Species Status Assessment Report for the Purple Lilliput Mussel (*Toxolasma lividum*)

Photo credit: The Mussel Project

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TABLE OF CONTENTS

ACRONYMS

AMD	acid mine and saline drainage
ANS	aquatic nuisance species
ANSP	Academy of Natural Sciences of Philadelphia
BMP	best management practices
CBD	Center for Biological Diversity
CM	Carnegie Museum of Natural History
Corps	U.S. Army Corps of Engineers
CWA	Clean Water Act
DNA	deoxyribonucleic acid
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESI	Ecological Specialists, Inc.
FR	Federal Register
GIS	geographic information system
HUC	Hydrologic unit codes
IDEM	Indiana Department of Environmental Management
INDNR	Indiana Department of Natural Resources
INHS	Illinois Natural History Survey
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KDEP	Kentucky Department for Environmental Protection
KYDOW	Kentucky Division of Water
KYFW	Kentucky Department of Fish and Wildlife Resources
KYSNPC	Kentucky State Nature Preserves Commission
LEC	Lewis Environmental Consulting
MU	Management Unit
MDC	Missouri Department of Conservation
MFM	Museum of Fluviatile Mollusks
MNFI	Michigan Natural Features Inventory
NHP	Natural Heritage Program
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
ODNR	Ohio Department of Natural Resources
OSUM	Ohio State University Museum
PPM	parts per million
RM	river mile
Service	U.S. Fish and Wildlife Service
SSA	Species Status Assessment
SWAP	State Wildlife Action Plan
TDEC	Tennessee Department of Environment and Conservation
TVA	Tennessee Valley Authority
TWRA	Tennessee Wildlife Resources Agency
UMMZ	University of Michigan Museum of Zoology
USDA	U.S. Department of Agriculture
USNM	U.S. National Museum
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

Purple Lilliput was first described in 1831 by Constantine Rafinesque as a small mussel with a thick shell, up to 1.5 inches (38 millimeters) in size, and thought to live up to 12 years. It is found in small streams to large rivers (such as the Tennessee River mainstem), and prefers a mixture of sand, gravel, and cobble substrates.

The Purple Lilliput mussel is historically known from 13 states, though now occurs in 9. It is currently found in six major river basins: Great Lakes, Ohio, Cumberland, Tennessee, Arkansas-White-Red, and Lower Mississippi. Known populations in the U.S. have declined from 272 historically to 146 today. For the purpose of this document, analysis and subsequent discussion focuses on management units, or river sub-basins occupied by one or more Purple Lilliput populations. Today there are 65 management units, while historically there were 135. It is important to note that a 58 percent (38 of the 65 MUs) are currently in low condition (*i.e.*, are predominantly composed of populations that are small with no evidence of recruitment or age class structure).

Projections 20 to 30 years into the future indicate that the number of populations could remain at 146 or drop to as low as 117, depending on the variety of considerations built into the scenarios we evaluated; while the number of management units could remain at 65 or drop as low as 52. There is currently the largest number of populations in the Arkansas-White-Red basin and smallest number of populations in the Great Lakes and Cumberland basins. The species is considered rare and critically imperiled in Ohio and Michigan (i.e., states with populations in the Great Lakes basin). Under future condition scenarios that could potentially result in worse conditions than current, peripheral populations in Ohio and Michigan could be lost. Populations in Virginia (Tennessee basin) and Oklahoma (Arkansas-White-Red basin) are considered potentially extirpated in this SSA due to the lack of records of the species since 2000.

In projecting the future viability of the Purple Lilliput, three scenarios were considered: (1) current influences remain constant 20–30 years into the future; (2) negative influences decrease due to elevated levels of conservation efforts over 20–30 years; and (3) negative influences increase in magnitude/intensity over 20–30 years. Historical, current, and future population projections are summarized below in Table ES-1. Our analysis articulates the ability of the species to withstand catastrophic events (redundancy), its adaptive potential across the six river basins where it is extant (representation), and the capability of populations to withstand stochastic disturbance (resiliency).

Table ES-1. Overall summary of current and future population conditions for Purple Lilliput populations and MUs across its range.

● **High** - Resilient populations with evidence of recruitment and multiple age classes represented. Likely to maintain viability and connectivity among populations. Populations are not linearly distributed (i.e., occur in tributary streams within a management unit). These populations are expected to persist in 20 to 30 years and beyond and withstand stochastic events. (*Thriving; capable of expanding range*.)

- **Medium** – Spatially restricted populations with limited levels of recruitment or age class structure. Resiliency is less than under high conditions, but the majority of populations (approximately 75 percent) are expected to persist beyond 20 to 30 years. (*Stable; not necessarily thriving or expanding its range*.)

- **Low** - Small and highly restricted populations, with no evidence of recent recruitment or age class structure, and limited detectability. These populations have low resiliency, are not likely to withstand stochastic events, and potentially will no longer persist in 20 to 30 years. Populations are linearly distributed within a management unit. (*Surviving, observable; but population likely declining*.)

(FUTURE CONDITION ONLY)

- **Very Low** - Populations are expected to no longer occur in a river/stream or management unit in the future (20–30 years). A population may be below detectable levels despite consistent survey effort within its formerly occupied range. (*No survival or survival uncertain; no longer observable*.)

	Historical	**Current**	**Future Scenario 1**	**Future Scenario 2**	**Future Scenario 3**
GREAT LAKES BASIN					
# very low populations	--	--	1	0	2
# low populations	--	3	2	1	1
# medium populations	--	--	0	2	0
# high populations	--	--	0	0	0
# total populations	15	3	2	3	1
# Management units	10[2]	3	2	3	1
# states	3[1]	3	2	3	1
OHIO RIVER BASIN					
# very low populations	--	--	0	0	2
# low populations	--	20	21	0	26
# medium populations	--	8	7	20	3
# high populations	--	3	3	11	0
# total populations[2]	73[2]	31	31	31	29
# Management units	35[2]	11	11	11	11
# states	4[2]	3	3	3	3
CUMBERLAND RIVER BASIN					

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[1] Accounts for states where the species currently resides and those states that the species is known to be extirpated from.

[2] Total values under the three future condition scenarios exclude the very low population counts given these populations would likely no longer exist in the future.

	Historical	Current	Future Scenario 1	Future Scenario 2	Future Scenario 3
# very low populations	--	--	2	0	2
# low populations	--	9	7	2	8
# medium populations	--	1	1	7	0
# high populations	--	0	0	1	0
# total populations[1]	29[2]	10	8	10	8
# Management units	17[2]	7	5	7	5
# states	2[2]	2	2	2	2
TENNESSEE RIVER BASIN					
# very low populations	--	--	1	0	6
# low populations	--	10	10	1	15
# medium populations	--	11	10	10	11
# high populations	--	11	11	21	0
# total populations[1]	71[2]	32	31	32	26
# Management units	27[2]	10	9	10	6
# states	4[2]	3	3	3	3
ARKANSAS-WHITE-RED RIVER BASIN					
# very low populations	--	--	3	0	13
# low populations	--	32	31	2	30
# medium populations	--	12	10	32	6
# high populations	--	5	5	15	0
# total populations[1]	58[2]	49	46	49	36
# Management units	31[2]	23	22	23	18
# states	3[2]	2	2	2	2
LOWER MISSISSIPPI RIVER BASIN					
# very low populations	--	--	3	0	5
# low populations	--	12	9	2	12
# medium populations	--	5	5	10	4

	Historical	Current	Future Scenario 1	Future Scenario 2	Future Scenario 3
# high populations	--	4	4	9	0
# total populations[1]	26[2]	21	18	21	16
# Management units	14[2]	11	10	11	9
# states	2[2]	2	2	2	2
TOTAL					
# very low populations	--	--	10 (6%)	0 (0%)	30 (19%)
# low populations	--	87 (59%)	80 (55%)	8 (6%)	92 (65%)
# medium populations	--	36 (25%)	33 (23%)	81 (55%)	24 (16%)
# high populations	--	23 (16%)	23 (16%)	57 (39%)	0 (0%)
# total populations[1]	272	146	136	146	116
# Management units	135	65	59	65	50
# states	13	9	8	9	7

This SSA Report for the Purple Lilliput includes:

(1) An introduction, including taxonomy (Chapter 1);
(2) A description of the SSA framework, including resiliency, redundancy, and representation (Chapter 2);
(3) A description of Purple Lilliput's ecology (Chapter 3);
(4) The resource needs of the Purple Lilliput as examined at the individual, population, and rangewide scales (Chapter 4);
(5) Characterization of the historical and current distribution, abundance, and demographic conditions of the Purple Lilliput across its range (Chapter 5);
(6) An assessment of the current factors that negatively and positively influence the Purple Lilliput, and the degree to which the various factors influence its viability (Chapter 6);
(7) Descriptions of future scenarios, including an evaluation of those factors that may influence the species in the future and a synopsis of resiliency, redundancy, and representation given the potential future condition scenarios (Chapter 7);
(8) An overall synthesis of this report (Chapter 8).

CHAPTER 1 - INTRODUCTION

1.1 Purpose of SSA

The Species Status Assessment (SSA) framework (Service 2016, entire) guides the development of an SSA report, which is an in-depth review of a species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The SSA report is easily updated as new information becomes available. As such, the SSA report is a living document that may be used to inform decision making under the Endangered Species Act of 1973, as amended (ESA).

Importantly, the SSA report is not a decisional document; rather, it provides a review of available information strictly related to biological status, in this case, of the Purple Lilliput mussel (also referred to herein as "the Purple Lilliput"). Any decisions regarding the legal classification of the Purple Lilliput are made after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the *Federal Register*, with appropriate opportunities for public input.

1.2 Species Basics - Taxonomy and Evolution

The Purple Lilliput (*Toxolasma lividum*; Figure 1-1) is a freshwater mussel currently found in the Great Lakes, Ohio, Cumberland, Tennessee, Arkansas-White-Red, and Lower Mississippi major river basins, within the States of Alabama, Kentucky, Missouri, Arkansas, Ohio, Illinois, Indiana, Michigan, and Tennessee (Appendix A; Figure 1-2). It is considered extirpated from North Carolina and Georgia, and considered potentially extirpated from Oklahoma and Virginia. Although it has never been collected within the state of Kansas, it occurs in the Spring River drainage nearby in Missouri and thus potentially occurs in Kansas, and may eventually be discovered there (Obermeyer *et al.* 1997, p. 49; Angelo *et al*. 2009, p. 95).

Figure 1-1. Purple Lilliput. Photo credit: Dr. Monte McGregor, Kentucky Department of Fish & Wildlife Resources (KDFWR).

The status of the Purple Lilliput within the states of Oklahoma and Virginia are considered potentially extirpated in this assessment because the species status in those states has been recognized as uncertain for some time (Branson 1984, p. 23; Jones and Neves 2007, p. 478). In the most recent NatureServe rangewide assessment, the Purple Lilliput was ranked as possibly extirpated (Table 1-1). These states are on the periphery of the range and represent the easternmost (Virginia), and westernmost (Oklahoma) extent of the known historical range of the species. In Oklahoma, the Purple Lilliput has not been observed within the state in over a century (Isley 1925, p. 67), but recent collection efforts are lacking, and it occurs just over the state line in Arkansas in the Poteau River Management Unit (MU)

(Vaughn and Spooner 2004, p. 339). With targeted survey effort, it is possible the Purple Lilliput will be eventually rediscovered in Oklahoma (Mather 2005, p. 233). In Virginia, despite mussel community survey efforts in the Clinch and North Fork Holston Rivers where it historically occurred, the Purple Lilliput has not been observed since 1996. The species occurs in the Clinch River MU downstream in Tennessee, and it is possible that the Purple Lilliput still occurs in Virginia, but is very rare (Jones 2015, p. 316; Ahlstedt *et al.* 2016, p. 3). Therefore, populations within these states are given a unique category of potentially extirpated in this SSA.

