the fact that Lock and Dam 4 (~RM 149) breached in 1965, dropping the water level ~6 feet (Williams 1969) and permanently draining its pool while recreating riverine habitat downstream of Lock and Dam 5, there would be little available habitat for the species anywhere in the Green River downstream of MCNP. About 25 L/FD specimens are known from 1969–1993 from the well-collected site immediately downstream of Lock and Dam 5 (OSUM online database; KSNPC database, R.R. Evans, pers. comm., 2007). In 2001 five live adult Pink Mucket were recorded from three sites in the ~8 RM Pink Mucket reach (R.R. Cicerello, KSNPC retired, unpub. data). Relative abundance was 0.3% (5 of 1608 mussels).

It is likely that Pink Mucket historically occurred over the lower half of the Green River (~210 RMs). Beginning in 2007 hatchery cultured juveniles of lower Tennessee River broodstock were released at Munfordville (~RM 225), a heavily-sampled site more than 10 RMs upstream of its known range (KDFWR 2007). Periodic augmentations of other cultured stock continue in this general reach (M. McGregor, Kentucky Department of Fish and Wildlife Resources [KDFWR], pers. comm., 2013). Juvenile releases have also taken place in MCNP (J.B. Layzer, USGS retired, pers. comm., 2009). The population is isolated from the Ohio River by three intact locks and dams in the lower river. A section of river downstream of Lock and Dam 5 is a state-designated mussel sanctuary (Cochran

and Layzer 1993). The Corps is considering removing several of the uppermost locks and dams on Green River, which would open up more riverine habitat for the species. Pink Mucket was considered sporadic in distribution and rare by Cicerello et al. (1991) and currently appears to be in decline, notwithstanding the recent augmentations, whose success remains unknown.

Barren River, Kentucky: The Barren River is a large southern tributary of the middle Green River draining a portion of south-central Kentucky and a very small portion of north-central Tennessee. The Pink Mucket population in the Barren River was discovered after the Recovery Plan was written. It is sporadic in distribution and very rare (Cicerello and Schuster 1991), occurring in the lowermost ~15 RMs downstream of Lock and Dam 1. A single fresh dead specimen was reported in 1988 (KSNPC database, R.R. Evans, pers. comm., 2007). Searching 37 main stem sites in 1993, fresh dead specimens were reported at a single site (Gordon and Sherman 1995). A single live individual was observed from among four sites surveyed in 2001, resulting in a relative abundance of 0.1% (1 of 1235 mussels) (R.R. Cicerello, KSNPC retired, unpub. data). Two live individuals were among 3775 mussels (relative abundance of 0.05%) found at two of four sites sampled in 2008 (Lewis Environmental Consulting 2008). The historical population probably occurred at least several miles further upstream of its current range in the Barren River. A portion of this habitat is now inundated by the lock and dam, while further upstream Barren River Reservoir influences the stream. Though habitat is considered unsuitable for Pink Mucket in the Green River in the vicinity of the Barren River confluence, the two streams may represent a single population due to host fish vagility. Current population status is unknown.

Cumberland River drainage

Cumberland River, Tennessee: The Cumberland River is one of the largest tributaries of the Ohio River, draining southern Kentucky and northern Tennessee and emptying into its parent river in its lowermost reaches in western Kentucky. The sizable Pink Mucket population is occasional in distribution and usually uncommon but may be generally distributed and common on a localized scale, primarily upstream of RM 279 in the middle Cumberland River in north-central Tennessee. The species was common in cull piles in this reach in 1976 (S.A. Ahlstedt, USGS retired, pers. comm., 2014). Collecting data from commercial harvesters over several days during 1982–1983, 121 L individuals were observed from several reaches between RMs 309.2–272.0 (Koch 1983). Estimated age ranged from 10–32 yrs. The smallest Pink Mucket was 2.7 in long, which might indicate recruitment was not occurring, reinforced by the fact that smaller individuals of other species were evident. Age data indicated that recruitment in mussel populations largely ceased about the time Cordell Hull Lock and Dam (CHL&D) was constructed in 1974 at RM 313.5. Eleven bait hauls from RM 297.8–297.6 over two days yielded 33 L individuals representing a relative abundance of 14.2% (33 of 232 total mussels) and making Pink Mucket the third most common among 20 species sampled (Koch 1983). In 1992, diving seven sites proposed for dredge and spoil disposal, six live Pink Mucket were recorded from two sites between RM 308.9–304.3 (Ahlstedt 1995–1996a). The highest catch rate (4 L/hr dive time) was at a proposed dredge site (RM 306.3).

In 2008 23 L Pink Mucket were recorded from nine sites between RMs 297.5–299.5 during 6.8 person hrs of dive time (D.W. Hubbs, TWRA, pers. comm., 2009). The majority of all mussels were found at ~RM 298. Since only 286 total mussels were recorded, Pink Mucket had a relative abundance of 8%. Catch rate (3.4/hr) and relative abundance (8%) for Pink Mucket appears exceedingly high relative to other extant populations, though relative abundance data is primarily due to the overall rareness of the current mussel community in the Cumberland River.

Pink Mucket historically occurred throughout ~550 main stem RMs downstream of Cumberland Falls. Mussels in general were abundant throughout the Cumberland River and this species was considered fairly common particularly in the middle and upper portions of the river during pre-impoundment surveys (Wilson and Clark 1914; Neel and Allen 1964), indicating a large historical population. Hypolimnetic discharges from three major dams—Wolf Creek on the Cumberland River at ~RM 450, forming the largest reservoir east of the Mississippi River; Dale Hollow on the Obey River (~RM 7), confluence at ~RM 370; and Center Hill on Caney Fork (~RM 27), confluence at ~RM 309—have been implicated in suppressed mussel recruitment rates in the current Pink Mucket reach (Heinricher and Layzer 1999). These coldwater discharges presumably disrupt the gametogenic cycle (Layzer et al. 1993), and have led to the extirpation of several rare species and short-lived species over the past 50 yrs (Gordon and Layzer 1989). The general lack of recruitment has led researchers to speculate that relic endangered mussel populations—including Pink Mucket—would disappear unless the thermal regime was returned to normal conditions (Heinricher and Layzer 1999). Recent age estimates may indicate that there has been some recruitment of Pink Mucket in this reach over the past ~25 yrs (D.W. Hubbs, TWRA, pers. comm., 2009). However, it is possible that ages have been considerably underestimated due to reduced growth rates from the hypolimnetic discharges (e.g., Neves and Moyer 1988). Wolf Creek and Center Hill dams, which have had extensive renovation activities conducted over the past several years to remedy serious seepage issues, are both considered at high risk for failure (Corps web site). The Corps has therefore maintained lowered reservoir levels behind both structures for several years beginning in 2005, though they are now restored to pre-2005 levels. The lowered pools have resulted in higher warm season temperatures in the Pink Mucket reach that has coincidentally allowed for increased spawning activity for mussels in general (D.W. Hubbs, TWRA, pers. comm., 2009).

Suitable Pink Mucket habitat appears very patchy and limited to a roughly 35 RM reach downstream of CHL&D at RM 313.5 (D.W. Hubbs, TWRA, pers. comm., 2009). Its status in the Cumberland River downstream of Old Hickory Lock and Dam (~RM 216) is unknown, but no records are available for several decades. Through a state-designated mussel sanctuary, the reach from ~RMs 313.5–292.5 is now protected from commercial harvest (D.W. Hubbs, TWRA, pers. comm., 2009). However, navigational activities remain a threat throughout the Pink Mucket reach. Though mussels are now uncommon in general, Pink Mucket appears to be one of the relatively more common species and the Cumberland River represents one of the best population's rangewide.

Tennessee River drainage

Tennessee River, Alabama, Tennessee, and Kentucky: The Tennessee River is the largest and downstream-most major tributary of the Ohio River draining major portions of Alabama, North Carolina, Tennessee, and Virginia, and minor portions of Georgia, Kentucky, and Mississippi. Pink Mucket is sporadic or occasional in distribution in most upper river lock and dam tailwaters where it is usually rare but may be generally distributed and uncommon in select beds downstream of Pickwick Landing Dam. The 1985 Recovery Plan documented Pink Mucket records from the tailwaters of all nine locks and dams except Chickamauga; live individuals have since been found there as well (D.W. Hubbs, TWRA, pers. comm., 2009).

Appropriate Pink Mucket habitat is generally limited to ~10–30 RMs in the upstream-most tailwaters in eastern Tennessee (Fort Loudon, Watts Bar, Chickamauga, and Nickajack). Occurrences are generally sporadic to locally occasional in these tailwaters, and the species is usually very rare. The lower ends of these reaches represent transitional areas between more riverine tailwater conditions and more lentic reservoir conditions. Habitat for this species appears adequate at best and occurrences are extremely sporadic in transitional areas. Survey work conducted in Watts Bar tailwaters from 1983–1993 may typify the status of Pink Mucket in other headwater tailwaters. Repetitive sampling in three mussel beds of the Watts Bar Lock and Dam (~RM 530) tailwaters (~RMs 529–520) during 1983–1985 and 1986–1993 yielded 26 and 30 L individuals, respectively (Ahlstedt and McDonough 1995–1996). Quadrat sampling and sieving for juveniles was conducted in 1993 to investigate recruitment levels. All Pink Mucket observed during these two periods were longer than 2.8 in (mean length of 3.8 and 4.1 during 1983–1985 and 1986–1993, respectively), which suggested to the authors that the population was “relic” and apparently not recruiting (Ahlstedt and McDonough 1995–1996). Both mussel species diversity and total abundance declined over the two sampling periods with recruitment being documented in the mussel community only for a single reservoir tolerant species. Further, the vast number of individuals of five common species sacrificed for quantitative age determination were very old (mean range of 33–49 yrs). Quantitative sampling at RM 518 in 2014 yielded a single live Pink Mucket among 240 10.8 ft² quadrats. The individual was estimated to be 12–15 yrs old, indicating recruitment since the Ahlstedt and McDonough (1995–1996) survey. The species may be currently stable in Watts Bar tailwaters.

In the southern bend of the Tennessee River in northern Alabama, the species is occasional in Guntersville (~RMs 348–300) and Wilson (~RMs 256–245) tailwaters, but sporadic in the highly truncated Wheeler (RMs 275–277) tailwaters, though still rare in each. While sampling 75 RMs of Guntersville tailwaters in 1991, a single live individual was found in a haphazard search (Ahlstedt and McDonough 1993). During 2008 quantitative sampling one live Pink Mucket was found among 6 sites in the RM 348–343 reach (Garner 2008). Eight live individuals were found in 2009 sampling at three sites over RMs 346.5–333.3, two of them during quantitative sampling. Four came from one qualitative dive at RM 333.3 (catch rate = 2.7/1 hr dive time) and all were deemed recently recruited at ~6–10 yrs old (Garner 2009).