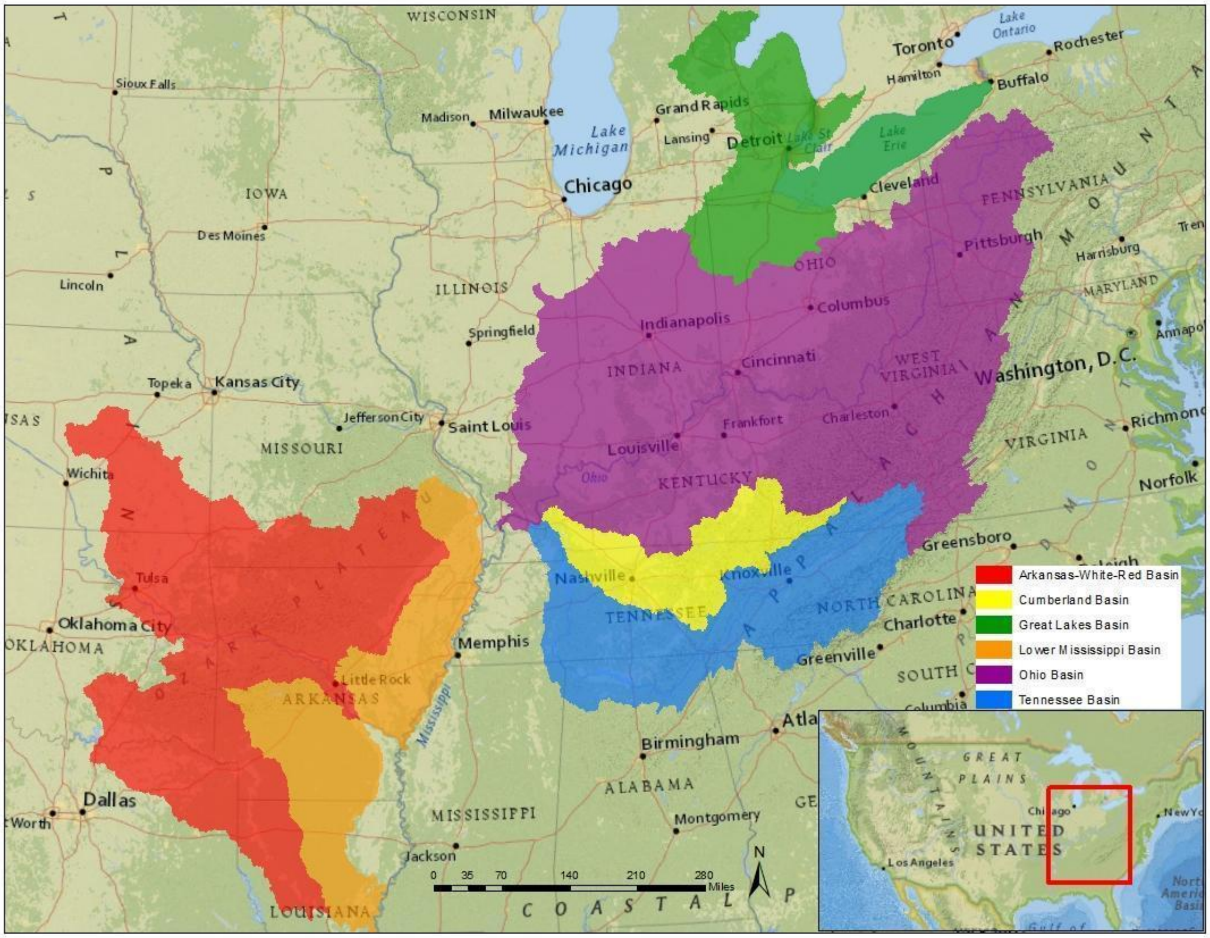

Figure 1-2. Purple Lilliput range map indicating the Great Lakes, Ohio, Cumberland, Tennessee, Arkansas-White-Red, and Lower Mississippi River basins. (Source: Service 2019a, unpublished data).

The six major river basins that Purple Lilliput inhabits (i.e., currently extant) are the Great Lakes, Ohio, Cumberland, Tennessee, Arkansas-White-Red, and Lower Mississippi River basins (Figure 1-2, above). For this assessment, we used information about the species historical range to partition Purple Lilliput into these six geographical units (basins).

A single population technically occurs in the Upper Mississippi basin, in Crooked Creek, Missouri, in the Whitewater River MU. Crooked Creek is a component of the man-made Headwater Diversion Channel constructed in 1913, which separated the Headwater Diversion Basin from the larger Little River Basin (Norman 1994, p. 37). The Little River drainage in Missouri is tributary to the Lower Mississippi basin, and the man-made diversion channel is not a natural physiographic or drainage separation. Thus, for the purposes of this SSA and analysis, the Purple Lilliput population in Crooked Creek (as well as the MU it occurs in) is considered part of the Lower Mississippi basin.

1.2.1 Taxonomy

The Purple Lilliput mussel belongs to the order Unionoida, also known as the naiads and pearly mussels. This group of bivalves has existed for over 400 million years (Howells *et al.* 1996, p. 1), representing over 600 species worldwide and over 250 species in North America (Strayer *et al.* 2004, p. 429; Lopes-Lima *et al.* 2018, p. 3). This Purple Lilliput SSA report follows the most recently published and accepted taxonomic treatment of North American freshwater mussels as provided by Williams *et al.* (2017, entire).

The Purple Lilliput (*Toxolasma lividum*) was originally described in 1831 by Constantine Rafinesque as *Unio glans* (Lea 1831, p. 82). *Toxolasma lividum* is part of a genus that includes seven mussel species (Williams *et al.* 2017, p. 44).

The currently accepted classification is:
- Phylum: Mollusca
- Class: Bivalvia
- Order: Unionoida
- Family: Unionidae
- Subfamily: Ambleminae
- Tribe: Lampsilini
- Genus: *Toxolasma*
- Species: *lividum*

1.3 Petition History

We, the U.S. Fish and Wildlife Service (Service), were petitioned by the Center for Biological Diversity (CBD), Alabama Rivers Alliance, Clinch Coalition, Dogwood Alliance, Gulf Restoration Network, Tennessee Forests Council, West Virginia Highlands Conservancy, Tierra Curry, and Noah Greenwald to list the Purple Lilliput as an endangered or threatened species under the ESA. This request was part of a 2010 petition to list 404 aquatic, riparian, and wetland species in the southeastern United States (CBD 2010, pp. 538–540). On September 27, 2011, we found that the petition presented substantial scientific or commercial information indicating that listing the Purple Lilliput may be warranted (76 FR 59836–59862); substantial findings were made for the other species in this same *Federal Register* notice, although analyses and findings for those other species are addressed separately.

1.4 State Listing Status

The states of Ohio, Indiana, and Michigan have state agency protective regulatory measures for freshwater mussels prohibiting the take or possession of any freshwater mussels without a scientific collector's permit. In many cases, landowner rights supersede these regulations. A variety of additional designations or status descriptions are assigned to the Purple Lilliput within other states, making it unlawful for anyone to take, possess, transport, export, process, sell or offer for sale or ship, and for any contract carrier to knowingly transport or receive for shipment, individuals or parts of the species. However, these designations are typically accompanied by wildlife management agency mandates and are not state statutory protections (Table 1-1). The states of Alabama, Tennessee, and Kentucky all have mussel harvest sanctuaries or designated reaches of rivers where it is unlawful to take, catch, or kill freshwater mussels, and also prohibit degradation of aquatic habitat. These measures provide some indirect protection to the Purple Lilliput.

Table 1-1. State and NatureServe conservation status of Purple Lilliput throughout its current and historical range.

State Status	AL	AR	IL	IN	KY	NC	OH	TN	MI	MO	VA	OK	GA
State Rank (Wildlife Action Plans) 2015	S2	S3	E	SC	E (S1)	SX	E	S1/S2	E (S1)	S1	E[1]	Tier[1]	NR
NatureServe (as of 2009)	S2	S2	S1	S2	S1	SX	S1	S1/S2	S1	S1	SH[1]	SH[1]	SH

KEY: E = endangered; SC = Special Concern; NR = not ranked/recognized; Tier 1 = Critical Conservation Need; SX = Presumed Extirpated; SH = Possibly Extirpated; S1 = Critically Imperiled; S2 = Imperiled; S3 = Vulnerable.

[1] The states of Virginia and Oklahoma have State Wildlife Action Plan (SWAP) status rankings of Endangered and Tier, respectively. However, NatureServe ranks the species in these states as SH = Possibly Extirpated. Due to the lack of live or fresh dead collection records of the species since 2000 within those states, the status of the Purple Lilliput in Virginia and Oklahoma is considered potentially extirpated in this SSA. The Purple Lilliput occurs in shared MUs across in adjacent states (Tennessee and Arkansas), and may be rediscovered in Virginia and Oklahoma with targeted collection efforts.

CHAPTER 2 - METHODOLOGY AND DATA

2.1 SSA Framework

This report is a summary of the SSA analysis, which entails three iterative assessment stages: species (resource) needs, current species condition, and future species condition (Figure 2-1).

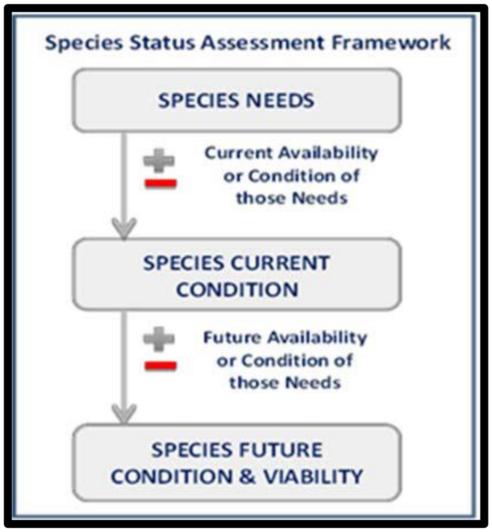

Figure 2-1. The three analysis steps in a Species Status Assessment (Service 2016, entire).

2.1.1 Species Needs

The SSA includes a compilation of the best available biological information on the species and its ecological needs at the individual, population, and rangewide levels based on how environmental factors are understood to act on the species and its habitat.

- Individual level: These resource needs are those life history characteristics that influence the successful completion of each life stage. In other words, these are survival and reproduction needs that make the species sensitive or resilient to particular natural or anthropogenic influences.

- Population level: These components of the Purple Lilliput's life history profile describe the resources, circumstances, and demographics that most influence **resiliency** of the populations.

- Rangewide level: This is an exploration of what influences **redundancy** and **representation** for the Purple Lilliput. This requires an examination of the mussel's evolutionary history and historical distribution to understand how the species functions across its range.

To assess the biological status of the Purple Lilliput across its range, we used the best available information, including peer-reviewed scientific literature and academic reports, and survey data provided by non-governmental organizations as well as state and Federal agencies. Additionally, we consulted with several species experts who provided important information and comments on Purple Lilliput distribution, life history, and habitat.

We researched and evaluated the best available scientific and commercial information on the Purple Lilliput's life history. To identify population-level needs, we used published literature, unpublished reports, information from consultants, and data from current agency survey and taxonomic research projects. To date, no specific life history study has been conducted on the

Purple Lilliput. Species-specific literature available includes observational information on Purple Lilliput reproductive aspects (Ortmann 1921, p. 89) and host fish suitability (Hill 1986, p. 5). Where applicable, surrogate life history information was also used from the closely related Lilliput (*Toxolasma parvum*), Savannah Lilliput (*Toxolasma pullus*), or Texas Lilliput (*Toxolasma texasiense*).

2.1.2 Current Species Condition

The SSA describes the current known condition of the Purple Lilliput's habitat and demographics, and the probable explanations for past and ongoing changes in abundance and distribution within areas representative of the geographic, genetic, or life history variation across the species range.

We considered the Purple Lilliput's distribution, abundance, and factors currently influencing the viability of the species. We identified known historical and current distribution and abundance, and examined factors that negatively and positively influence the species. Scale, intensity, and duration of threats were considered for their impacts on the populations and habitat across life history stages. The magnitude and scale of potential impacts to the Purple Lilliput or its habitat by a given threat are described using a High/Moderate/Low category scale.

How Populations Were Evaluated For Current Conditions

For the current condition analyses, the Purple Lilliput was considered extant if a live individual or fresh dead specimen was collected since 2000[3], or collections of the species have been made since 1990 with no available negative mussel survey data from the stream to dispute that the species still occurs there. Given the timing and frequency of mussel surveys conducted throughout the species' range, collections or observations of live individuals or fresh dead specimens since 2000 likely indicate the continued presence of a species within a river or stream (Stodola *et al.* 2014, p. 1). For large water bodies such as the Tennessee River, or for streams that have not received consistent survey effort, it is difficult to determine whether a lack of occurrence since 1990, relative to pre-1990 information, reflects a lack of sampling or a decline in abundance or distribution (Haag and Cicerello 2016, pp. 65–66).

Presumed extirpation was determined by documentation in literature, reports, or from communications with state malacologists and aquatic biologists. General reference texts on regional freshwater mussel fauna provided substantial information on species distribution, both past and present, including (but not limited to): Oesch (1984), Gordon and Layzer (1989), Parmalee and Bogan (1998), Williams *et al.* (2008), Harris *et al.* (2009), Watters *et al.* (2009), Stodola *et al.* (2014), and Haag and Cicerello (2016). The current status of the Purple Lilliput in Virginia and Oklahoma is potentially extirpated based on the best available current information, and Kansas has been hypothesized to potentially harbor populations of the species, but no specimens have been located in the state (Angelo *et al.* 2009, p. 95).