Wilson tailwaters mussel populations are not faring well, having suffered periodic dieoffs (J.T. Garner, Alabama Department of Conservation and Natural Resources [ADCNR], pers. comm., 2009). Quantitative sampling in 2008 at six sites spanning RM 252–247 yielded no Pink Mucket, though a live individual was sampled qualitatively (Garner 2008). The same quantitative sampling regime in 2009 produced one live individual in quadrats (Garner 2009). A total of 400 cultured subadult Pink Mucket were released in corrals in Wilson tailwaters in 2004, some of which continue to survive 10 yrs later (Garner 2008). Few recent records are available for Kentucky tailwaters in western Kentucky (five fresh dead in 1981, two live in 1985, one live in 1987; KSNPC database, R.R. Evans, pers. comm., 2007), making the species sporadic and rare there (Cicerello et al. 1991).

Pink Mucket in Pickwick Landing tailwaters, in western Tennessee, was once sporadic and rare. For instance, while sampling 96 sites in a 113 RM reach, only “one or two” live individuals were observed in 1972 from the mussel sanctuary a few miles downstream of the dam at RM 206.7 (Yokley 1972). And in 1978, Pink Mucket was still very rare, representing only 0.08% relative abundance (8 of 9566 total mussels), during a survey conducted from the dam to RM 125.9 (Gooch et al. 1979). However, the population has improved substantially over the intervening years. In late 2007 divers logged ~34 hrs of bottom time searching 24 sites around Diamond, Wolf, and Swallow Bluff Islands (Hubbs 2008a). In deep run habitats associated with these islands, the species is generally distributed but uncommon. A total of 51 L Pink Mucket were recorded at a rate of 1.5/hour, and included 27 L from Diamond Island (RMs 198–195), 22 L from Wolf Island (RMs 194.0–191.5), and 2 L from Swallow Bluff Island (RMs 170–169). Estimated age recorded for 27 individuals indicated that 22 (81%) were 10 yrs old or younger (Hubbs 2008a). The total Pink Mucket reach in the tailwater extends from ~RM 205–80 (D.W. Hubbs, TWRA, pers. comm., 2009). The reach between ~RM 105–80 is considered transitional from tailwater to impoundment habitat conditions of Kentucky Reservoir; Pink Mucket becomes highly sporadic in occurrence and extremely rare in abundance in this area. Regardless, Pickwick Landing tailwaters represents one of the longest contiguous reaches of occupied habitat rangewide for Pink Mucket.

Pink Mucket was historically distributed throughout the ~650 RM main stem of the Tennessee River, but the series of nine main stem dams eliminated habitat for the species from considerable river reaches. The species remains threatened by the same factors affecting populations in other navigational channels (e.g., channel maintenance activities, barging facilities, potential for chemical spills). Pink Mucket in all but Gunterville and Pickwick Landing tailwaters is susceptible to being eradicated by single stochastic events due to its rarity and occurrence in limited reaches of habitat. Aggregate mining occurs in ~RMs 180–130 in Pickwick Landing tailwaters. Some of the very best Pink Mucket habitat that occurs in association with large islands (e.g., Diamond, Wolf) is off limits to mining (D.W. Hubbs, TWRA, pers. comm., 2009). In 2004 a relatively small number of hatchery propagated Pink Mucket were released into Wilson tailwaters, Alabama (J.B. Layzer, USGS retired, pers. comm., 2004). Brief monitoring assessments of these animals indicate they persist despite suffering some level of predation (J.T. Garner,

ADCNR, pers. comm., 2009). Harvest-free mussel sanctuaries have been designated for short reaches in Watts Bar, Chickamauga, Nickajack, Wilson, Pickwick Landing (D.W. Hubbs, TWRA, pers. comm., 2009), and Kentucky (Crowell and Kinman 1993) tailwaters downstream of each dam.

Cumulatively, the species is thought to persist in ~250 RMs of the Tennessee River tailwaters. There is evidence of recruitment and the population status continues to improve in Guntersville (J.T. Garner, ADCNR, pers. comm., 2009) and especially Pickwick Landing (D.W. Hubbs, TWRA, pers. comm., 2008) tailwaters. Other tailwater populations are very small and generally declining. The Tennessee River in general and Pickwick Landing tailwaters, in particular, clearly represents the best Pink Mucket population east of the Mississippi River and one of the top two rangewide, though it remains uncommon in most tailwaters.

Holston River, Tennessee: The Holston River is one of the two large tributaries (along with the French Broad River) that form the Tennessee River, draining northeastern Tennessee, southwestern Virginia, and a small portion of northwestern North Carolina. Pink Mucket status in the Holston River was considered historical at the time the Recovery Plan was written. The species is occasionally distributed and rare downstream of Cherokee Dam (RM 52.3). A 1981 survey of seven sites yielded no evidence of a Pink Mucket population (Ahlstedt 1991a). However, low water conditions exacerbated by profuse macrophytic growth precluded a more thorough survey (which would have included additional sites). A 2002 survey produced seven live and one fresh dead Pink Mucket from 5 of 20 sites over ~RMs 27–14 (S.J. Fraley, North Carolina Wildlife Resources Commission [NCWRC], unpub. data). No recruitment has occurred for decades in this aging population due to adverse tailwater quality from Cherokee Dam. However, Pink Mucket and other species in 2002 showed signs of recent growth and reinvigoration below the dam apparently following decades of little to no growth, and a gravid female was found, but contained only unfertilized ova (J.B. Layzer, USGS retired, pers. comm., with S.J. Fraley, NCWRC, pers. comm., 2009). Improved mussel status has been attributed to water quality improvements due to modified releases from Cherokee Dam by TVA, and may have improved the likelihood for the long-term survival of Pink Mucket in the Holston River (S.J. Fraley, NCWRC, pers. comm., 2009). However, periodic releases continue to send coldwater pulses through the length of the Cherokee tailwaters (D.W. Hubbs, TWRA, pers. comm., 2009).

French Broad River, Tennessee: The French Broad River is one of the two large tributaries (along with Holston River) that form the Tennessee River, draining east-central Tennessee and western North Carolina. The Pink Mucket population in the French Broad was considered historical at the time the Recovery Plan was written. Despite having lost ~80% of its native mussel fauna post-impoundment, a sporadic Pink Mucket population persists in the lower French Broad River where it is very rare (Layzer and Scott 2006). A live female and fresh dead male were found at a site during the 1988–2002 study (J.B. Layzer, USGS retired, pers. comm., 2009). The population, which may have occurred upstream ~80 RMs historically based on habitat (pre-impoundment,

though records are unavailable), continues to be affected by tailwater conditions from Douglas Dam at ~RM 32. However, recent discharge improvements (e.g., minimum flows in 1987, reaeration in 1993) make the prognosis for a recruiting, sustainable Pink Mucket population “good” given current habitat conditions (Layzer and Scott 2006). This population may be linked with the Holston River population by its vagile hosts (see section II.C.1). Its current status is unknown.

Clinch River, Tennessee: The Clinch River is a major tributary of the uppermost Tennessee River, draining southwestern Virginia and northeastern Tennessee. Pink Mucket occurs very sporadically and is very rare in the reach upstream of Norris Reservoir in Tennessee. It was found live in the tailwaters of Melton Hill Reservoir (~RM 20) in 1982, but subsequent sampling in 2001 failed to detect its continued presence. Pink Mucket is now considered extirpated in this lower reach of the Clinch River. A single fresh dead specimen was collected at RM 184.5 in 1979 (Ahlstedt 1991b) and a live individual was found ~RM 160 in 1993 (S.A. Ahlstedt, USGS retired, pers., comm., 2009). Pink Mucket was more widely distributed in the lower 200+ RMs of the river (presumably into VA to at least RM 226; Neves 1991; S.A. Ahlstedt, USGS, retired, pers. comm., 2014) historically before three impoundments disrupted nearly 150 miles of potential habitat. The extremely small population is threatened by coal mining, oil, and natural gas activities in the upper watershed and agricultural runoff. The current status of this population is unknown. The species has been propagated using Tennessee River broodstock for augmentation in the Virginia and Tennessee portions of the river. Since 2010, several thousand individuals have been translocated using lower Tennessee River broodstock (M. Bradley, Virginia Department of Game and Inland Fisheries, pers. comm., 2013).

Paint Rock River, Alabama: The Paint Rock River is a small southerly-flowing tributary of the southern bend of the Tennessee River in northeastern Alabama and a small portion of southeastern Tennessee. Pink Mucket occurrences are very sporadic and the species very rare in Paint Rock River, which probably represents the smallest stream of occurrence rangewide. Only two records are known, both live individuals observed at RM 17 in 1983 (Ahlstedt 1995–1996b) and RM 34 in 2008 (Fobian et al. 2008). The former individual was <5 yrs of age (Recovery Plan) while the latter individual was the only Pink Mucket found in a thorough survey of the entire main stem. Several other surveys during the 1960s to the early 2000s failed to detect the species (reviewed in Fobian et al. 2008). It is arguable that these records represent chance occurrences of individuals from a source Tennessee River population in Guntersville tailwaters. The small stream size lends credence to this hypothesis (see section II.C.1); several other large river species are also known from lower Paint Rock River (Fobian et al. 2008). The highly sporadic nature of Pink Mucket records in the river makes it difficult to accurately assess its status, which is therefore unknown.

Bear Creek, Alabama: Bear Creek is a northerly-flowing tributary of the southern bend of the Tennessee River in northwestern Alabama and a small portion of northeastern Mississippi. Pink Mucket in Bear Creek—discovered after the Recovery Plan was written—is known from a single live individual found in 1999 (McGregor and Garner

2004). The gravid female was found a few miles upstream of the influence of Pickwick Landing Reservoir and appeared stressed from stranding by recent low water (J.T. Garner, ADCNR, pers. comm., 2009). It is arguable that this record represents a chance occurrence of an individual from a source Tennessee River population in the Wilson tailwaters (see section II.C.1). Its status is therefore unknown in Bear Creek.

Lower Mississippi River Basin

St. Francis River, Missouri: The St. Francis River is a large south-flowing tributary of the lower Mississippi River draining considerable portions of southeastern Missouri and northeastern Arkansas. This Pink Mucket population was considered historical at the time the Recovery Plan was written. Currently, the species is very sporadically distributed and very rare in the upper portion of the river in Missouri. The species was first found in 1972 upstream of Wappapello Reservoir (dam at ~RM 306) (MDC database, S.E. McMurray, pers. comm., 2009). No evidence of an extant Pink Mucket population was found during 1986 sampling at 113 sites along the length of river downstream of the dam (Ahlstedt and Jenkinson 1991) nor at 25 additional sites sampled in 1987 (Jenkinson and Ahlstedt 1993–1994), though a relic specimen was found downstream of the reservoir in 1986. The species was also absent from 63 sites sampled in the lowermost ~125 RMs in Arkansas in 1993 (Posey 1997). A 2002 survey of 32 main stem sites in Missouri also produced no evidence of Pink Mucket (Hutson and Barnhart 2004). However, that same year a single live individual was found at RM 269.5 in the upper end of an ~45 RM channelized portion of the stream between ~RMs 275–230 (MDC database, S.E. McMurray, pers. comm., 2009). Only seven individuals of four mussel species were found at that site in 1986 (Ahlstedt and Jenkinson 1991). It is conceivable that habitat quality at the site has improved from its proximity to the reach upstream of RM 275, which was characterized as being “largely unmodified” in 1986 (Ahlstedt and Jenkinson 1991). Pink Mucket potentially occurred throughout ~350 RMs of the St. Francis River (~465 RMs total length) historically before major flow alterations were made (e.g., channelizing, dredging, ditching, dikes, diversions, floodways) in the 1900s throughout the lower 300 RMs. Known currently from only a single site, its status in the St. Francis River is unknown but clearly tenuous.

White River drainage

White River, Arkansas: The White River is a large tributary of the lower Mississippi River draining considerable portions of southern Missouri and northern Arkansas. The Pink Mucket population in the White River was not known at the time the Recovery Plan was written. The main stem and several tributaries (e.g., Black, Current, Spring, Eleven Point rivers) collectively represent a significant Pink Mucket population cluster. Pink Mucket is generally sporadic to locally occasional in distribution but always rare in portions of the river downstream from ~RM 275 for roughly 200 RMs. Most records are from the upper ~50 RMs of this reach. A 1986 survey covering RMs 254.6–230.7 found Pink Mucket shells (condition unknown) at 8 of 12 sites (Miller and Harris 1987, in Harris and Gordon 1987) over the reach between RMs 254.3–236.2 (Arkansas Game and Fish Commission [AGFC] database, W.R. Posey, II, pers. comm., 2009). During 1991–

1994 sampling at 51 mussel beds from RM 257 downstream (from Black River confluence to the mouth), four live individuals were recorded from 4 beds (Christian 1995). Three of these individuals were from 10.8 ft² quadrat samples in three beds (RMs 228.0, 99.0, and 63.5) while the fourth was from qualitative sampling at RM 223. Four live individuals were found at three sites surveyed in 1995 between RMs 264–274 (AGFC database, W.R. Posey, II, pers. comm., 2009). Three live Pink Mucket were found in 2 (RMs 221.0 and 155.6) of 22 beds originally sampled by Christian (1995) and resampled in 2000 (Harris and Christian 2000, in Harris et al. 2009). Only a relic shell was found in 2002 from among 49 sites surveyed in an ~30 RM reach spanning the White River from Guion (~RM 325) to Batesville (~RM 295) (Harris 2002, in Harris et al. 2009).

The species was likely distributed historically over at least 500 RMs of the 690-mile long main stem, with a record known at least as far upstream as the vicinity of Branson, Missouri (Utterback 1915–1916, from map in Oesch 1995). However, a series of main stem (Table Rock, Taneycomo, and Bull Shoals) and tributary (Norfolk) reservoirs and/or their hypolimnetic releases has destroyed habitat for this species for ~200 RMs of the middle and upper White River. Also in the middle reach of the river three locks and dams were constructed which further disrupted riverine habitat for Pink Mucket. Lowered temperatures from hypolimnetic releases appear to be ameliorated in the Batesville area (~RM 295, location of Lock and Dam 1) with the first mussel aggregation occurring a few miles upstream (J.L. Harris, ASU, pers. comm., 2009). Continuing downstream, mussel beds in the middle White River remain limited in number and sporadic in occurrence until the vicinity of Oil Trough (~RM 275) (C.L. Davidson, FWS, pers. comm., 2009).

Fresh dead Pink Mucket shells were observed in <1-yr old dredged spoil piles in 1986, indicating direct mortality from channel maintenance activities (Miller and Harris 1987, in Harris and Gordon 1987). There is the potential for the navigation channel to be extended upstream to Batesville (C.L. Davidson, FWS, pers. comm., 2009). In addition to channel dredging, aggregate mining was listed as an ongoing threat to the Pink Mucket population (Harris and Gordon 1987). Zebra Mussels invaded the White River in the early 1990s (Christian 1995). However, 20 years later the invasive species remains rare in the river (C.L. Davidson, FWS, pers. comm., 2014). The widespread distribution of Pink Mucket in the White River—it represents the longest contiguous reach of occupied habitat for the species rangewide—would suggest that it represents one of the larger populations rangewide, but its sporadic distribution and rarity over much of the inhabited reach negates that status. Recruitment, if occurring, is so low in the river as to be undetectable making its current status unknown (J.L. Harris, ASU, pers. comm., 2009).

Black River, Arkansas and Missouri: The Black River is the largest tributary of the White River drainage draining southeastern Missouri and northeastern Arkansas. Its mouth is at ~RM 257 on the White River. Pink Mucket is occasionally distributed and rare over an ~160 RM reach downstream from Poplar Bluff, Missouri, except for select beds in the middle reach of the Arkansas portion of the stream where it is generally distributed and uncommon in status. Nine live Pink Mucket were found at 7 of 13

Missouri sites sampled during 1981–1982 (Buchanan 1996) and two live individuals were found at RMs 75.1 and 80.7 in 1985 while sampling a reach of the Black River in Arkansas (Miller and Hartfield 1986, in Harris and Gordon 1987). A survey of the entire main stem in Arkansas conducted during 1991–1992 produced 30 L Pink Mucket from 18 mussel beds between ~RMs 164–144, and a single live individual was also found at RM 50.6 (Rust 1993, in Harris et al. 1997). Five live animals were found at RM 151.1 for a relative abundance in that bed of 1.3%, relatively high on a rangewide scale. During a 2003 survey 31 sites were sampled on a 98-RM reach of river in Missouri downstream from the dam to the state line. Four live Pink Mucket females were observed between 10 and 50 RMs of the state line. One individual was estimated to be ~6 yrs old (Hutson and Barnhart 2004). In this reach, Pink Mucket had a low relative abundance of 0.04% (4 of 9489 total mussels).

Historically, the Pink Mucket population probably occurred from about Clearwater Reservoir (RM 257.4) in Missouri downstream to the lower main stem, though no records are known from the lowermost 50 RMs in AR. Habitat changes in the last ~50 RMs may exclude the species from this more lowland reach of the Black River (J.L. Harris, ASU, pers. comm., 2009). Since ca. 1980, no records are known in the previously inhabited ~50 RM reach downstream from Clearwater Dam suggesting that releases from Clearwater Reservoir may have contributed to its localized demise. Residual effects of past metals mining activities may continue to impact Pink Mucket in Missouri while very localized commercial harvest is a potential threat in Arkansas. The Black River Pink Mucket population is clearly the largest among the White River drainage population cluster, the second longest contiguous reach inhabited by the species, and among the best populations rangewide. Its current status is considered stable (Harris et al. 1997), and recent recruitment is evident in both the Missouri (Hutson and Barnhart 2004) and Arkansas (J.L. Harris, ASU, pers. comm., 2004, 2009) portions of the river.

Current River, Arkansas: The Current River is a large western tributary of the Black River draining portions of southeastern Missouri and northeastern Arkansas. Pink Mucket is known in the Arkansas portion of the stream from a single record of a live individual and fresh dead specimen found in 1983 in the lower main stem at ~RM 25 a few miles downstream of the state line (Recovery Plan; Buchanan 1996; AGFC database, W.R. Posey, II, pers. comm., 2009). Numerous sites have been sampled in Missouri without finding evidence of its occurrence there (Buchanan 1996; McMurray 2008). It is debatable whether these records represent chance occurrences of individuals from the Black River population or a true population that is dependent on its parent population for sustainability (see section II.C.1). Its current status is unknown.

According to the Recovery Plan, the species was formerly known from a Current River tributary, Little Black River, in Missouri. A survey ca. 2000 failed to locate the species there and it is now considered extirpated from the Little Black River (Bruenderman 2001a).

Spring River, Arkansas and Missouri: The Spring River is a large western tributary of the Black River draining south-central Missouri and north-central Arkansas. Pink

Mucket is occasionally distributed and rare in approximately the lowermost 30 RMs. Six live Pink Mucket were among 3372 total mussels (relative abundance = 0.2%) found during a 1984 mussel relocation project (ASU 1984, in Harris and Gordon 1987). In addition to the very low relative abundance, the species was found at the extremely low density of 1/0.004 ft². During 1983–1984 a total of 10 L individuals and 3 FD specimens were observed at seven sites (AGFC database, W.R. Posey, II, pers. comm., 2009). Sampling conducted by the Corps in the Spring River in 1985 failed to find evidence of Pink Mucket (Miller and Hartfield 1986, in Harris and Gordon 1987). A 1991 survey produced 11 L Pink Mucket at four of six sites in an ~11 RM reach (Rust 1993). Thirty sites were sampled during 2005–2006 but only a few relic Pink Mucket shells were found (Harris et al. 2007). However, a live individual was found at a site in 2005 during another visit to the stream (AGFC database, W.R. Posey, II, pers. comm., 2009).

Mussels generally do not occur in springs or in the portions of spring runs near spring heads due to adverse water chemistry conditions. The water quality effects of Mammoth Spring—a first magnitude spring (discharge of >100 ft³/second) that represents the largest in Arkansas—on the Spring River mussel fauna may become ameliorated just downstream from the confluence with the South Fork Spring River, where habitat becomes more suitable for mussels in general (C.L. Davidson, FWS, pers. comm., 2014). This indicates that the current range of Pink Mucket in the Spring River may be similar to its historical range.