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[3] We used the year 2000 in this analysis for consistency due to highly variable recent survey information across the range of the Purple Lilliput, and available state heritage databases and information support for the likelihood of the species continued presence within this timeframe.

There is no systematic sampling regime to monitor the Purple Lilliput's distribution and status across its range, and the species generally has a widespread but sporadic distribution. There is little trend information available from populations, and fluctuations in abundance are largely undocumented. A general challenge of estimating the precise abundance and occurrence of freshwater mussels is exemplified by spatial aggregations in reproduction and the association between mussel occurrence and patchily-distributed habitat (Smith *et al.* 2003, p. 9).

The Purple Lilliput frequently occurs along stream margins or shorelines, and in some cases, overbank reservoir habitats that are frequently not targeted or are overlooked during mussel surveys and inventories. Its current abundance in the impounded mainstem Tennessee River in North Alabama is puzzling and unexplained. As a result of these habitats being under-surveyed, the Purple Lilliput likely is not detected in many localities where it maintains populations.

We gathered information from a large body of published and unpublished survey work performed rangewide since the early 1900s. More recent published and unpublished distribution and status information was provided by biologists from State Natural Heritage Programs (NHP), Department of Natural Resources (DNR) programs, other state and Federal agencies, academia, and museums; all information was compiled into spreadsheets for reference. Occurrence data were grouped by named stream and state, then organized by 8-digit hydrologic unit code watershed (HUC 8)[4]. All records were also added to a Geographic Information System (GIS) database to facilitate spatial analyses. Additional detail on the current condition analysis methodology is presented in Chapter 5.

Defining Management Units

The smallest measure of the Purple Lilliput occurrence is at the river or stream reach, which varies in length. Occasional or regular interaction among individuals in different reaches not interrupted by a barrier likely occurs, but in general, interaction is strongly influenced by habitat fragmentation, reproductive aggregations, and distance between occupied river or stream reaches. Available data were organized by named river or stream that was subsequently used as the unit to delineate an individual population. In this context, "river or stream" and "population" are used synonymously herein.

Once released from their fish host, freshwater mussels are benthic, generally sedentary aquatic organisms and closely associated with appropriate habitat patches within a river or stream (Downing *et al.* 1993, p. 149). Seasonal vertical movements within substrates commonly occur in response to temperature, day length, and fluctuating water levels and discharge, but horizontal

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[4] Hydrologic unit codes (HUC) are two to twelve-digit codes based on the four levels of classification in a hydrologic unit system, as described in Seaber *et al.* (1987) and United States Geological Survey (USGS) (2018). In summary, the United States is divided into successively smaller hydrologic units arranged or nested within each other. Each successively smaller hydrologic unit/code contains successively smaller drainage areas, river reaches, tributaries, etc. HUC 8 is the fourth-level (cataloguing unit) that maps the sub-basin level, which is analogous to medium-sized river basins across the United States.

movement is less frequent and typically covers only short distances (Amyot and Downing 1997, p. 349).

The Purple Lilliput range includes lengthy rivers, such as the Ouachita River in the Lower Mississippi basin, which includes populations fragmented primarily by dams. Therefore, separate populations are designated for each HUC 8 through which these streams flow (if there was an occurrence record for the stream in that watershed). The HUC 8 watershed is termed an MU in this report. Management units are defined as a HUC 8, which are identified as most appropriate for assessing population-level resiliency. We used range-wide species occurrence data to create maps indicating the historical and current distribution of Purple Lilliput among 65 MUs and 146 populations currently known to be extant. The HUC 8 MU approach has been used for other wide-ranging aquatic species for the purposes of an SSA (e.g., the Longsolid mussel (*Fusconaia subrotunda*) (Service 2018a, entire); the Round Hickorynut (*Obovaria subrotunda*) (Service 2019b, entire)).

2.1.3 Future Species Condition

The SSA forecasts a species' response to probable future scenarios of environmental conditions and conservation efforts. As a result, the SSA characterizes the species' ability to sustain populations in the wild over time (viability) based on the best scientific understanding of current and future abundance and distribution within the species habitat.

To examine the potential future condition of the Purple Lilliput, we developed three future scenarios focusing on a range of conditions based on projections for habitat degradation or loss, invasive or nonnative species, genetic isolation, and climate change; beneficial conservation actions were also considered. The range of what may happen in each scenario is described based on the current condition and how resilience, representation, and redundancy may change. We chose a time frame of 20 to 30 years for our analysis based on planning documents and climate modeling that informs future conditions. This time frame also captures at least two generations of this species. The scenarios considered the most probable threats with the potential to influence the species at the population or rangewide scales, including potential cumulative impacts if applicable.

For this assessment, we define viability as the ability of the Purple Lilliput to sustain resilient wild populations over time. Using the SSA framework (Figure 2-1, above), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf *et al.* 2015, entire; Service 2016, entire).

- ***Resiliency*** is assessed at the population level and reflects a species' ability to withstand stochastic events (events arising from random factors). Demographic measures that reflect population health, such as fecundity, survival, and population size, are the metrics used to evaluate resiliency. Resilient populations are better able to withstand disturbances such as random fluctuations in reproductive rates and fecundity (demographic stochasticity), variations in rainfall (environmental stochasticity), and the effects of anthropogenic activities.

- ***Representation*** is assessed at the species level and characterizes the ability of a species to adapt to changing environmental conditions. Metrics that speak to a species' adaptive potential, such as genetic and ecological variability, can be used to assess representation. Representation is directly correlated to a species' ability to adapt to changes (natural or human-caused) in its environment.

- ***Redundancy*** is also assessed at the species level and reflects a species' ability to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk of such an event across multiple, resilient populations. As such, redundancy can be measured by the number and distribution of resilient populations across the range of the species.

To evaluate the current and future viability of the Purple Lilliput, we assessed a range of conditions to characterize the species' resiliency, representation, and redundancy. Throughout this analysis, when data were lacking for the Purple Lilliput, we used information available from closely related mussel species, such as the Lilliput, Savannah Lilliput, or Texas Lilliput.

CHAPTER 3 - SPECIES BACKGROUND AND ECOLOGY

3.1 Physical Description

Mollusks are mostly aquatic and are named from the Latin molluscus, meaning "soft." Their soft bodies are often enclosed in a hard shell made of calcium carbonate ($CaCO_3$), which functions as an exoskeleton. This shell is secreted by a thin sheet of tissue called the mantle, which encloses the internal organs (Figure 3-1).

Purple Lilliput adult mussels are small, with a relatively thick, inflated, oval shell (up to 1.5 inches (in) (38 millimeters (mm)) (Williams *et al.* 2008, p. 719). The shell typically darkens with age. The anterior end of the shell is rounded and the posterior end is pointed to rounded in males and truncated in females. Internally, the lateral and cardinal teeth are well developed. The umbo cavity is shallow to moderately deep and the nacre (the lustros interior layer of the shell) is purple, which is a distinct shell characteristic.

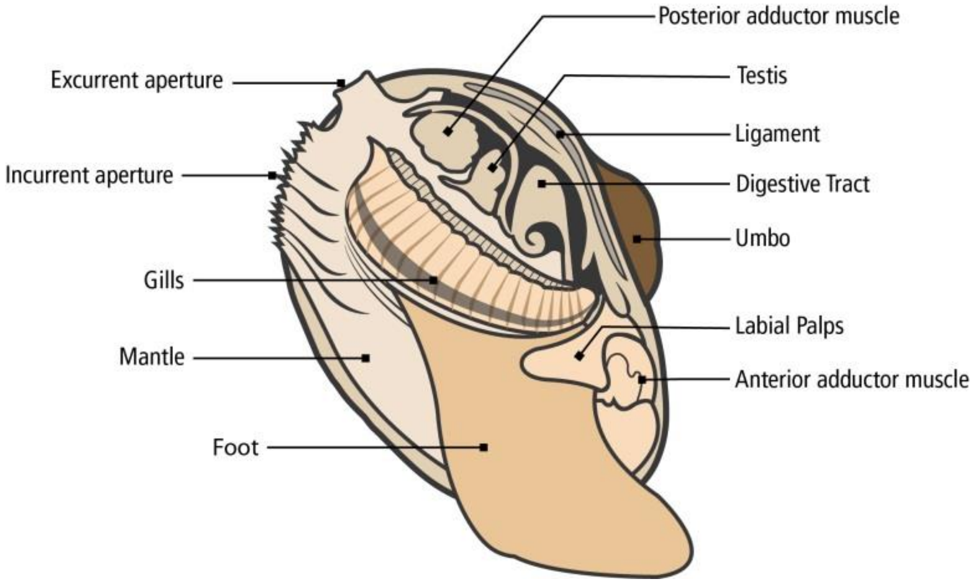

Figure 3-1. Generalized internal anatomy of a freshwater mussel. (Image courtesy of Matthew Patterson, Service).

3.2 Genetics

To our knowledge, there are no comprehensive studies that thoroughly address intraspecific divergence in genetic diversity across the range of the Purple Lilliput. A recent examination of the phylogenetic relationships within *Toxolasma* using deoxyribonucleic acid (DNA) found that the Purple Lilliput does not show geographic structure despite multiple gene analyses, and is likely most closely related to the federally endangered Pale Lilliput (*Toxolasma cylindrellus*) (Campbell and Harris 2006, p. 2).

3.3 Life History

There are no studies on the life history or average life expectancy of the Purple Lilliput. Based on aging thin sections of shells, the closely related Lilliput (i.e., *Toxolasma parvum*) was found to live at least 5 years (Haag and Rypel 2011, p. 229), Savannah Lilliput was found to live to 9 years (Hanlon and Levine 2004, p. 294), and the Texas Lilliput was found to live to 11 years (Haag and Rypel 2011, p. 229).

In multiple mussel species, more northerly populations have been shown to exhibit slower growth rates and greater longevity than more southern populations, which is attributed to latitudinal differences in water temperatures and growing seasons. Because most available data on lilliput species is from southern populations, it is likely that northern populations exhibit slower growth rates and greater longevity (Haag and Rypel 2011, p. 245). At this time, however, the best available information suggests that the Purple Lilliput is a relatively short-lived species estimated to live 5 to 10 years, but possibly living up to 15 years.

Growth rate and sex-specific data are available for the closely related Texas Lilliput, indicating that growth rate and maximum size are greater in males than females (Haag and Rypel 2011,

p. 237). The Purple Lilliput is like the Texas Lilliput in exhibiting sexual dimorphism of its shell, and most sexually-dimorphic species show differences between sexes in growth characteristics (Haag and Rypel 2011, p. 237). Other variation in mussel longevity and growth is likely related to site-specific factors and response to changes in environmental conditions such as water quality and habitat conditions present at a given location (Haag and Rypel 2011, p. 243). The growth rate slows as individual's age. Depending on water quality and other environmental conditions, negative growth is possible or could even be expected as individual's age and shells erode.

The Purple Lilliput can be found in a wide range of habitats and a variety of substrates in rivers and streams at depths less than 3.3 feet (ft) (1 meter (m)) (Gordon and Layzer 1989, p. 34). It may be located in coarse substrates such as cobble and gravel, or fine-particle substrates such as packed sand, silty clay, and mud. It is commonly collected in and near shorelines, backwaters, and in vegetation and root masses in waters just a few centimeters deep. Purple Lilliput also exhibits some ability to inhabit lentic (still water) environments (Roe 2002, p. 5). In unimpounded reaches, the species is commonly found in a range of slow to swift currents, and it has been collected from shallow, rocky gravel points, mud, and sandbars in overbank areas and embayments (Parmalee and Bogan 1998, p. 231; Williams *et al.* 2008, p. 720).

Purple Lilliput and other adult freshwater mussels within the genus *Toxolasma* are suspension-feeders that filter water and nutrients to eat. Mussels may shift to deposit feeding, though reasons for this are poorly known and may depend on flow conditions, water levels, or temperature. Ciliary tracks on the adult foot apparently facilitate this feeding behavior. Their diet consists of a mixture of algae, bacteria, detritus, and microscopic animals (Gatenby *et al.* 1996, p. 606; Strayer *et al.* 2004, p. 430). It has also been surmised that dissolved organic matter may be a significant source of nutrition (Strayer *et al.* 2004, p. 431). Such an array of foods, containing essential long-chain fatty acids, sterols, amino acids, and other biochemical compounds, may be necessary to supply total nutritional needs (Strayer *et al.* 2004, p. 431).

For their first several months, juvenile mussels ingest food through their foot and are thus deposit feeders, although they may also filter interstitial pore water and soft sediments (Yeager *et al.* 1994, p. 221; Haag 2012, p. 26). Due to the mechanisms by which food and nutrients are taken in, freshwater mussels collect and absorb toxins (see section 6.1.3, below). Additionally, recent evidence emphasizes the importance to riverine mussels of the uptake and assimilation of detritus and bacteria over that of algae (Nichols and Garling 2000, p. 881).

3.4 Reproduction

The Purple Lilliput has a complex life cycle (see Figure 3-2) that relies on fish hosts for successful reproduction, similar to other mussels. In general, mussels are either male or female (Haag 2012, p. 54). Males release sperm into the water column, which are taken in by the female through the incurrent aperture where water enters the mantle cavity. The sperm fertilize eggs that are held within the female's gills in the marsupial chamber. The Purple Lilliput is one of

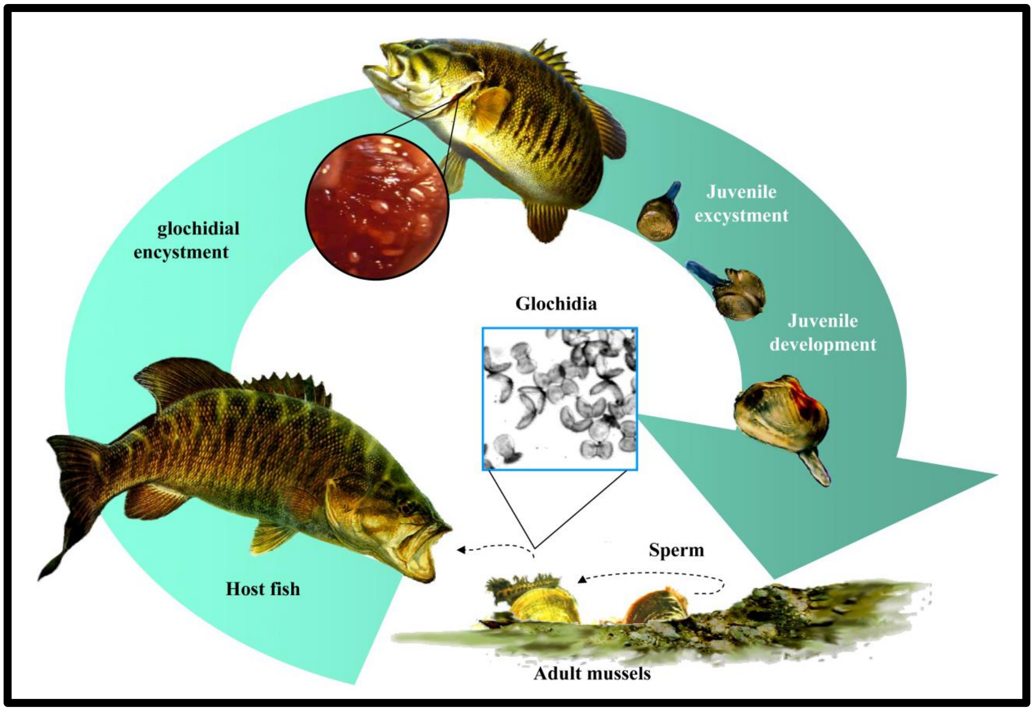

Figure 3-2. Generalized freshwater mussel life cycle. Freshwater mussels such as the Purple Lilliput have a complex life history involving an obligate parasitic larval life stage, called glochidia, which are wholly dependent on host fish. (Image courtesy Shane Hanlon, Service).

numerous freshwater mussel species that brood their larvae (called glochidia) only in the outer pair of their four gill plates. The developing larvae remain in the gill chamber until they mature and are ready for release.

The Purple Lilliput is considered to be a long-term brooder. Gravid females have been reported from May through July (Ortmann 1921, p. 89). However, some Michigan populations have been found to function as short-term brooders by producing multiple broods per year (Hoeh *in* NatureServe 2019; Vaughn 2012, p. 987). Savannah Lilliput gravid females (in a man-made reservoir) were found from late April through early August, though highest development and glochidial activity was observed prior to late July (Hanlon and Levine 2004, p. 293), suggesting peak reproduction occurs in spring and early summer months. Additionally, glochidial hosts for Purple Lilliput are known to include Green Sunfish (*Lepomis cyanellus*) and Longear Sunfish (*Lepomis megalotis*) (Hill 1986, p. 17).

The closely related Lilliput (i.e., *Toxolasma parvum*) reaches sexual maturity at age 1, while the Texas Lilliput is estimated (based on growth rate) to reach sexual maturity at age 2 (Haag 2012, p. 425). Using information from these surrogate species, we estimate the age of sexual maturity for the Purple Lilliput to be 1 to 2 years. While fecundity estimates are unavailable for the Purple Lilliput, similar mussel species (such as other members of the genus *Toxolasma*) likely produce large numbers of glochidia soon after maturity. Mean fecundity in the Texas Lilliput was reported as 20,089–33,500 (n = 4 individuals; Haag 2012, p. 750). However, mean annual fecundity is variable and strongly related to body size, and can be driven by local environmental conditions (Haag and Staton 2003, p. 2,128). Given the lack of species-specific data, we assume the Purple Lilliput has similar fecundity.

Like other species in the tribe Lampsilini, the Purple Lilliput likely targets suitable host fish (i.e., sunfish) by displaying mantle lures that mimic prey items of those fish (Haag 2012, p. 170). The lure of the Purple Lilliput consists of two thin flaps that terminate in thumb-like, inflatable tubes (caruncles) that resemble small worms (Figure 1-1). The characteristic, paired caruncles in *Toxolasma* perform a slow circling motion while the ventral mantle margin performs a fast rippling movement (Barnhart *et al.* 2008, p. 380). The caruncles rotate in opposite directions resembling twiddling thumbs but periodically and simultaneously reverse directions. This behavior is accompanied by gaping of the shell and a rippling of the mantle margin to expose the swollen gills (Kraemer 1984, pp. 226–229).

At times when female Purple Lilliput is gravid, the outward ends of the water tubes (substructures of the gills) are white and beadlike and resemble fish eggs (Kraemer 1970, p. 229). For this species, the lure's motion may serve primarily as an initial attraction, while the gill's mimicry of fish eggs serves to elicit attacks by potential host fish (Haag 2012, p. 175). Transmission of glochidia and subsequent infection occur when host fishes strike and rupture the gravid gill.

Toxolasma have what are considered to be primitive mantle lures within the Lampsilini for host fish attraction strategies, and they typically release fragile conglutinates that break up readily. The glochidia snap shut upon contacting a fish and generally must attach to the gills, head, or fins to successfully infect the fish (Vaughn and Taylor 1999, p. 913). For most mussels, the glochidia will die if they do not attach to a fish within a short period. Once on the fish, the glochidia are engulfed by tissue from the host fish that forms a cyst. The cyst protects the glochidia and aids in their maturation. The larvae draw nutrients from the fish and develop into juvenile mussels, weeks to months after initial attachment.

CHAPTER 4 - RESOURCE NEEDS

As discussed in Chapter 3, the Purple Lilliput has a multi-staged life cycle: fertilized eggs to glochidia to juveniles to adults. The life cycle represents several stages that have specific requirements (resource needs) that must be met (Table 4-1) for the mussel to progress to the next stage.

4.1 Individual-level Resource Needs

In the following subsections, we outline the resource needs of individuals including physical habitat and diet.

Table 4-1. Requirements for each life stage of the Purple Lilliput mussel.

Life Stage	Resources Needed to Complete Life Stage[5]	Source
Fertilized eggs - early spring	● Sexually mature males upstream or in close proximity to sexually mature females ● Appropriate spawning temperatures	Berg *et al.* 2008, p. 397; Haag 2012, pp. 38–39
Glochidia - late spring to early summer	● Enough natural variability in water levels or discharge to attract host fish ● Presence of host fish for attachment	Strayer 2008, p. 65; Haag 2012, pp. 41–42
Juveniles - excystment from host fish to approx. 0.5 in (~13 mm) shell length	● Host fish dispersal ● Appropriate interstitial chemistry; low salinity, low ammonia, low copper and other contaminants, high dissolved oxygen. ● Appropriate substrates for settlement	Dimmock and Wright 1993, pp. 188–190; Sparks and Strayer 1998, p. 132; Augspurger *et al.* 2003, p. 2,574; Augspurger *et al.* 2007, p. 2,025; Strayer and Malcom 2012, pp. 1,787–1,788
Adults - greater than 0.5 in (13 mm) shell length	● Appropriate substrate ● Adequate food availability (phytoplankton and detritus) ● High dissolved oxygen ● Appropriate water temperature	Yeager *et al.* 1994, p. 221; Nichols and Garling 2000, p. 881; Chen *et al.* 2001, p. 214; Spooner and Vaughn 2008, p. 308

4.1.1 Suitable Aquatic Habitats

Most North American freshwater mussel species evolved in flowing water ecosystems (e.g., rivers and streams), and are highly adapted to the conditions in those ecosystems (Haag 2012, pp. 110–111). Flowing water offers many favorable characteristics for mussels, including generally ample dissolved oxygen levels, low acidity, regular replenishment of food items and removal of waste products, a diverse range of physical habitats, and a diversity of fish species. Favorability of these characteristics is sufficient to make stream ecosystems productive environments for mussels, even if certain stream habitats may undergo conditions too harsh to support mussel populations (e.g., areas subject to scouring or periodic drying). At the same time, a number of mussel species are able to inhabit still, or non-flowing, water bodies, such as reservoirs, lakes, and ponds. However, they often do so only in specific habitats or at low numbers, compared to flowing water bodies.

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[5] These resource needs are common among North American freshwater mussels; however, due to lack of species-specific research, parameters specific to Purple Lilliput are unavailable.

As described in Section 3.3 (Life History), the Purple Lilliput occurs in a variety of habitats, but is found most often in rivers and streams. It can occur in the overbanks of reservoirs and at the mouths of rivers (Williams *et al.* 2008, p. 720). However, many lentic, or still water habitats from which the Purple Lilliput has been reported have direct connections to flowing streams and experience at least seasonal flows and water level fluctuations. The extent to which lentic habitats help sustain populations of the Purple Lilliput has not been well evaluated, nor has the likelihood that naturally glaciated lakes or impoundments will provide productive, long-term habitats for the species. At this time, the best available information indicates that the Purple Lilliput uses a range of habitats, where it may exhibit a clumped distribution.

Perturbations that disrupt natural flow patterns (e.g., dams and diversions) have a potential negative influence on Purple Lilliput resilience metrics. Purple Lilliput habitat needs seasonally-variable suitable aquatic habitats to deliver oxygen, enable passive reproduction, and deliver food to filter-feeding mussels (see Table 4-1, above). Further, moving water removes contaminants from interstitial spaces and excess quantities of fine sediments that can cause mussel suffocation. Stream velocity is not static over time, and variations may be attributed to seasonal changes (with higher flows in winter/spring and lower flows in summer/fall), extreme weather events (e.g., drought or floods), or anthropogenic influence (e.g., flow regulation via impoundments). The Purple Lilliput relies on sight-feeding fishes as part of its life cycle; therefore, turbidity during critical reproductive periods may impact glochidial attachment and ultimately decrease recruitment in any given population (McLeod *et al.* 2017, p. 348).

While mussels have evolved in habitats that experience seasonal fluctuations in discharge and water levels, global weather patterns can have an impact on the normal regimes (e.g., El Niño or La Niña). Even during naturally occurring droughts, mussels can become stressed because either they exert energy to move to deeper waters or they may succumb to desiccation (Haag 2012, p. 109). Droughts during the late summer and early fall may be especially stress-inducing because streams are already at their naturally occurring lowest flow rate during this time.

4.1.2 Appropriate Water Quality and Temperatures

Freshwater mussels, as a group, are particularly sensitive to changes in water quality parameters, including (but not limited to): dissolved oxygen (generally below 2–3 parts per million (ppm)), salinity (generally above 2–4 ppm), ammonia (generally above 0.5 ppm total ammonia-nitrogen (TAN)), elevated temperature (generally above 86 °Fahrenheit (°F) (30 °Celsius (°C)), excessive total suspended solids (TSS), and other pollutants (see discussion in Chapter 6). Habitats with appropriate levels of these parameters are considered suitable, while those habitats with levels outside of the appropriate ranges are considered less than suitable.

Appropriate water temperature thresholds for the Purple Lilliput are unknown; thus, we must rely on the best available information for other mussel species, which primarily focuses on temperatures necessary for reproduction. Specifically, glochidia metamorphosis for the closely-related Savannah Lilliput occurs on fishes at 73.4 °F (23 °C) (Hanlon and Levine 2004, p. 292).