A railroad that parallels the river throughout much of the Pink Mucket reach extending upstream has resulted in multiple toxic spills in recent years (C.L. Davidson, FWS, pers. comm., 2009) and is a potential source for future stochastic events. Recreational development in the watershed also appears to be a threat (J.L. Harris, ASU, pers. comm., 2009). The Spring River population appears to be recruiting (J.L. Harris, ASU, pers. comm., 2009) and its status was considered “stable but low” in overall population size (Harris et al. 1997). Lack of live individuals or fresh dead specimens during the 2005–2006 survey suggests that the species may be declining in the river.

Eleven Point River, Arkansas: The Eleven Point River is a tributary of the lower Spring River draining portions of southeastern Missouri and northeastern Arkansas. The Pink Mucket population was discovered after the Recovery Plan was written. The species is known from a single record of two fresh dead specimens collected in 2003 in the lower main stem (AGFC database, W.R. Posey, II, pers. comm., 2009). Two sites surveyed during 2005 revealed no evidence of Pink Mucket (Harris et al. 2007). No records are known from the Missouri portion of the stream, where only a few mussel species are known (Buchanan 1996) despite surveys at over a dozen sites (McMurray 2008). High velocities characterize the stream and potential habitat appears to be limited due to unstable substrates from scouring (J.L. Harris, ASU, pers. comm., 2009). It is arguable that these records represent chance occurrences of individuals from the Spring River population (see section II.C.1). Current status is unknown.

Red River drainage

Ouachita River, Arkansas: The Ouachita River is a large northern tributary of the lower Red River draining southern Arkansas and northeastern Louisiana. The Pink Mucket population in the Ouachita was considered historical at the time the Recovery Plan was written. At present, it is occasionally distributed over an ~95 RM reach of the 605-RM Ouachita River upstream of ~RM 335 in Arkansas where it is rare in abundance. From 1983–2007 a total of 16 L individuals and 10 FD specimens were recorded from ~15 sites (AGFC database, W.R. Posey, II, pers. comm., 2009). The first systematic survey of the river in Arkansas was conducted during 1992–1995 between ~RM 376 and the state line at RM 221.6 (Posey 1997). Eight live Pink Mucket were found in 7 of 61 mussel beds (and 7 of 847 quadrats) identified with occurrences distributed over an ~41 RM reach (~RMs 375–334) downstream of the Little Missouri River confluence (Posey 1997). Six live individuals were found in 1999 at 5 of 119 sites upstream of the Caddo River confluence (Harris 1999, in Harris et al. 2009), and in 2006 four live Pink Mucket were found at four of six sites (Harris 2006, in Harris et al. 2009). With one exception, no more than three individuals of Pink Mucket have been found at any one sampling site since 1993. The exception was in 2013 when nine L were found at a site in Ouachita County, in addition to five L at two other sites in the same county (AGFC database, W.R. Posey, II, pers. comm., 2014). A single live individual was estimated to be 2 years old (C.L. Davidson, FWS, pers. comm., 2014).

The species may have occurred historically upstream to the vicinity of Blakely Mountain Dam (~RM 470) which impounds Lake Ouachita west of Hot Springs (J.L. Harris, ASU, pers. comm., 2009). However, habitat was lost when Blakely Mountain, Carpenter, and Rimmel dams were constructed, their respective reservoirs filled, and the subsequent effects of their hypolimnetic discharge occurred. Rimmel Dam, a hydropeaking facility at Jones Mill (~RM 435), has widely fluctuating discharges that continue to affect Pink Mucket habitat. The upstream end of the species' reach is ~6 RMs downstream of the dam (J.L. Harris, ASU, pers. comm., 2009). There is a navigation channel downstream of Camden, Arkansas (~RM 344) and six locks and dams are located in the lower two-thirds of the river. The Corps continues to periodically maintain the navigation channel to Camden with petroleum from Millers Bluff (~RM 300, well downstream of the known Pink Mucket reach), and wood chips as essentially the only commodities barged downstream (G. Temple, Corps, pers. comm., 2009; C.L. Davidson, FWS, pers. comm., 2014). Pink Mucket occurs in the river downstream to the upper ~10 RMs (~RM 335–345) of the navigation channel (Posey 1997), which is a considerable distance upstream of Thatcher Lock and Dam at RM 281.9. Dam discharges, aggregate mining, oil and natural gas extraction, and navigational maintenance activities threaten the population (Harris and Gordon 1987).

Though 3 among 7342 identifiable archeological valves (relative abundance = 0.04%) for Pink Mucket were collected from a Louisiana site several miles upstream of the Bayou Bartholomew confluence (Peacock and Chapman 2001), no modern Pink Mucket records are available for the ~220 RM portion of the Ouachita River in Louisiana (B. Gregory, Louisiana Natural Heritage Program [LNHP], pers. comm., 2009). Mussel habitat, however, appears to be adequate locally in Louisiana downstream of the state line (C.L. Davidson, FWS, and J.L. Harris, ASU, pers. comm., 2009). If Pink Mucket continues to

inhabit the poorly sampled Louisiana portion of the Ouachita River, it may occur at virtually undetectable levels, clearly warranting additional sampling (M. Sikes, FWS, pers. comm., 2014). The current population in Arkansas was considered “stable but low” by Harris et al. (1997) and has continued to appear stable over the past ~25 years and is recruiting (J.L. Harris, ASU, pers. comm., 2009; C.L. Davidson, FWS, pers. comm., 2014).

Little Missouri River, Arkansas: The Little Missouri River is a western tributary of the Ouachita River draining a portion of west-central Arkansas. Its confluence with the Ouachita River is at ~RM 377. The Pink Mucket population was discovered after the Recovery Plan was written. The species occurs from ~RM 40 downstream, where it is generally sporadic in distribution but more occasional in the downstream one-third of this reach, but always rare. Sampling the lowermost ~10 RM reach during 1995–1997 three live individuals were observed qualitatively at three sites between RMs 9.5–7.3 (Davidson 1997). Surveying 131 sites in 2004 over a ~52 RM reach (~RMs 62–10), six live Pink Mucket were found at five sites (Christian and Harris 2004). Five of six individuals were from ~RMs 18–12 with another Pink Mucket found well upstream at ~RM 40. Fifty additional sites sampled upstream from ~RM 40 produced no Pink Mucket; only 25 sites had any mussels (Davidson 1997; Christian and Harris 2004). Overall mussel diversity and abundance are low based on these studies. Operation of the Narrows Dam has affected mussels in general and probably Pink Mucket habitat in the upper river (J.L. Harris, ASU, pers. comm., 2009). Numerous log jams compromise mussel habitat in the lower river (C.L. Davidson, FWS, pers. comm., 2009) and an inordinate number of cutoffs are also apparent in the Pink Mucket reach (J.L. Harris, ASU, pers. comm., 2009). The log jams may be due to past cutoff formation and subsequent bank instability over time. The historical range of the species, though unknown, may have extended upstream 10–20 RMs or more past RM 40. The overall population is very small and appears to be reach restricted. Its status is unknown but may ultimately be dependent upon the Ouachita River population for sustainability.

Saline River, Arkansas: The Saline River is an eastern tributary of the Ouachita River draining a large portion of south-central Arkansas, with its confluence just north of the Louisiana state line. The Pink Mucket population in the Saline River was not known at the time the Recovery Plan was written. At present it occurs over ~125 RMs, or over most of the main stem with the exception of the downstream-most and upstream-most ~25 RM reaches. The population generally appears occasional in distribution and is uncommon in abundance. However, Pink Mucket occurrences are sporadic and its status rare in the upper one-third of the main stem upstream of U.S. 167 crossing (Davidson and Clem 2002; Harris et al. 2009) and generally distributed but uncommon in some particularly dense beds in the lower half of the river (C.L. Davidson, FWS, pers. comm., 2009). During 2001–2002 sampling 14 L individuals were found at 13 sites over 99 RMs in the middle portion of the stream (Davidson and Clem 2002). Pink Mucket represented 0.12% relative abundance among the 11,204 mussels found. During another survey in 2003–2004 eight live Pink Mucket were recorded from six sites over 51 RMs in the lower river (Davidson and Clem 2004). The two surveys covered separate but contiguous river reaches and collectively documented Pink Mucket from 19 of 169 sites. The species

represented 0.07% relative abundance among the 21,316 mussels recorded over the two surveys. One individual estimated to be 4–7 yrs old represented the only evidence of recent recruitment in the population (Davidson and Clem 2002). Fourteen live Pink Mucket were found in 2006 at four sites ($n = 1-8/\text{site}$) sampled (Harris 2006, in Harris et al. 2009). At least two new sites for Pink Mucket were located in 2008 where eight live individuals were observed (C.L. Davidson, FWS, pers. comm., 2008). Sampling during 2010–2012 revealed 40 live individuals at 11 of 13 previously sampled beds (C.L. Davidson, pers. comm., 2014). Estimates of the numbers of Pink Mucket occurring in each bed generally ranged in the hundreds to low thousands.

The Saline River Pink Mucket population appears isolated and clearly disjunct from the Ouachita River population due to the Felsenthal Lock and Dam on the latter river. Timberlands comprise ~70% of the watershed making the preservation of streamside buffers important to limit potential sedimentation impacts (Davidson and Clem 2002). A 25-yr flood in spring 2009 caused considerable bed load movement which blew out mussel beds in the lower river leaving hundreds of thousands of mussels stranded, but only two Pink Mucket were found (J.L. Harris, ASU, pers. comm., 2014).

The species may have historically occurred throughout the length of the ~175 RM main stem to the mouth. Recent studies suggest Pink Mucket is rare or uncommon at best on a relative abundance basis in an ~125 RM reach of the Saline River, and during 2010–2012 relative abundance measured only 0.05–0.26% (C.L. Davidson, FWS, pers. comm., 2014). However, since mussels in general are very dense and abundant (up to 37.8/ft²) in some of the ~200 mussel beds (density > 0.9/ft² in “beds”) and ~60 other mussel “aggregations” (density < 0.9/ft²) identified in the river (C.L. Davidson, FWS, pers. comm., 2008), it would appear that total Pink Mucket population size is substantial. Estimates from 2010–2012 may suggest that its population could number in the high tens of thousands of individuals in the river. The population appears to be recruiting and considered stable in conservation status (J.L. Harris, ASU, pers. comm., 2009). The Saline River, representing one of the longest contiguous reaches of occupied habitat rangewide, clearly harbors the best Pink Mucket population west of the Mississippi River and probably one of the top two rangewide.