4.1.3 Food and Nutrients

Adult freshwater mussels, including the Purple Lilliput, are filter-feeders, drawing in suspended phytoplankton, zooplankton, rotifers, protozoans, detritus, and dissolved organic matter from the water column (Strayer *et al.* 2004, p. 430) and from sediment; juvenile mussels are capable of pedal and deposit feeding to collect food items from sediments (Vaughn *et al.* 2008, pp. 409–411). Glochidia can derive what nutrition they need from their obligate fish hosts (Barnhart *et al.* 2008, p. 372). Freshwater mussels must keep their shells open, or gaped, to obtain food and facilitate gas exchange, but they often respond to water quality impairments by closing their shells (Bonner *et al.* 2018, p. 141). Food supply is not generally considered limiting in environments inhabited by the Purple Lilliput, but nonnative species such as the Asian Clam (*Corbicula fluminea*) may compete for food resources. Food limitation may be important during times of elevated water temperature, as both metabolic demand and incidence of valve closure increases concomitantly, resulting in reduced growth and reproduction (Bonner *et al.* 2018, p. 6).

4.2 Population- and Species-level Needs

In order to assess the viability of a species, the needs of individuals are only one aspect. This section examines the larger-scale population- and species-level needs of the Purple Lilliput.

4.2.1 Connectivity of Aquatic Habitat

The fragmentation of river habitat by dams and other aquatic barriers (e.g., perched or undersized culverts) is one of the primary threats to aquatic species in the U.S. (Martin and Apse 2014, p. 7). Dams, whether made by humans or nature (e.g., from American Beaver (*Castor canadensis*) or wind thrown debris), have a profound impact on in-stream habitat as they can change lotic systems (flowing water) to lentic systems. Although the Purple Lilliput has shown evidence of colonization of lotic and lentic water bodies, more populations are known from lotic systems. Moreover, fragmentation by dams or culverts generally involves loss of access to quality habitat for one or more life stages of freshwater species. In the case of mussels, fragmentation can result in barriers to host fish movement, which in turn, may influence mussel distributions. Barriers to movement can cause isolated or patchy distributions of mussels, which may limit both genetic exchange and recolonization (Jones *et al.* 2006, p. 528). While the Purple Lilliput appears to be somewhat adaptable to lentic conditions, habitat connectivity is paramount for rangewide persistence.

4.2.2 Dispersal-Adult Abundance and Distribution

Mussel abundance in a given stream reach is a product of the number of mussel beds and the density of mussels within those beds (aggregations of freshwater mussels). For populations of Purple Lilliput to be healthy, individuals must be numerous with multiple age classes, and populations show evidence of recruitment. For Purple Lilliput populations to be resilient, there must be of sufficient density such that local stochastic events do not eliminate the population. A non-linear distribution over a large area (occurrence in tributaries, in addition to the mainstem) also helps buffer against stochastic events that may impact populations. Additionally, mussel abundance facilitates reproduction; mussels do not actively seek mates, rather males release sperm into the water column, where it drifts until a female takes it in (Moles and Layzer 2008, p. 212). Therefore, successful individual reproduction and population viability require sufficient numbers of female mussels downstream of sufficient numbers of male mussels.

Mussel abundance is indicated by the number of individuals found during a sampling event. Mussel surveys rarely are a complete census of the population; instead, density is estimated by the number found during a survey event using various statistical techniques. We do not have population estimates for most populations of Purple Lilliput, nor are the techniques directly comparable (i.e., same area size searched, similar search time); thus, we use the number of individuals captured within a population as an index over time. While we cannot precisely determine population abundances at these sites using these numbers, we are able to determine if the species is abundant or rare at the site, and examine this over time if those data are available.

4.2.3 Host Fish

Host fish species for the Purple Lilliput have been identified as the Longear Sunfish and Green Sunfish (Hill 1986, p. 5). These widespread and common fishes occur in a variety of river and reservoir habitats throughout the eastern U.S. (Etnier and Starnes 1993, pp. 411, 421). The Green Sunfish is considered tolerant of adverse conditions and known for its ability to adapt to and exploit new habitats. There are likely some secondary hosts capable of transforming juvenile Purple Lilliput at a low rate.

4.3 Uncertainties

Life history uncertainties for the Purple Lilliput include the age at maturity, patterns of age structure within populations (number within each age class or cohort in any population), fecundity, and sex ratios. The time period to complete metamorphosis on host fishes, including ranges of water temperatures at which transformation occurs, is unknown. Where data were lacking for the Purple Lilliput, we used information available from other species of the genus *Toxolasma* including the Lilliput, Savannah Lilliput, and Texas Lilliput, and assume that these parameters are similar to the Purple Lilliput. The Lilliput and Texas Lilliput co-occur (sympatry) in large portions of the range of the Purple Lilliput. Purple Lilliput-specific diet studies have not been conducted, and growth curves have not been developed.

Purple Lilliput relies on a consistent level of reproductive success to maintain populations, but the actual environmental events that cue variations (increases or decreases) in reproductive success, which is indicated by recruitment in successive sampling events, is not documented. Additionally, numeric water quality criteria specific for Purple Lilliput threshold tolerances are unknown. The species' capability to move and disperse is acknowledged as glochidia attached to fish, but the distance that adults are capable of dispersing within appropriate habitats is unknown. Population estimates are also lacking due to inconsistent survey efforts and methodologies.

In many situations, abundance and precise locality information for most populations considered extirpated is lacking, and therefore it is difficult to specifically attribute localized extirpation to a specific stressor or resource need. For this species, it is possible that there are populations of the

Purple Lilliput that have been to this point undetected, in part due to its sporadic, frequently clumped distribution, small size, and habitat preferences. However, we believe that this is a comprehensive evaluation of the Purple Lilliput throughout the range of the species at the basin and MU levels, and any new populations that may be identified are within the current and historical range.

4.4 Summary of Resource Needs

As discussed in Chapter 1, we define viability as the ability of the Purple Lilliput to sustain populations in the wild over time (i.e., 20 to 30 years for the purpose of this assessment). The availability and quality of those resources, as well as the level of negative and beneficial influences acting upon those resources, will determine whether populations are resilient over time. Based upon the best available scientific and commercial information (summarized in sections 4.1 and 4.2, above), and acknowledging existing ecological uncertainties (section 4.3, above), the Purple Lilliput's resource and demographic needs (Figure 4-1, below) are characterized as:

- Water with appropriate water quality and temperate conditions, such as (but not limited to) dissolved oxygen above 2–3 ppm, ammonia generally below 0.5 ppm TAN, temperatures generally below 86 °F (30 °C), and (ideally) an absence of pollutants.

- Water levels that vary with respect to the timing, magnitude, duration, and frequency of river discharge events.

- Suspended food and nutrients in the water column including (but not limited to) phytoplankton, zooplankton, protozoans, detritus, and dissolved organic matter.

- Availability of sufficient host fish numbers to provide for glochidia infestation and dispersal. Host fish species include (but may not be limited to): Green Sunfish and Longear Sunfish.

- Connectivity among populations. Although the species' capability to disperse is evident through historical occurrence within a wide range of rivers and streams, the fragmentation of populations has resulted in isolation and only patches of what once was occupied contiguous river and stream habitat. Genetic exchange occurs between and among mussel beds via sperm drift and host fish movement. For genetic exchange to occur, connectivity must be maintained.

- Most freshwater mussels are patchily distributed, and are often separated by stream reaches in which mussels are absent or rare (Vaughn 2012, p. 983). The Purple Lilliput is often a component of a healthy mussel assemblage.

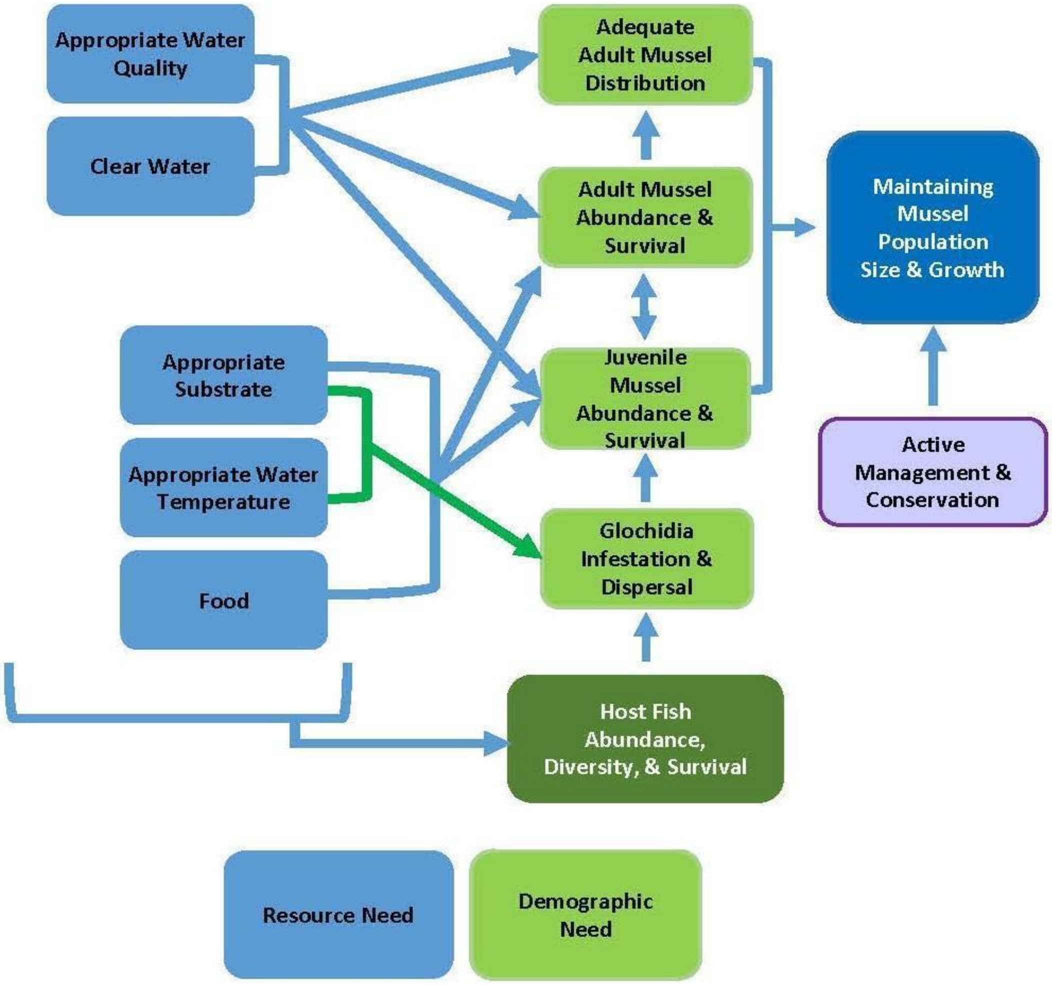

Figure 4-1. Resource and demographic needs of the Purple Lilliput.

CHAPTER 5 - CURRENT CONDITIONS, ABUNDANCE AND DISTRIBUTION

Fundamental to our analysis of the Purple Lilliput was the determination of scientifically sound analytical units at a scale useful for assessing the species (see section 2.1.2, above). In this report, we defined Purple Lilliput MUs and populations based primarily on known occurrence locations and stream connectivity. We acknowledge that specific Purple Lilliput demographic and genetic data to support this construct are sparse. However, this approach for assessing the species' condition has been used for other wide ranging mussels in the eastern United States, therefore, it was considered an acceptable construct for this SSA report.

After identifying the factors (i.e., stressors) likely to affect the Purple Lilliput, we estimated the condition of each Purple Lilliput population and MU. The population size metric used was selected because the supporting data were relatively consistent across the range of the species and at a resolution suitable for assessing the species at the population level. Due to the clumped distribution of the species, the extent of each population is variable, but populations generally have been sampled with enough frequency to establish a baseline of known extent. Threat levels were evaluated for each population largely based on the available data on water and habitat quality. The output was a condition score for each Purple Lilliput population and MU that was then used to assess the Purple Lilliput across its range under the concepts of resiliency, representation, and redundancy. We acknowledge there is uncertainty regarding some of the scientific data and assumptions used to assess the biological condition of the Purple Lilliput (see section 5.4, below).

The Purple Lilliput is wide-ranging and historically known from the Great Lakes, Lower Mississippi, Arkansas-White-Red, Tennessee, Cumberland, and Ohio River basins. Although some populations and MUs are no longer occupied, it currently occurs in all of these basins. It is currently known from Indiana, Illinois, Michigan, Ohio, Kentucky, Missouri, Arkansas, Tennessee, and Alabama. The status of the species in Oklahoma and Virginia is likely extirpated, based on the best available information. While the species is considered extirpated from North Carolina and Georgia, only one record has been documented from each of these states. The results of surveys conducted since 2000 indicate the currently occupied range of the Purple Lilliput includes 146 rivers and streams, and 65 MUs. A summary of all known extant populations and MUs is found in Appendix A.