Bayou Bartholomew, Arkansas and Louisiana: Bayou Bartholomew is another large south-flowing eastern tributary of the Ouachita River draining portions of southeastern Arkansas and northwestern Louisiana. The Pink Mucket population in Bayou Bartholomew was discovered after the Recovery Plan was written. The ~280 RM stream is one of the longest rivers in the US that is unchannelized and undammed its entire length (Brooks et al. 2008). The Pink Mucket population is rare and distributed very sporadically. It is known from only two records, including two live individuals found in Louisiana in 1992 during a survey focusing on a 3.7 RM reach ~35 RMs downstream of the state line (George and Vidrine 1993; Vidrine 1993). In addition, four relic valves were found in 2004 at a site just upstream of the state line during a survey of the entire reach in Arkansas (Brooks et al. 2008). Two subsequent and more site intensive surveys in Louisiana during 1994 and 2000–2001 failed to detect any evidence of the species (Vidrine 1995; Pezold et al. 2002; Alley 2005), though diving was not employed during

sampling efforts. Habitat appears to be limited in the Arkansas portion of the bayou (J.L. Harris, ASU, pers. comm., 2009). Agricultural impacts—including excessive sedimentation, water withdrawals for irrigation, and chemicals associated with widespread cotton production—are considered major threats to the molluscan fauna (George and Vidrine 1993; J.A. Brooks, University of Louisiana at Monroe [ULM], pers. comm., 2005). Its status is unknown.

b. Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):

Fifteen polymorphic microsatellite DNA loci were isolated from 15 individuals of Pink Mucket from the Tennessee and Meramec rivers (Eackles and King 2002). Allelic diversity among individuals ranged from 6–17 (mean = 10.4) alleles per locus and individual heterozygosity ranged from 20.0–86.7% (mean = 46.9%). Though preliminary, a much larger sample size including individuals from all major river drainages where the species is known would allow for more accurate assessment of population structure, gene flow, kinship, and genetic relationships among stream populations (Eackles and King 2002). This data is critical for assessing heterogeneity of cultured individuals for the purposes of population restoration management.

It is likely that given its large river habitat, the entire Ohio River drainage (the entire species' range east of the Mississippi River) historically represented a single metapopulation. Populations west of the Mississippi River are not as clear cut, but clusters existed in southern tributaries of the lower Missouri River, and the White and Red/Ouachita river drainages. Habitat alteration began on a grand scale during the large reservoir construction boom of the early and mid-20th century (Haag 2009a). Additional reaches of habitat became unsuitable for other reasons during this period. By the late 1900s, most extant Pink Mucket populations were disjunct, small, and suffered the effects, to varying degrees, of genetic isolation, including reduced genetic variation, genetic drift, and inbreeding depression (Allendorf et al. 2012). Empirical information on genetic structure of Pink Mucket populations needed to delineate connectivity and relationships among populations and levels of genetic isolation is currently lacking.

An effective population size (EPS) is required to maintain genetic heterogeneity and population viability (Soulé 1980; Allendorf et al. 2012). Isolated populations eventually die out when population size drops below the EPS or threshold level of sustainability. The dearth of evidence for recruitment in many Pink Mucket populations makes recruitment reduction or outright failure suspect. These populations may be experiencing the bottleneck effect of not attaining EPS. Small, isolated, below EPS-threshold populations of short-lived species theoretically die out within a decade or so. However, below-threshold populations of long-lived species like Pink Mucket might take decades to die out, even if they have experienced decades of total recruitment failure (Ahlstedt and McDonough 1993). Due to barriers to genetic interchange from habitat destruction, many small isolated populations of this species could be slowly expiring.

II.C.1.c. Taxonomic classification or changes in nomenclature:

Much taxonomic confusion has focused on Pink Mucket over the past several decades (e.g., Harris and Gordon 1987). Three distinct issues are discussed below. *Which scientific name for Pink Mucket is valid, *Lampsilis abrupta* (Say, 1831) or *L. orbiculata* (Hildreth, 1828)?*

At the time of the Recovery Plan, most investigators considered the scientific name of Pink Mucket to be *Lampsilis orbiculata*. Based on a reevaluation of the original description of *L. orbiculata*, Frierson (1924) determined that Hildreth had actually redescribed *Obovaria retusa* (Lamarck, 1819) or possibly *Obovaria subrotunda* (Rafinesque, 1820). Though the issue of *L. orbiculata* referring to a species different than *L. abrupta* was clearly resolved by Frierson (1924), *L. orbiculata* continued to be incorrectly used for over half a century in references to Pink Mucket (Williams et al. 2008). Therefore, as correctly pointed out 90 years ago by Frierson (1924), *L. orbiculata* refers to a species different from *L. abrupta*. *Lampsilis orbiculata* has been determined a junior synonym of *O. subrotunda* (Gordon 1992; Williams et al. 2008). A synonymy for Pink Mucket is presented in Bogan and Parmalee (1983).

*Are *Lampsilis abrupta* and *L. higginsii* (Lea, 1857) the same or distinct taxonomic entities?*

These two large river taxa are very similar in appearance (e.g., Wilson and Clark 1914) and have at various times been referred to as separate species, subspecies, and the same species (citations in Gordon 1980 and Bogan and Parmalee 1983). Though considered to be distributed allopatrically, they have even been reported from the same site (e.g., Ouachita River, Arkansas; Wheeler 1918). *Lampsilis abrupta* occurs in the Ohio River drainage, western tributaries of the lower Mississippi River basin, and from large tributaries to the lower Missouri River that drain the Ozark Highlands Physiographic Province. *Lampsilis higginsii* occurs in the Mississippi River basin upstream from the Missouri River confluence (FWS 2004) as well as in the Missouri River drainage upstream of the Ozarks (Anonymous 2005). It seems likely that the two may have historically occurred sympatrically (if not syntopically) in the lower Missouri River. They are both currently considered valid species (Turgeon et al. 1998), though their similar status (both are endangered under the Act) and combined distribution—especially their allopatric partitioning of the Missouri River—could be considered evidence of conspecificity.

Is Pink Mucket a species complex?

Investigators have long considered the potential for Pink Mucket to represent a species complex (e.g., Stansbery and Kokai 1978). Two potentially taxonomically distinct species have been noted. One is the population cluster in the Ouachita River drainage (Ortmann 1919; D.L. Stansbery, OSUM, pers. comm., in Bogan and Parmalee 1983), and the other is comprised of populations draining the northern and northeastern Ozark Highlands Physiographic Province (Osage, Gasconade, and Meramec rivers) (M.E. Gordon, pers. comm., 2009). A comprehensive phylogenetic analysis and taxonomic

distinction study is needed to definitively answer this question and the previous one as well.

d. Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, etc.), or historical range (e.g. corrections to the historical range, change in distribution of the species' within its historical range, etc.):

The Recovery Plan stated that Pink Mucket was historically known from at least 25 streams. Recent sampling efforts and a more-thorough search of historical data from the literature and museum records brings this total to at least 48 streams. Pink Mucket generally occurred in large streams in the Ohio River drainage and in some tributaries of the lower Missouri and Mississippi rivers that drain the Ozark Plateaus and Ouachita Highlands Physiographic Provinces. This distribution indicates that Pink Mucket is an endemic species within the Mississippian Region, one of four North American mussel faunal regions defined by Haag (2009b). The species inhabits five mussel provinces within the Mississippian Region: Ohioan, Tennessee-Cumberland, Upper Mississippi, Mississippi Embayment, and Interior Highlands.

In all, at least 20 streams are considered to have lost their Pink Mucket populations: Allegheny River, Pennsylvania; Monongahela River, Pennsylvania; Muskingum River, Ohio; Levisa Fork, Kentucky; Scioto River, Ohio; Salt River, Kentucky; Wabash River, Indiana/Illinois; Tippecanoe River, Indiana; White River, Indiana; West Fork White River, Indiana; East Fork White River, Indiana; Obey River, Tennessee; Caney Fork, Tennessee; Nolichucky River, Tennessee; Little Tennessee River, Tennessee; Flint River, Alabama; Limestone Creek, Alabama; Mississippi River, Kentucky; Little Black River, Missouri; and the Little River, Arkansas. Its occurrence in Levisa Fork implies that the species probably also occurred in its parent stream, the Big Sandy River, Kentucky/West Virginia. Numerous sites in these streams have been surveyed over the past several decades or since Pink Mucket was considered extant. At best, relic shells are all that have been found. Roughly 1000 RMs of former Pink Mucket range have been lost in these streams with the construction of large dams (e.g., Tippecanoe, Obey, Little Tennessee rivers; Caney Fork; Limestone Creek), navigational dams (e.g., Allegheny, Muskingum rivers), and general habitat degradation from pollution and other sources (e.g., Monongahela, Scioto, Wabash, Flint, Little Black rivers; Levisa Fork).

The loss of Pink Mucket populations from 20 streams combined with extensive reaches of degraded and now unsuitable habitat in streams with extant but reach-limited populations (e.g., Ohio, Cumberland, Osage, White Rivers) indicates that a considerable extent of its former distribution has been lost rangewide. A general estimate of the total linear range that is currently occupied by Pink Mucket is ~1300 RMs (see section II.C.1.a); lost habitat resulting in range restriction in the Ohio and Cumberland rivers alone (~1400 RMs) easily exceeds this figure. We've estimated that >4400 RMs (~77%) of its former distribution has been lost in the 29 streams that continue to harbor extant populations. Coupled with losses in the 20 streams of historical occurrence of ~1000 RMs, we believe it is likely that ~5400 RMs of the historical distribution of Pink Mucket

have collectively been lost over the past century. This represents an 80% decline of the ~6700 RMs of total historical linear range for the species.

The loss of certain river populations has caused Pink Mucket to become extirpated from the States of Indiana (B.E. Fisher, Indiana Department of Natural Resources [IDNR], pers. comm., 2007), Pennsylvania (R.M. Anderson, FWS, pers. comm., 2004), and Virginia (Neves 1991) (though reintroduction efforts are underway). Though the species was considered extirpated from Illinois in 1997 (Cummings and Mayer 1997), the species is extant in the lower Ohio River bordering this state. The record of a Little River specimen in Arkansas ~4 RMs downstream of the Oklahoma state line makes it highly possible that the species may occur (occurred?) in Oklahoma, but this is unsubstantiated; Oklahoma is therefore not considered within the historical range of Pink Mucket. Given a proximal source population, it is possible that some streams will naturally regain their historical Pink Mucket populations. For example, it is possible that the Ohio River population may someday serve as a source for natural reintroductions into several tributary streams and reaches of the Ohio now devoid of Pink Mucket (e.g., Allegheny, Muskingum, Wabash rivers; Ohio River main stem reaches in Pennsylvania, Indiana).