5.1 Historical Conditions For Context

To summarize the overall current conditions, Purple Lilliput populations and MUs were considered extant if a live individual or fresh dead specimen was collected since 2000, or collections of the species were made since 1990 with no available negative mussel survey data of the population or MU to dispute that the species still occurs within the water body. Populations were considered extirpated based on documentation in literature, reports, or from communications with state malacologists and aquatic biologists. General reference texts on regional freshwater mussel fauna were considered, such as Oesch (1984), Gordon and Layzer (1989), and Parmalee and Bogan (1998). Substantial information on species distribution, both past and present, was provided by Williams *et al.* (2008), Harris *et al.* (2009), Watters *et al.* (2009), and Haag and Cicerello (2016).

The Purple Lilliput is known historically from 272 populations and 135 MUs in 13 states. While 126 populations are considered extirpated, it currently occurs in every major drainage basin in which it has been documented: the Great Lakes, Lower Mississippi, Arkansas-White-Red, Tennessee, Cumberland, and Ohio River basins (Appendix A). It also has one population in Crooked Creek, a tributary to the Whitewater River in Missouri, which geographically falls within the Upper Mississippi basin due to a man-made diversion channel. For the purposes of current and future condition analyses, this population is considered part of the Little River drainage, with which it would connect naturally if not for the diversion channel, and a component of the Lower Mississippi basin.

Although the species is considered extirpated from North Carolina and Georgia, and its current status in Virginia and Oklahoma is unknown, substantial geographic range reductions have not been observed to date. However, considerable range-thinning (localized extirpation, or diminishment of populations) has occurred (Strayer 2008, p. 16). While populations and MUs in the Ohio and Tennessee basin have been disproportionately lost at a higher level than other basins, the species continues to be represented in all of the basins it has been documented, and approximately 50 percent of historically occupied MUs persist (Figure 5-1). In total, 119 populations and 67 MUs are considered extirpated:

- 10 populations and 5 MUs in the Great Lakes basin,
- 36 populations and 23 MUs in the Ohio River basin,
- 19 populations and 10 MUs in the Cumberland River basin,
- 39 populations and 17 MUs in the Tennessee River basin,
- 10 populations and 8 MUs in the Arkansas-White-Red basin, and
- 5 populations and 4 MUs in the Lower Mississippi basin.

All populations and MUs considered extirpated along with the authority and the year of the record are found in Appendix B. In many instances, the specific cause for extirpation is unknown, and is likely attributable to a variety of compounded threats. Suggested causes include impaired water quality due to pollution and land use changes; the introduction of nonnative species; and habitat alteration and loss, fragmentation, and degradation due to agriculture and impoundment (Watters 2000, p. 269).

5.2 Current Population Abundance, Trends, and Distribution

To assess the distribution, abundance, and (if data are available) trends of Purple Lilliput populations, we first assigned a status category of extant or extirpated to each population and MU. Due to lack of consistency of survey efforts, population size (Table 5-1) was based on counts summarized from inventory data. Next, we developed threat condition categories (Table 5-2) based on our qualitative assessment of the magnitude and immediacy of a potential threat within each population. Lastly, we assigned a low/moderate/high overall condition category to each population based on the combined consideration of the aforementioned population size and threat information (Table 5-3).

General references on regional mussel fauna provided substantial information on species distribution, including (but not limited to) Oesch (1984), Gordon and Layzer (1989), Parmalee and Bogan (1998), Williams *et al.* (2008), Harris *et al.* (2009), Watters *et al.* (2009), and Haag and Cicerello (2016).

Population size for each river or stream was based on inventory data collected for freshwater mussels since 2000 (Appendix A). Various state and Federal agencies, academic institutions, and non-governmental organizations conducted inventories. Population size was ranked as small (rare in collections or surveys), medium (occasional-to-common in collections or surveys), or large (abundant in collections or surveys) (see Table 5-1).

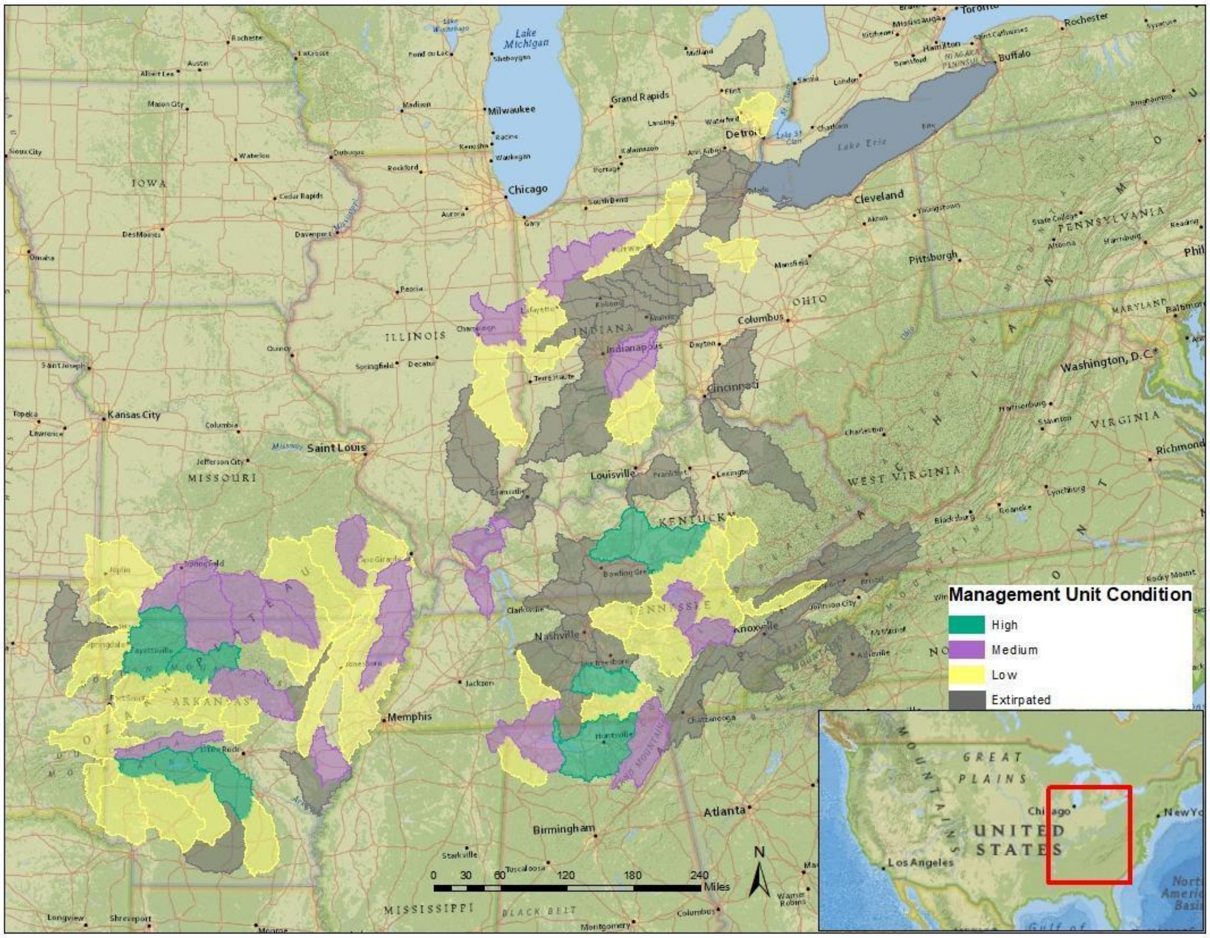

Figure 5-1. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC 8s) of Purple Lilliput mussel in the United States. Currently occupied MUs are represented with low, medium, and high condition categories as described in Chapters 2 and 5 (Service 2018, unpublished data).

Population size for each river or stream was based on inventory data collected for freshwater mussels since 2000 (Appendix A). Various state and Federal agencies, academic institutions, and non-governmental organizations conducted inventories. Population size was ranked as small (rare in collections or surveys), medium (occasional-to-common in collections or surveys), or large (abundant in collections or surveys) (see Table 5-1).

Our estimates of the size of each population are derived from information summarized in Appendix A. Of important note regarding these estimates: some populations are ranked as small population sizes, but data on the species occurrences in these rivers and streams are scarce. It is therefore difficult to make inferences about their current and future condition. Although there is some uncertainty in the status of these populations, it was our goal to be as inclusive as possible regarding the current condition of the species, so these small populations were included for the purposes of this SSA. Available negative mussel data (mussel surveys in the river or stream that failed to detect Purple Lilliput) and information on threats to the aquatic fauna in these watersheds was also used to inform this analysis.

Potential threats to the Purple Lilliput or its habitat were categorized in terms of magnitude and immediacy based on the best available information in literature or other sources, such as State Wildlife Action Plans (SWAP), watershed planning documents, or Clean Water Act (CWA) 303(d) lists of impaired waters. We ranked threat levels based on their apparent or likely magnitude of presence in the drainage (Table 5-2). Purple lilliput population characteristics (extent and size) were considered relative to current threats.

Severe water pollution and habitat alteration in basins in which the Purple Lilliput occurs are associated with extirpation of mussel species (Neves 1993, p. 4). The most frequently cited causes of lost or declining populations are water quality degradation, channelization, chemical contaminants, mining, sedimentation and habitat alteration (Neves 1993, p. 4; Williams *et al.* 1993, p. 5; Watters 2000, p. 261). Expanding human populations within the range of the species (e.g., Lawler *et al.* 2014, p. 55; Terando *et al.* 2014, p. 3) will invariably increase the likelihood that many of these factors may negatively influence the viability of Purple Lilliput populations into the future. Our estimates of the magnitude and immediacy of potential threats to each population are summarized from information presented in Appendix A.

Table 5-1. Population size categories to help describe the Purple Lilliput's abundance within rivers and streams throughout its current range.

Category	Description
Small (rare in collections or surveys)	Less than 10 individuals (live or fresh dead) reported from the river/stream since 2000; usually qualitative collections of varying effort; not enough information available to generate a population estimate; population potentially represented only by non-reproducing individuals. These populations are not likely contributing to species resiliency.
Medium (occasional-to-common in collections or surveys)	10–25 individuals (live, fresh dead, or weathered dead/relic[6]) reported from the river/stream since 2000; or some quantitative information available for a population estimate that indicates detectable population density and more than one age class represented.
Large (abundant in collections or surveys)	More than 25 individuals (live, fresh dead, or weathered dead/relic) reported from the river/stream in any given sampling event since 2000; or a population estimate is available for the population and identifies densities sufficiently high to suggest a healthy population (*e.g.*, multiple age classes and evidence of ongoing recruitment).

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[6] A "fresh dead" Purple Lilliput refers to shells that still have flesh attached to the shell, or at least retain a luster to their nacre, and may have a hinge intact and pliable, indicating relatively recent death. A "weathered dead" Purple Lilliput shell has a loss of periostracum, which may be peeling, and faded or dull nacre. A "relic" Purple Lilliput has a chalky nacre. A weathered dead/relic shell typically indicates the mussel died years or potentially even decades ago.

Table 5-2. Categories to describe the magnitude and immediacy of potential threats influencing the Purple Lilliput. Public land holdings within the river or stream where the Purple Lilliput occurs were incorporated into these threat category levels.

Category	Description
Low	Threats to freshwater mussels or aquatic fauna have been identified in this HUC and are in the literature or available in SWAPs - threats are minimal (potential threats identified but direct tie to loss of mussels possibly lacking) compared to other occupied rivers and streams or MUs that harbor the species.
Moderate	Threats to freshwater mussels or aquatic fauna have been identified or evaluated in this HUC and are in literature or available in SWAPs - threats are moderate (multiple threats identified but may not be imminent, or the status of the threat is unknown) compared to other occupied rivers and streams or MUs that harbor the species.
High	Threats to freshwater mussels or aquatic fauna have been identified and evaluated in this HUC and are in literature or available in SWAPs - threats are substantial (multiple threats identified and imminent) and cumulative, compared to other occupied rivers and streams or MUs that harbor the species.

5.3 Estimated Viability of Purple Lilliput Mussel Based on Current Conditions

We define Purple Lilliput viability as the ability of the species to sustain healthy populations in natural river systems within a biologically meaningful timeframe. Using the SSA framework, we describe the species' current viability in terms of resiliency, representation, and redundancy.

5.3.1 Resiliency

Resiliency describes the ability of populations to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health, for example, birth versus death rates and population size. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities. For the purpose of this SSA, with a lack of broad demographic data, each population's estimated size and extent helps provide a measure of resiliency given that larger mussel populations distributed over a larger area would be better able to rebound from stochastic events than smaller populations with limited distribution.

Populations and MUs were ranked according to the following overall condition categories: high, medium, and low (Table 5-4). As discussed above under section 5.2, these categories were informed by each population's extent, size, and probable threat level, with population size weighted more heavily than extent and threat level because of more limited information on current population extent and threats to the Purple Lilliput. Overall condition categories for each of the currently extant Purple Lilliput populations are presented in Table 5-5, below.

Table 5-3. Categories for estimating the overall current condition of Purple Lilliput mussel populations.

High (Stronghold) Populations	Medium Populations	Low Populations
Significant populations generally distributed, with evidence of recent recruitment, and currently considered resilient.	Small, generally restricted populations with limited levels of recent recruitment and resiliency, and susceptible to extirpation within 30 years.	Very small and highly restricted populations with no evidence of recent recruitment and questionable resiliency, and that may be on the verge of extirpation in the immediate future.

Condition category tables are a structured way to assess the current and future state of populations based on specific variables related to the ability of populations to adapt to changing environmental conditions and withstand stochastic or catastrophic events. Condition category tables are a transparent way to illustrate to the public which variables we are assessing and how these variables contribute to the overall status of populations. The tables allow us to weigh the variables differently depending on the importance of a variable to the species ecology.

Using condition category tables is a common Service practice in SSAs when further quantitative methods to assess population risk on a continuous scale may be inappropriate due to insufficient data. Assigning condition or health based on multiple criteria, which is what the condition table does, is common in a variety of applications, such as: NatureServe's element occurrence rank, International Union for Conservation of Nature's (IUCN) red list criteria, and area-specific indices of biological integrity[7].

Table 5-4. Extant populations of Purple Lilliput by major river basin, management unit (8 digit HUC), and their generalized population condition.

Major River Basin	Management Unit	State	Contiguous Population (occupied river/stream)	Current Condition
Great Lakes	Blanchard	OH	Blanchard River	Low
	Clinton	MI	Clinton River	Low
	St. Joseph	MI	Lake Wilson	Low
Ohio	Upper Green	KY	Green River	High
	Upper Green	KY	Russell Creek	Medium
Ohio	Lower Ohio Bay	IL	Big Grand Pierre Creek	Medium

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[7] These examples are detailed at the following three internet sites: *http://help.natureserve.org/biotics/Content/Record_Management/Element_Occurrence/EO_Rank_a_species_EO.htm http://www.iucnredlist.org/static/categories_criteria_3_1 https://www.pugetsoundstreambenthos.org/BIBI-Scoring-Types.aspx*

Major River Basin	Management Unit	State	Contiguous Population (occupied river/stream)	Current Condition
Ohio	Vermilion	IL, IN	Jordan Creek	High
		IL	Middle Fork North Fork Vermilion River	Medium
		IL, IN	North Fork Vermilion River	Medium
		IL	Middle Fork Vermilion River	Low
Ohio	Middle Wabash-Little Vermilion	IN	Little Pine Creek	Low
			Big Pine Creek	Low
			North Fork Coal Creek	Low
Ohio	Embarras	IL	Brushy Fork	Low
Ohio	Tippecanoe	IN	Kuhn Lake	Medium
			Sechrist Lake	Low
			Grassy Creek	Medium
			Tippecanoe	High
			Lake Maxinkuckee	Low
			Big Monon Ditch	Low
Ohio	Muscatatuck	IN	Vernon Fork Muscatatuck River	Low
			Graham Creek	Low
			Big Creek	Low
Ohio	Upper East Fork White	IN	Clifty Creek	Low
Ohio	Flatrock-Haw	IN	Flatrock River	Medium
Ohio	Driftwood	IN	Brandywine Creek	Low
			Little Blue River	Medium
Ohio	Driftwood	IN	Sugar Creek	Low

Major River Basin	Management Unit	State	Contiguous Population (occupied river/stream)	Current Condition
Ohio	Eel	IN	Cedar Lake	Low
			Round Lake	Low
			Shriner Lake	Low
			Eel River	Low
			Paw Paw Creek	Low
Cumberland	Lower Cumberland-Old Hickory Lake	TN	Peyton Creek	Low
			Goose Creek	Low
			Little Goose Creek	Low
Cumberland	Upper Cumberland-Cordell Hull Reservoir		Flynn Creek	Low
	Caney		Hickman Creek	Low
			Smith Fork	Low
	Upper Cumberland-Lake Cumberland	KY	Buck Creek	Low
	Rockcastle		Horse Lick Creek	Low
	South Fork Cumberland		Little South Fork Cumberland River	Low
	Obey	TN	Wolf River	Medium
Tennessee	Pickwick Lake	AL	Cypress Creek	Medium
			Town Creek (Colbert/Lawrence Co.)	Medium
			Big Nance Creek	Medium
			Shoals Creek	Low
			Tennessee River (Pickwick Reservoir)	High
	Buffalo	TN	Buffalo River	Low

Major River Basin	Management Unit	State	Contiguous Population (occupied river/stream)	Current Condition
Tennessee	Bear	AL	Bear Creek	Low
	Lower Tennessee	KY	East Fork Clarks River	Medium
	Guntersville Lake	AL	Town Creek	Medium
			Tennessee River	Low
	Wheeler Lake	AL	Second Creek	High
			First Creek	Medium
			Goldfield Branch (embayment)	High
			Fox Creek	Medium
			Spring Creek	High
			Round Island Creek	Low
			Limestone Creek	Low
			Piney Creek	Low
Tennessee	Wheeler Lake	AL	Flint River	Medium
			Hurricane Creek (1) (Flint trib)	High
			Lick Fork	Medium
			Larkin Fork	Medium
			Estill Fork	High
			Hurricane Creek (2) (Paint Rock trib)	High
			Little Paint Creek	High
			Paint Rock River	High
			Tennessee River	High
Tennessee	Upper Clinch-Tennessee, Virginia	TN	Clinch River	Low
	Upper Elk (TN)		Elk River	Low
	Emory		Clear Creek	Medium

Major River Basin	Management Unit	State	Contiguous Population (occupied river/stream)	Current Condition
Tennessee	Upper Duck	TN	Big Rock Creek	Low
			Duck River	High
Arkansas-White-Red	Spring	MO	Coon Creek	Low
	Spring		Shoal Creek	Low
	Elk		Indian Creek	Low
	James		James River	Medium
	James		Finley Creek	Low
			Flat Creek	Low
	Bull Shoals		Swan Creek	Medium
			Bull Creek	Medium
	North Fork White		Bryant Creek	Medium
			North Fork White River	Medium
	Eleven Point		Eleven Point	Medium
	Lower Black		West Fork Fourche Creek	Low
	Upper Black		Black River	Low
	Current		Jacks Fork River	Low
	Current		Big Barren Creek	Low
			Current River	Low
			Little Black River	Low
			North Prong Little Black River	Low
Arkansas-White-Red	Spring	AR	South Fork Spring River	Medium
			Spring River	Medium
Arkansas-White-Red	Beaver Reservoir		Upper White River	High

Major River Basin	Management Unit	State	Contiguous Population (occupied river/stream)	Current Condition
		AR	War Eagle Creek	High
	Illinois		Illinois River	Low
	Frog-Mulberry		Frog River	Low
			Mulberry River	Low
	Dardanelle Reservoir	AR	Cadron Creek	Low
		AR	East Fork Illinois Bayou	Low
			Middle Fork Illinois Bayou	Low
		AR	Illinois Bayou	Low
			Big Piney Creek	Low
	Little Red	AR	Archey Fork Little Red River	High
			South Fork Little Red River	Medium
		AR	Turkey Creek	Low
			Beech Fork Little Red River	Low
	Little Red	AR	Middle Fork Little Red River	High
			Big Creek	Low
	Cadron	AR	Jones Creek	Low
			East Fork Cadron Creek	Low
			North Fork Cadron Creek	Medium
	Lake Conway-Point Remove	AR	East Fork Point Remove Creek	Medium
			West Fork Point Remove Creek	Low
Arkansas-White-Red	Fourche La Fave	AR	Black Fork Fourche LaFave River	Low

Major River Basin	Management Unit	State	Contiguous Population (occupied river/stream)	Current Condition
			South Fourche LaFave River	Medium
Arkansas-White-Red	Poteau	AR	Jones Creek	Low
			Ross Creek	Low
			Poteau River	Low
Arkansas-White-Red	Mountain Fork	AR	Mountain Fork Little River	Low
	Lower L AR, OK		Saline River	Low
	Strawberry		Strawberry River	Low
	Buffalo		Buffalo River	High
Lower Mississippi	Whitewater	MO	Crooked Creek	Low
	Little River Ditches	MO	Castor River	Low
		AR	Ditch 28	Medium
	Upper St. Francis	MO	St. Francis River	Medium
	Lower St. Francis	AR	Tyronza River	Low
	Lower St. Francis	AR	National Ditch	Medium
		MO	Varney River	Low
	Cache	AR	Cache River	Low
	Big		East Fork Flat Creek	Medium
	Upper Ouachita		Caddo River	Low
			Ouachita River	Low
	Ouachita Headwaters		South Fork Ouachita River	High
			Ouachita River	Low
	Upper Saline		Middle Fork Saline River	Low
			Little Alum Creek	Medium
			Alum Fork Saline River	High

Major River Basin	Management Unit	State	Contiguous Population (occupied river/stream)	Current Condition
Lower Mississippi	Upper Saline	AR	South Fork Saline River	Low
			North Fork Saline River	High
			Saline River	High
	Little Missouri		Little Missouri River	Low
	Lower Saline		Saline River	Low

The overall current condition of the Purple Lilliput indicates the species has moderate resiliency: 86 of the 146 populations (59 percent) are in low condition compared to 36 populations (25 percent) in moderate condition, and 23 populations (16 percent) in high condition. Although 59 percent of the populations are considered low condition, the remainder of the populations (and MUs) that are considered moderate or high condition are spread throughout the historical range of the species, including across 9 states.

It is important to note that at least of 24 (28 percent) of these 86 populations currently ranked as low condition are based on surveys that pre-date 2000. Additionally, many low condition populations have five or fewer live or fresh dead collection records since 2000. This can be partially explained by a sporadic occurrence of individuals within populations, and a lack of survey effort targeting river and stream margins, along shorelines, habitats typically preferred by the species. Therefore, we assume that there are more individuals within populations that have gone undetected, but many of these populations are relatively small in terms of abundance.

Threats that are acting upon the high condition populations[8] include habitat and water quality degradation through nonpoint source agricultural runoff, siltation and erosion from poor farming practices, invasive species, increased urbanization, and the introduction of contaminants resulting from agricultural chemicals, as well as wastewater treatment discharges and mining activities (Ecological Specialists, Inc. (ESI) 1998, p. 84; Cicerello 1999, p. 6; Fobian *et al*. 2014, p. 348; Davidson *et al.* 2014, p. 29; Ahlstedt *et al.* 2017, p. 100).

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[8] High condition populations include Upper White River, War Eagle Creek, Archey Fork Little Red River, Middle Fork Little Red River, Buffalo River, South Fork Ouachita River, upper Ouachita River, Alum Fork Saline River, upper Saline River in Arkansas, Tennessee River (Pickwick Reservoir), Second Creek, Goldfield Branch, Spring Creek, Hurricane Creek (Flint River tributary), Estill Fork, Hurricane Creek (Paint Rock River tributary), Little Paint Creek, Paint Rock River, Tennessee River in Alabama, upper Duck River in Tennessee, upper Green River in Kentucky, Jordan Creek in Illinois and Indiana, and Tippecanoe River in Indiana. Conditions are described in detail in Appendix A.

5.3.2 Representation

Representation reflects the ability of a species to adapt to changing environmental conditions. The greater the diversity, the more successfully a species can respond to changing environmental conditions. In the absence of genetic data for the Purple Lilliput, we six representative units (i.e., six major river basins) where Purple Lilliput is currently found: Great Lakes, Ohio, Cumberland, Tennessee, Arkansas-White-Red, and Lower Mississippi basins.

We considered geographic range as a surrogate for geographic variation and proxy for potential local adaptation and adaptive capacity. We used hydrographic (management) units (at the HUC 8 level; see additional discussion in Chapter 2) to help define representation because watershed boundaries and natural and artificial barriers constrain ecological processes, such as genetic exchange and ultimately adaptive capacity for aquatic species (Funk *et al*. 2018, p. 14). The best available data indicates the Purple Lilliput has not been extirpated from any major river drainages or basins compared to historical information. The Purple Lilliput is at the highest risk of losing major river basin representation in the Great Lakes basin, with three populations currently known. As a result, the species is considered very rare if not extirpated from Ohio and extremely rare in Michigan (Badra 2004, p. 31; Watters *et al.* 2009, p. 302).

5.3.3 Redundancy

Redundancy refers to the number of populations of a species and their distribution across the landscape, reflecting the ability of a species to survive catastrophic events. The greater the size or number of populations, and the more widely they are distributed, the lower the likelihood a single catastrophic event will cause a species to become extinct.