Several historical records are herein considered erroneous or are discounted because they are unsubstantiated. Though the species may once have occurred in the Mississippi River, Kentucky, literature records noted in the Recovery Plan from the Mississippi and Illinois rivers in Illinois and Iowa are assumed to actually represent *Lampsilis higginsii* (FWS 2004). Despite a record for the Duck River, Tennessee (University of Michigan Museum of Zoology [UMMZ] database, accessed through their web site; Johnson 1980) and the proximity of a large source population in the Tennessee River, Pink Mucket is not considered a part of the Duck River mussel fauna (Ahlstedt et al. 2004). A record for the Niagara River, New York and Ontario, Canada (Robertson and Blakeslee 1948), though accepted by Johnson (1980), was considered plausible but unsubstantiated by Strayer and Jirka (1997). According to Harris et al. (1997, citing Christian 1995), a single pink mucket was tentatively identified from the Cache River, Arkansas. However, no mention of Pink Mucket from the Cache River was found in Christian's 1993 thesis or in the mussel database maintained by AGFC (W.R. Posey, II, AGFC, pers. comm., 2009). This record is therefore considered unsubstantiated.

Pink Mucket uses large, wide-ranging, highly mobile species of black basses, crappies, and perches as host fishes for its glochidia (Williams et al. 2008). The highly mobile nature of hosts coupled with a history of localized occurrences in many streams suggests new Pink Mucket records will turn up in extant, historical, or potentially new streams of occurrence.

e. Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem):

Pink Mucket is generally rare or uncommon in abundance, typically sporadic or occasional in distribution, and occurs in discreet reaches in most streams of occurrence. The Cumberland River has the only population that maintains a comparatively high

relative abundance, and in only select streams is the species found to be generally distributed albeit on a very local scale, such as individual mussel beds (e.g., Meramec, Osage, Kanawha, Cumberland, Tennessee, Black, Saline rivers). It tends to inhabit beds with relatively high species diversity, a characteristic that appears to improve fitness in rare species (Spooner 2007), possibly through diverse species aggregations providing nutritive or other energy subsidies (Vaughn et al. 2008).

Pink Mucket is often distributed in habitat patches, typically mussel beds (density $> 0.9/\text{ft}^2$) or less dense mussel aggregations (density $< 0.9/\text{ft}^2$). Connectivity between beds is especially important to rare species because their populations are small and commonly subject to local extirpations from demographic stochasticity (Newton et al. 2008; see section II.C.2.e.). This phenomenon highlights the need for ready colonization from other beds to reestablish its presence and maintain populations within individual rivers and river clusters (e.g., White River drainage). Most populations are reach-limited and isolated from one another by dams and otherwise unsuitable habitat. Unlike individual rivers and river clusters with relatively long reaches of potentially suitable habitat, small disjunct populations have no connectivity to outside populations. Having highly vagile host fishes alone would seem to indicate that recolonization potential for Pink Mucket is high in long reaches of suitable habitat. However, the scarcity of individuals and spotty distribution in even these stream reaches (e.g., Ohio River) indicates that other factors must be at play in limiting its abundance within suitable beds. Even in the middle White River drainage population cluster where there are no absolute barriers to dispersal within several hundred miles of linked habitat, Pink Mucket is a rare species and its distribution is generally sporadic or occasional.

According to the Recovery Plan, literature, museum, and other records indicate that Pink Mucket has always been an uncommon species. It is possible that it naturally exhibits a very low level of juvenile survivorship and recruitment relative to other mussel species.

f. Other:

Though development of propagation technology for initiating population restoration efforts was not specifically mentioned in the recovery plan, these activities are likely the best way to recover mussel species, given adequate habitat conditions in which to conduct population restoration activities. At the time of the Recovery Plan, there were no freshwater mussel culture facilities anywhere in the United States. Since that time, several culture facilities have been established to work on imperiled mussels. Over the past several years life history knowledge has become sufficient for several of these facilities to successfully culture Pink Mucket. Indeed, the species has proven to be one of the most readily cultured North American species; many thousand juveniles are commonly produced from single females. As a result of these activities, some stream populations are presently being augmented (see section II.C.1.a.) while reintroductions are being planned in other streams using propagated individuals. Pink Mucket culture and population restoration plans should be completed prior to implementation of recovery actions.

2. Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

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

The Recovery Plan included discussions on impoundments, siltation, and pollution in considering threats to Pink Mucket populations. Some emerging threats that were not pertinent, non-existent, or poorly understood in 1985 are also discussed below.

The literature review in Vaughn and Taylor (1999) provides a more detailed discussion of tailwater effects on mussels than included in the Recovery Plan. The study elaborates how tailwater conditions may affect mussel communities for many miles downstream of dam sites. In a study on the Little River, Oklahoma, two “extinction gradients” of mussels caused by hypolimnetic dam releases were identified (Vaughn and Taylor 1999). The upper gradient occurs downstream from a main stem reservoir (Pine Creek, constructed in 1969) located ~40 RMs upstream of the Mountain Fork River confluence. The mussel fauna did not “recover” (e.g., regarding abundance, species diversity) from the effects of the dam for >30 RMs, with no rare species being detected until this distance was reached. The second gradient occurs downstream of the Mountain Fork River (Broken Bow Dam, constructed in 1968, occurs ~20 RMs upstream of its confluence with the Little River), apparently ~10 RMs to the only site, in Arkansas, that Pink Mucket has ever been found in the river. Very few live mussels—all common species—were found in the reach sampled downstream of this cold, trout-stocked tailwater tributary (C.C. Vaughn, Oklahoma Biological Survey [OBS], pers. comm., 2009). A statistically significant increase in both mussel abundance and species diversity was found with increased distance from the dam, the so-called recovery zone. Combined with a lower main stem impoundment (Millwood), it appears that reservoirs and their tailwaters have negatively influenced most of the lower river downstream from the Mountain Fork River (~75 RMs) and very possibly resulted in the extirpation of Pink Mucket from the Little River. Extinction gradients can be expected in several other Pink Mucket streams as well (see section II.B.3 Recovery Criterion 4).

How dam discharges are managed has in some instances changed since the listing of the Pink Mucket and resulted in improved habitat conditions in tailwaters, such as in the Tennessee River drainage by TVA (see section II.B.3 Recovery Criterion 4). Modifications in dam operations (e.g., modified releases, minimum flows, ramping down rates) are being implemented on the privately maintained Bagnell Dam on the Osage River (S.E. McMurray, MDC, pers. comm., 2009) through the FERC relicensing process. Changes in flow discharges are needed for Corps maintained dams in the middle Cumberland River drainage to ameliorate the effects of decades of hypolimnetic releases on its Pink Mucket population. The Corps has determined that the two largest dams (Wolf Creek and Center Hill) in the middle Cumberland River drainage are also at high risk for failure (Corps web sites) and this puts the species at additional risk from the catastrophic habitat alterations that would result from a major dam failure.

Some Pink Mucket populations appear to be suffering from ongoing habitat degradation due to the continuing impacts of historical land use practices. Channel and bank degradation has been noted in Missouri in the Meramec River (Roberts and Bruenderman 2000) and the Gasconade River (Bruenderman et al. 2001b). Previously stable Meramec River habitats once harbored considerable mussel populations ca. 1980, but by 2000 had degraded to the point where these populations were decimated. This was attributed to instream aggregate mining, riparian buffer alterations, and accelerated runoff from impervious surfaces in developed areas (e.g., metropolitan St. Louis) (Roberts and Bruenderman 2000). Mid-channel substrates at most sites in the Gasconade were generally unstable and lacked mussels (Bruenderman et al. 2001b). Similar conditions are not uncommon in other Pink Mucket streams, which represents an ongoing threat that may partially explain its patchy distribution.

Mining was overlooked as a threat in the Recovery Plan. Metals mining in the Big, Black, and St. Francis rivers, instream aggregate mining in the Tennessee, Osage, Gasconade, Meramec, White, and Ouachita rivers, and fossil fuel extraction in the Kanawha, Elk, and Clinch rivers threaten their respective Pink Mucket populations (see section II.B.3 Recovery Criterion 4). Take from aggregate mining is a perpetual concern for the species in these streams despite regulatory oversight (see section II.C.2.d). Effects of these activities are summarized by Neves et al. (1997) and Roell (1999).

Hydrological variability influences the distribution of mussels in streams. Distinct communities may be associated with hydrologically flashy and hydrologically stable streams (Di Maio and Corkum 1995). High shear stress, peak flows, and substrate movement limits mussel communities, reduces abundance (particularly for juveniles), and animals become increasingly dislodged downstream (Layzer and Madison 1995; Myers-Kinzie et al. 2002; Gangloff and Feminella 2006). Recruitment is also significantly reduced in high discharge years (Howard and Cuffey 2006). Developmental activities result in an increase in percentage of impervious surfaces in a watershed, which can also affect stream hydrology in a number of ways. They increase stream temperatures, sediment loads, stormwater volumes, and speeds at which runoff enters streams resulting in stream channel instability, streambed scour, bank erosion, and channel widening, with consequent loss of instream and riparian habitats and mussel and host fish populations (Brim Box and Mossa 1999; DeWalle et al. 2000; Paul and Meyer 2001; Myers-Kinzie et al. 2002; Schuster et al. 2005). As little as 10% of a watershed in impervious surface can cause channel instability (Booth 1991; Booth and Reinelt 1993). Channel instability issues appear to be contributing to the decline of Pink Mucket in at least the Meramec River.

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

Though overutilization for commercial purposes was not specifically identified as a threat to Pink Mucket in the threat's section of the Recovery Plan, tasks within the narrative outline tacitly implied that commercial harvest was considered a substantial threat to the species (see section II.B.3 Recovery Criteria 2 and 3). The Recovery Plan stated that the species was not specifically sought by commercial shellers, rather it was harvested

incidentally due to similarity of appearance to commercially valuable species (the Recovery Plan also failed to mention indiscriminate collecting from brail sampling).

In the mid-1980s much commercial harvest was conducted by brail, a mechanical method that indiscriminately harvested mussels from stream bottoms. Today, nearly all commercial harvest is conducted by divers, who selectively harvest individuals of a few commercially valuable species that bear only superficial resemblance to Pink Mucket. Diving is therefore considered much less detrimental to the resource than brailing (Baker 1993).

Through the 1980s and into the early 1990s, increases in demand and shell prices resulted in a substantial increase both in the number of licensed commercial harvesters and tons of mussels harvested. This was particularly true in Tennessee (Todd 1993; Hubbs 1995), whose resources were considered the highest quality by the Japanese, who at that time enjoyed a near monopoly in the cultured pearl industry (Fassler 1997). Overall harvest in the U.S. over this time period peaked in 1990 then declined markedly due to a variety of factors (e.g., increasing competition from China, fear that the Zebra Mussel would decimate U.S. mussel stocks) (Fassler 1997). Demand and prices have remained at lower levels since that time (Hubbs 2008b), thus further reducing harvest threats for Pink Mucket.

Mussel sanctuaries have also been established or expanded in rivers with Pink Mucket populations (e.g., Ohio, Green, Cumberland, Tennessee rivers) and several states have outright banned harvest (see section II.B.3 Recovery Criterion 2), thus further reducing the potential for take of this species. For these reasons, the current threat to Pink Mucket from commercial harvest is virtually nonexistent.

c. Disease or predation:

The Recovery Plan did not specifically discuss disease or predation as limiting factors for this species. We have no new information on disease that would indicate that it is a limiting factor.

d. Inadequacy of existing regulatory mechanisms:

The inadequacy of existing regulatory mechanisms was not specifically considered a limiting factor in the Recovery Plan. Regulations associated with aggregate mining have been attributed to the deteriorating health of the Meramec River Pink Mucket population. In 1998, a court ruling that deauthorized the Corps from regulating aggregate mining reduced regulatory protection of stream mussel habitat (Roberts and Bruenderman 2000). Prior to that time, the Corps prohibited instream mining and required permittees to establish riparian buffers. While the Corps still reviews mining permits under purview of Section 404 of the Clean Water Act (CWA) for depositing fill in streams, and Section 10 of the Rivers and Harbors Act for navigable waterways (the lower ~50 RMs of the Meramec), many aggregate mining operations no longer fall under their regulatory authority. Therefore, problems with aggregate mining have been exacerbated by

inadequate state regulations and enforcement (S.E. McMurray, MDC, pers. comm., 2009). Both regulated and unregulated aggregate mining is a threat in several other Pink Mucket streams as well (e.g., Tennessee, Osage, Gasconade, White, Ouachita rivers).

Point source discharges have been reduced since the inception of the CWA, but this may not provide adequate protection for suspension-feeding mussels, particularly early life stages, that can be impacted by extremely low levels of certain contaminants. The prevalence of some toxic compounds like ammonia and pesticides makes them strong candidates for enigmatic mussel declines, or declines where obvious sources of stress are not apparent (Haag 2012). Recent toxicological studies demonstrated that U.S. Environmental Protection Agency (EPA) water quality criteria for copper and ammonia were not protective of all mussel life stages (Augspurger et al. 2003; Wang et al. 2007a, b). Ammonia is highly detrimental to mussels and may be a localized problem where agricultural runoff and wastewater effluents enter streams (Goudreau et al. 1993; Haag 2012). Though the EPA ambient water quality criteria for copper and ammonia have since been modified (EPA 2007, 2013), the new copper criteria is still not protective of mussels during acute and chronic exposures (Wang et al. 2011). Previously, EPA water quality criteria for primary pollutants (e.g., chlorine, copper) and non-priority pollutants (e.g., ammonia) were derived from a toxicity database that did not include available data for mussels. They now include mussel data in toxicity databases when setting water quality criteria for pollutants if those data meet their data quality objectives. There may also be a delay in the time that some states implement the new EPA water quality criteria standards, at least for ammonia. For example, Missouri still has not implemented the new ammonia criteria, and when they do it will be phased in as existing permits expire (S.E. McMurray, MDC, pers. comm., 2014). It could be many years before lower ammonia criteria are actually implemented there.

Pharmaceuticals and personal care products (PPCPs) are appearing in surface waters at alarming rates and represent a major emerging threat to aquatic organisms (Daughton and Ternes 1999; Kolpin et al. 2002). These compounds may adversely affect mussel reproductive biology, including feminization of males, untimely sperm discharge, and mantle display disruption (Cunha and Machado 2001; Gagné et al. 2001; Gagné et al. 2004; Gagné et al. 2006; McMaster 2001; Bringolf et al. 2010). Municipal wastewater treatment technology is lagging in the ability to remove many PPCPs and organic wastewater contaminants, so these compounds continue to affect mussel populations (Gagné et al. 2004; Bringolf et al. 2010). Despite advances in strengthening pollutant criteria, a dearth of data on the effects of metals, pesticides, and PPCPs on mussel life stages may continue to prevent existing regulations, such as the CWA, from being fully and effectively utilized in protecting mussels.

e. Other natural or manmade factors affecting its continued existence:

The Recovery Plan did not mention any other natural or manmade factors that threaten the Pink Mucket. However, several issues warrant discussion.

Rare species are more susceptible to population extirpations and eventual extinction due to a lack of recolonization potential and other factors (Sjögren 1991). High levels of isolation make natural repopulation of any extirpated population impossible without human intervention. Stochasticity becomes an increasing threat to small, isolated, and declining populations of rare organisms (Lande et al. 2003; Newton et al. 2008) with two categories recognized: environmental and demographic. Environmental stochasticity includes both natural (e.g., extreme droughts) and anthropogenic factors (e.g., chemical spills) that affect all populations and individuals within populations similarly. Populations vary in size naturally over time due to environmental stochasticity, which affects all individuals in similar ways. Chemical spills are a constant concern due to the association of highways, railroads, and pipelines with Pink Mucket streams. Pink Mucket occurrence in several navigation channels—particularly in one of the two best populations in the lower Tennessee River navigation channel—are especially worrisome. These transportation vectors increase the probability that stochastic events will affect Pink Mucket populations. Demographic stochasticity includes factors that affect individuals in a population differently (e.g., individual rates of fertilization, recruitment, survival, and fecundity). When such population parameters are highly reduced, imperiled species like Pink Mucket could be pushed below the threshold of minimum viable population size, even where they occur in high quality habitats (Lande et al. 2003; Haag and Williams 2013). Each random process characterizing environmental and demographic stochasticity may exacerbate the effects of others in rare and declining mussel populations (Haag 2012). Environmental stochastic events are more liable to be catastrophic for populations that are linearly distributed, while demographic stochastic events are more liable to be catastrophic for small populations—both scenarios can potentially be highly detrimental to the majority of Pink Mucket populations.

Species that are restricted in range and population size are 1) susceptible to loss of genetic diversity due to genetic drift, 2) increasingly susceptible to inbreeding depression, and 3) less likely to adapt to environmental changes (Allendorf et al. 2012). The deleterious effects of habitat fragmentation and population isolation are a primary threat for imperiled mussels (Haag 2012). Haag and Williams (2013) considered fragmentation the paramount issue for mussel conservation in general, and advocated critical measures to address the issue (e.g., dam removals, modification of tailwater releases to improve water quality). Given the sporadic distribution and low population size of most Pink Mucket populations, fragmentation and isolation are especially major concerns for this species (see section II.C.1.b).

The Recovery Plan did not mention the deleterious effects of rarity, habitat fragmentation, and population isolation on imperiled species. Such species are always more susceptible to population extirpations and eventual extinction. Species that are restricted in range and population size are more likely to suffer loss of genetic diversity due to genetic drift, increasingly susceptible to inbreeding depression, and less likely to adapt to environmental changes (Allendorf et al. 2012). Once isolated Pink Mucket populations are lost, the absence of an available source population makes recolonization impossible without human intervention (Sjögren 1991).

Extinctions due to population fragmentation have a time lag during which species must pay an extinction debt sometime in the future (Tilman et al. 1994; Hanski and Ovaskainen 2002). Models predict that those species whose populations are fragmented and restricted to isolated habitat patches due to past habitat destruction are increasingly threatened with extirpation. Further, even good competitors and abundant species are susceptible to eventual extirpation due to the extinction debt principle. A second wave of mussel extinctions can therefore be expected from species whose populations are isolated by altered habitats (Haag 2009a). Further, this second extinction wave could affect more species than did the initial extinction wave (Haag 2012). Even if all anthropogenic threats could be ameliorated, we will likely lose disjunct Pink Mucket populations to below-threshold EPS resulting from the unpaid extinction debt. Evidence indicates that general degradation continues to decrease habitat patch size and to act insidiously in the decline of several isolated and very small Pink Mucket populations. Once isolated, Pink Mucket populations are lost, the absence of an available source population makes recolonization impossible without human intervention. Pink Mucket in some of these streams will likely die out in the foreseeable future if population restoration programs are not enacted promptly (see section II.C.1.b).

Zebra Mussels have invaded streams throughout most of the range of Pink Mucket since the Recovery Plan was written. These nonindigenous species are particularly prevalent in navigational channels where barge traffic has served as an effective means of transporting them long distances as well as providing regular infestations of new stock. Their populations reached alarming densities in certain large rivers, raising alarms about the threat to imperiled species like Pink Mucket (Chaffee 1997) and the potential that commercial harvest would be severely compromised (Fassler 1997). After first detection in 1991 in the lower Ohio River, they expanded rapidly and by 1994 thickly carpeted the bottom of the river where “*all*” native mussels observed were covered with “large numbers of adult Zebra Mussels” (Chaffee 1997, emphasis hers). Their numbers spiked in September 1994 at ~527,000/ft², when heavy infestation of live mussels was shown to have reduced unionid growth rates (Payne and Miller 2002). By July 2005, their density was cut ten-fold (to 54,000/sq. ft), and subsequent cohorts through 2001 had not been particularly dense (Payne and Miller 2002). Likewise, spiking Zebra Mussel populations in the upper Ohio River are thought to have negatively impacted its Pink Mucket population (P.A. Morrison, FWS, pers. comm., 2004). Mussel mortality rates of up to 30% were attributed to Zebra Mussel invasions in the upper Ohio River in 2000 (ESI 2002). Currently, the threat from Zebra Mussels to native mussels in the Ohio River has largely abated since densities have continued to decline markedly in recent years. Due to extremely low densities in other Pink Mucket streams, Zebra Mussels do not appear to have been a significant threat to any other population.

Global climate change is well-documented and generally accepted within the scientific community and now included in general conservation planning (Heino et al. 2009; Poff et al. 2012). The ultimate results of climate change remain unknown, but increased periods of drought are a possibility in some areas, as are changes in precipitation and water temperature cycles (Strayer and Dudgeon 2010). Physiological tolerances (e.g., temperature, dissolved oxygen) of most mussel species are largely unknown, but changes

that cross critical thresholds could disrupt life stages or host availability. The ability to physiologically adapt to changes likely varies among mussel species. Laboratory experiments determined that dewatered conditions (a surrogate for drought) significantly reduced burrowing in Pink Mucket, and that increasing temperature diminished both burrowing and byssal thread production in the species (Archambault et al. 2013, 2014). Drought conditions and warming stream waters may therefore have sub-lethal effects on the wellbeing of Pink Mucket populations.

D. Synthesis

General threats to the species remain similar to 1976 when this species was listed as endangered in the Federal Register and to 1985 when the Recovery Plan was written (e.g., habitat degradation from impoundments, sedimentation, pollution). An exception is commercial harvest, which is now nearly non-existent as a threat to the species. Threats that were not mentioned in the Recovery Plan but exist today include the deleterious effects of habitat fragmentation and population isolation, stochasticity, toxic pharmaceuticals and personal care products, and emerging issues such as climate change that threaten Pink Mucket populations rangewide. Extant populations are now primarily affected by navigational activities, reservoir releases, mining practices, inadequately treated wastewater discharges, and factors associated with small disjunct populations (e.g., stochasticity, low genetic diversity, habitat fragmentation and population isolation). There have been few significant improvements regarding these threats since 1985. At least 2 of the 16 populations considered extant in the Recovery Plan are now deemed extirpated. In addition, much biological and distributional information that was unknown when the Recovery Plan was written is now available, including fish hosts, life history aspects, the discovery or rediscovery of several stream populations (bringing total extant populations to 29), and development of propagation technology to culture individuals for population restoration activities.

Redundancy

Redundancy reduces the risk that a portion of the species' range will be negatively affected by a catastrophic natural or anthropogenic event by spreading risk across a larger area. Pink Mucket redundancy is low. The total population size for Pink Mucket, though undetermined, is relatively small based on information summarized in section II.C.1.a (e.g., significant loss of total range, infrequent occurrence in apparently suitable habitat, very low relative abundance compared to other mussels, overall rarity of the species). With few exceptions, its 29 extant populations are: 1) small and have low relative abundance (rarely are more than one or two individuals found per sample and a third of its populations are known from only one or two animals observed over the past 30 yrs); 2) sporadically or occasionally distributed in most rivers and nearly all river reaches; 3) generally limited in linear extent (over half of the stream populations occur over <16 RMs), and 4) typically lacking evidence of recent recruitment.

Representation

Representation describes the ability of a species to adapt to changing environmental conditions. Pink Mucket is a relatively rare big river mussel that was widely distributed historically in at least 48 streams in the lower half of the Mississippi River basin. At present, 29 streams continue to support populations of this species. A current estimate of the total occupied linear range in these

streams is ~1300 RMs. At least 19 streams with ~1000 RMs of former range have lost their Pink Mucket populations. Elimination from these streams combined with extensive reaches of unoccupied range in extant streams of occurrence (~4400 RMs), indicates that ~5400 RMs of its total former range no longer supports the species. This represents an ~80% loss of the ~6700 RMs total known historical distribution of Pink Mucket over the past century.

Resiliency

Resiliency describes the ability of the species to withstand stochastic disturbance events, which is associated with population size, growth rate, and habitat quality. The species is considered generally distributed and relatively common only in a narrow reach of Cumberland River, sites associated with several islands in Pickwick Landing tailwaters of lower Tennessee River, and single beds in a few other streams. In all other streams or stream reaches the species is sporadic or occasional in distribution and generally considered rare or uncommon in abundance. With many disjunct populations and its overall scarcity, the species is highly susceptible to localized extirpations from the genetic implications of extremely low population size and because of threats that are extremely difficult if not impossible to control. Stochastic events are a concern for all populations, particularly those that are in navigation channels, associated with major ground transportation networks, reach-limited, and very small in size.

Due to the continued threats in navigation channels—where two of the largest populations occur—and from stressors in other streams, we conclude that, at this time, Pink Mucket continues to meet the definition of an endangered species under the Act.

III. RESULTS

Recommended Classification:

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

IV. RECOMMENDATIONS FOR FUTURE ACTIONS

Priority Actions:

- 1) Prepare a species status assessment to evaluate the species status under the ESA and to help inform recovery planning prior to development of the next five-year review. Any revision would address the species' current range and the known status of its populations, while adding propagation technology as a recovery tool, and other actions and activities needed for recovery.
 - a. Within the Recovery Plan, prepare a rangewide population restoration and monitoring plan for the species to guide managers on which populations and rivers to focus reintroduction and augmentation efforts.
- 2) Conduct a rangewide phylogenetic analysis to determine if distinct taxonomic or evolutionarily significant populations are evident and to guide managers in source population selection for reintroductions and augmentations.

- 3) Conduct habitat assessments in unoccupied streams and stream reaches to determine the feasibility of population restoration activities (e.g., lower Ouachita River, Louisiana).
- 4) Reintroduce populations in streams within its historical range in reaches that have suitable habitat and water quality conditions. This can be achieved through the propagation of juveniles and/or release of infected host fishes. For example, the following Cumberlandian Region streams were recommended by the Cumberlandian Region Mollusk Restoration Committee (CRMRC) (2010) for reintroduction: Tennessee River drainage – Nolichucky River, Tennessee; Duck River, Tennessee; Elk River, Alabama/Tennessee; Emory River, Tennessee; upper French Broad River, Tennessee; upper Holston River, Tennessee; and Hiwassee River, Tennessee; Cumberland River drainage – Cumberland River, Barkley Dam tailwaters, Kentucky; Rockcastle River, Kentucky; and Big South Fork, Tennessee/Kentucky.
- 5) Conduct a population genetics study that specifically provides information critical for maintaining adequate levels of genetic diversity, particularly as they relate to hatchery cultured individuals (e.g., population structure, gene flow, kinship; e.g., Eackles and King 2002).
- 6) Continue to augment and expand select extant populations through the propagation and subsequent growout of juveniles and/or release of infested host fishes. For example, the following Tennessee River streams were recommended by CRMRC (2010) for augmentation: upper Clinch River, Virginia/Tennessee; and Paint Rock River, Alabama (though the latter is a lower priority due to the potential for it not representing a true population; see section II.C.1).
- 7) Determine the degree of threats (e.g., from mining, pollutants, navigation activities) to extant populations, and devise a plan to address these threats.
- 8) Work with partners to solicit funding from various sources (e.g., Corps mitigation, Endangered Species Act Section 6) to fund propagation, reintroduction, and augmentation efforts.
- 9) Determine the conservation status of extant populations through periodic monitoring including a quantitative component that provides basic population size estimates and a sampling design specifically for searching for juveniles, thus facilitating the assessment of recruitment into a population.
- 10) Continue to work with FERC and other partners through the relicensing process in modifying the discharges of private dams to improve habitat conditions in tailwaters.
- 11) Continue to work with TVA, the Corps, and other partners in modifying non-private dam discharges to improve habitat conditions in tailwaters.
- 12) Continue to work with EPA and other partners to ensure that national water quality criteria for ammonia and other contaminants are protective of all life stages of the species.

Other Actions:

- 1) Continue to refine propagation technology for laboratory culture, translocation methodologies (including streamside infestations), and population restoration activities.
- 2) Conduct population viability analyses and explore other aspects of demographics of significant extant populations (e.g., recruitment and mortality rates, longevity, sex ratios).
- 3) Conduct studies to determine if hydraulic factors can affect species patchiness and potentially rareness in large river habitats (e.g., Newton et al. 2008).

- 4) Map stable substrate patches in large river habitats using hydraulic variables and GIS technology, and ground truth species use of these habitat patches.
- 5) Once stable habitat patches are identified, use models to: 1) predict patch extent and location spatially and temporally and 2) conduct threat assessments from particular stressors.
- 6) Monitor Zebra Mussel and other nonindigenous species that may pose a threat to its populations.

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UMMZ online database:

http://www.ummz.lsa.umich.edu/mollusks/databases/ummz_search.html

Individuals and affiliations of personal communications and unpublished data cited in this review (those noted as currently retired may not have been so when contacted):

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U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW of Pink Mucket (*Lampsilis abrupta*)

Current Classification: Endangered
Recommendation resulting from the 5-Year Review

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

Appropriate Listing/Reclassification Priority Number, if applicable _____

Review Conducted By: Bob Butler and Janet Mizzi

FIELD OFFICE APPROVAL:

Lead Field Supervisor, Fish and Wildlife Service

Approve JANET MIZZI Digitally signed by JANET MIZZI
Date: 2019.06.25 10:36:39 -0400 Date _____

REGIONAL OFFICE APPROVAL:

Lead Regional Director, Fish and Wildlife Service

Approve Franklin Nordstrom Date 7/23/19

Acting Assistant
Cooperating Regional Director, Fish and Wildlife Service

Concur Do Not Concur

Signature LORI NORDSTROM Digitally signed by LORI NORDSTROM
Date: 2019.07.22 10:05:00 Date _____

Cooperating Regional Director, Fish and Wildlife Service

Concur Do Not Concur

Signature Stephen Reich, Acting Assistant Regional Director for Ecological Services Date 7/11/19

APPENDIX A: Summary of peer review for the 5-year review of Pink Mucket (*Lampsilis abrupta*)

A. Peer Review Method:

This was not a PRB peer review. The author of this review selected three individuals that collectively had decades of experience with mussel surveys and research and were well acquainted with Pink Mucket, its habitat, and status. A memorandum was sent via email on June 13, 2014 to the peer reviewers soliciting their comments on a draft of the 5-year review. Comments from all three individuals were received by July 30, 2014.

B. Peer Review Charge:

Peer reviewers were specifically asked if they agreed with the scientific information that we compiled on the Pink Mucket.

C. Summary of Peer Review Comments/Report:

All peer reviewers did not disagree with our assessments of population status. Some minor additional information on threats and population status was also received.

D. Response to Peer Review:

All comments and suggested edits were carefully considered and incorporated where deemed appropriate in the final draft of the 5-year review. Comments were generally in agreement with our assessments and other information contained in the document. No major concerns were voiced.