Purple Lilliput populations are widely distributed over nine states, and the redundancy metric used in this SSA is number of populations and MUs (Table 5-4, Appendix A).

- The Great Lakes basin contains 3 populations and 3 MUs;
- The Ohio River basin contains 30 populations and 11 MUs;
- The Cumberland River basin contains 10 populations and 7 MUs;
- The Tennessee River basin contains 32 populations and 10 MU;
- The Arkansas-White-Red Rivers basin contains 49 populations and 23 MUs; and
- The Lower Mississippi River basin contains 20 populations and 10 MUs.

The total number of extirpated populations and MUs by river basin are:

- 36 populations (23 MUs) in the Ohio,
- 19 populations (10 MUs) in the Cumberland,
- 39 populations (17 MUs) in the Tennessee;
- 10 populations (5 MUs) in the Great Lakes,
- 5 populations (4 MUs) in the Lower Mississippi, and
- 10 populations (8 MUs) in the Arkansas-White-Red

Given the current status encompasses 146 populations and 65 MUs throughout its range, the species currently retains adequate redundancy for withstanding and surviving potential catastrophic events. However, it is important to note that a high percentage (58 percent; 38 of the 65 MUs) are currently in low condition (*i.e.*, are predominantly composed of populations that are small with no evidence of recruitment or age class structure). Overall, the species has decreased redundancy across its range compared to its historical range due to extirpation of 126 populations (46 percent).

5.4 Uncertainties of Current Condition

For a wide-ranging, sporadically distributed species with variable data availability across populations, there are many uncertainties including:

- Some gene flow potentially occurs among populations and MUs, although the timing and frequency of gene flow among these is not known.

- We acknowledge that specific Purple Lilliput demographic and genetic data to support the approached construct are sparse. However, this approach for assessing the species' condition has been used for other aquatic species in the eastern U.S. and is based on the best available science; therefore, it was considered an acceptable construct for this SSA.

- Many of the populations and MUs ranked as low condition have very little information available; some have had only one documented collection of the species, with no additional survey data to confirm recent presence or absence.

- Information on threats for such a large distributional range came from a wide variety of sources such as published literature and mussel survey reports. There is a paucity of information available on threats specific to the Purple Lilliput. In most instances, threats were reported to the entire mussel fauna or aquatic fauna in general, and threats to mussels in general are poorly understood.

CHAPTER 6 - FACTORS INFLUENCING VIABILITY

In this chapter, we evaluate past, current, and future factors affecting what the Purple Lilliput needs for long-term viability. Aquatic systems face myriad natural and anthropogenic factors that influence species viability (Neves *et al.* 1997, p. 44). Generally, these factors can be categorized as either environmental stressors (e.g., development, agriculture practices, forest management, dam operation) or systematic changes (e.g., climate change, invasive species, barriers, regulatory frameworks, conservation management practices). Current and potential future effects, along with current distribution and abundance, help inform viability, and therefore vulnerability to extinction.

Negative factors influencing the viability of Purple Lilliput are presented below. In addition to describing the potential impacts and sources of each influence (Figure 6-1, below), we present examples from within the species' range in an attempt to illustrate the scope and magnitude of

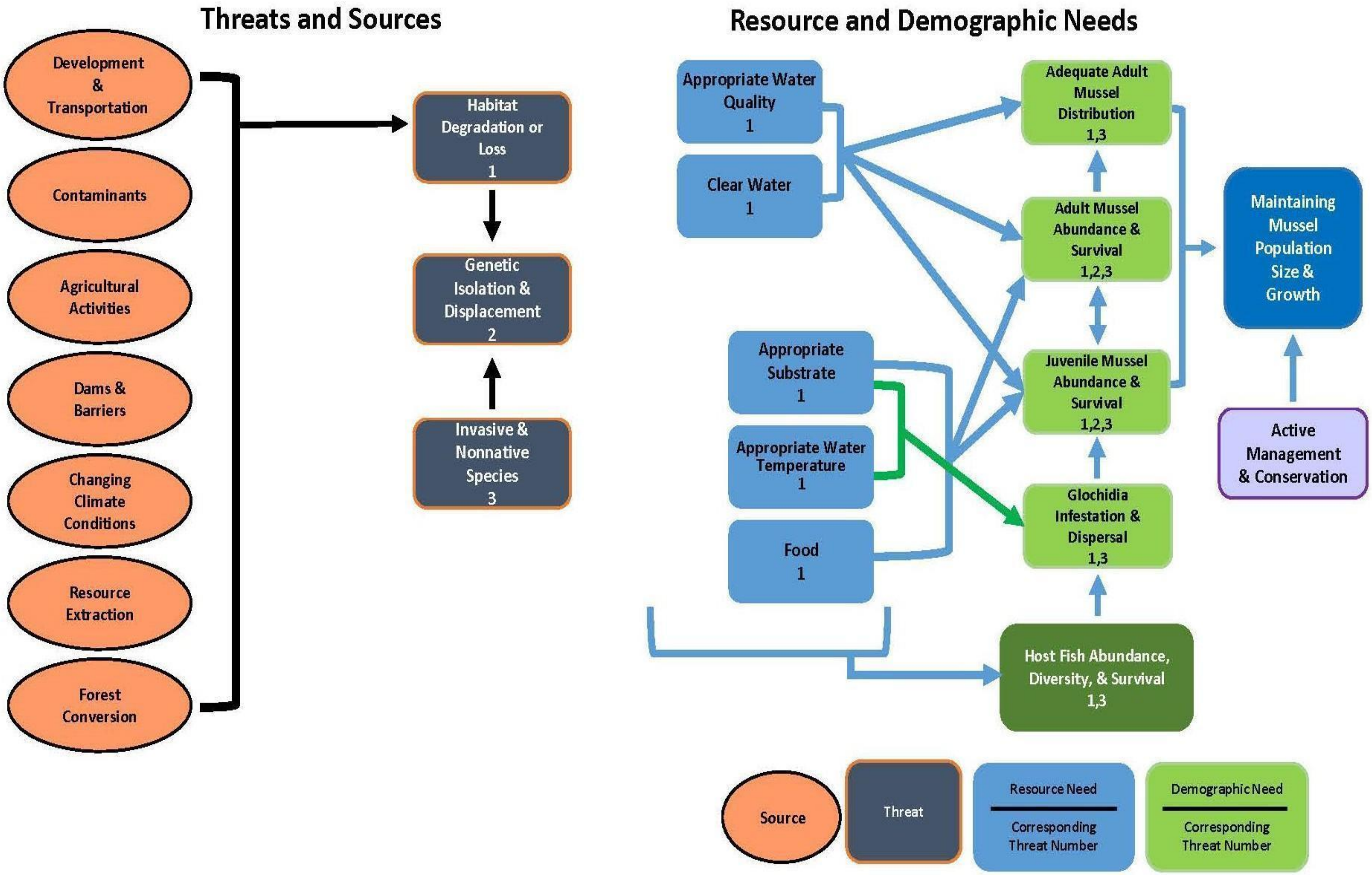

Figure 6-1. Influence diagram for Purple Lilliput, depicting threats, sources of threats, resources needs, and demographic needs.

the impacts based on the best available scientific and commercial information. Additionally, we present a summary of the beneficial conservation measures (regulatory and voluntary) occurring to reduce the impacts, and if those conservation measures are considered effective.

6.1 Habitat Degradation or Loss

6.1.1 Agricultural Activities

Unlike other threats, agricultural activities are pervasive across the range of the Purple Lilliput. Populations are located in areas across 9 states that have varying levels of agricultural activity. The effects of agricultural activities on the Purple Lilliput are widespread and have been attributed as a factor in the reduction of populations and MUs across its historical range. Not only are impacts from agricultural activities widespread, they are also multi-faceted, affecting water quality, stream discharge, and stream substrate quality. Additionally, the effects of agricultural activities that degrade water quality and result in habitat deterioration are not frequently detected until after the event(s) occur.

Extensive stream channelization for agriculture and instream snag removal has resulted in severe impacts to the freshwater mussel fauna and habitat in the Paint Rock River MU, including the lower reaches of Estill Fork and Hurricane Creek (Ahlstedt 1995–96, p. 65). Channelization activities, which include channel enlargement, channel realignment, clearing and snagging, and manipulation of banks, were widespread in lowland areas and in the lower reaches of rivers and streams in the 20th century (Haag and Cicerello 2016, p. 60). Studies indicate that even if active channelization activities are not currently occurring in rivers and streams occupied by the Purple Lilliput, impacts of these actions can have permanent effects such as habitat destabilization, which result in altered habitat that may be more suitable for nonnative species, or in some situations elimination of the mussel fauna (Hubbard *et al.* 1993, p. 142; Watters 2000, p. 274; Haag and Cicerello 2016, p. 60). These impacts include the reduction of suitable substrates for mussel settlement and growth, and increased suspended sediments and siltation, which adversely affects mussel feeding and respiration (Ebert 1993, p. 157).

6.1.1.1 Nutrient Pollution

Farming operations, including concentrated animal feeding operations, can contribute to nutrient pollution when not properly managed (EPA 2016, entire). Fertilizers and animal manure, which are both rich in nitrogen and phosphorus, are the primary sources of nutrient pollution from agricultural sources. If fertilizers are not applied properly, at the right time of the year and with the right application method, water quality in the stream systems can be affected. Excess nutrients affect water quality when it rains or when water and soil containing nitrogen and phosphorus wash into nearby waters or leach into groundwater. Excess nitrogen and phosphorus may cause algal blooms in surface waters (Carpenter *et al.* 1998, entire). Fertilized soils and livestock can be significant sources of nitrogen-based compounds like ammonia and nitrogen oxides (Carpenter *et al.* 1998, entire).

Ammonia can be harmful to aquatic life if large amounts are deposited to surface waters (see section 6.1.3, Contaminants, below). The lack of stable stream bank slopes from agricultural clearing or the lack of stable cover crops between rotations on farmed lands can increase the amount of nutrients that enter nearby streams by way of increased soil erosion (cover crops and other vegetation will use excess nutrients and increase soil stability) (Barling and Moore 1994, p. 543). Livestock often use streams or artificial in-line ponds as a water source, which degrades water quality and stream bank stability and reduces water quantity available for aquatic fauna, like the Purple Lilliput, that may occur downstream from these agricultural activities.

6.1.1.2 Water Withdrawal for Irrigation

Irrigation is the controlled application of water for agricultural purposes through manmade systems to supply water requirements not satisfied by rainfall. It is common practice to pump water for irrigation from adjacent streams or rivers into a reservoir pond, or spray it directly onto crops. If the water withdrawal is excessive, this may cause impacts to the amount of water available to downstream sensitive areas during months with reduced discharge, resulting in dewatering of channels and stranding of mussels. Some water withdrawal is done illegally (without permit if needed, or during dry time of year, or in areas where sensitive aquatic species occur without consultation).

6.1.1.3 Agriculture Exemptions from Permit Requirements

“Normal” farming (practices consistent with proper, acceptable customs and standards), silviculture, and ranching activities are exempt from the Section 404 permitting process under the CWA. This includes activities such as construction and maintenance of farm ponds, irrigation ditches, and farm roads. If an agricultural activity might affect rare aquatic species, the Corps does require farmers to ensure that any “discharge shall not take, or jeopardize the continued existence of a threatened or endangered species, or adversely modify or destroy the critical habitat of such species,” and to ensure that “adverse impacts to the aquatic environment are minimized.” However, the Corps does not require farmers to consult with appropriate State or Federal Agencies regarding these sensitive species, and oversight of these activities is limited. Agricultural Best Management Practices (BMP) generally are not required unless the applicant is receiving Federal grant funds; therefore, compliance is sporadic.

Agricultural impacts have been documented in streams where Purple Lilliput occurs. Sedimentation and other non-point source pollution, primarily of agricultural origin, have been identified as a primary threat to aquatic fauna within multiple major river basins, including the Great Lakes, Ohio, Cumberland, Tennessee, Arkansas-White-Red and Lower Mississippi River basins (Obermeyer *et al.* 1997). Agricultural erosion is listed among the factors affecting the Clinch River and is identified as a threat to river health (Zipper *et al.* 2014, p. 810). The Elk River Management Unit in Tennessee, which has a low condition population, has intensive agricultural activity and row-crop development (Woodside *et al.* 2004, p. 10). In the Illinois River Management Unit in Arkansas and Oklahoma, water quality has been impaired by elevated levels of nutrients, bacteria, and sediment, much of it related to poultry and cattle production (Oklahoma Conservation Commission 2010, pp. 62–70).

Hanlon *et al.* (2009, p. 11) hypothesize that land use legacies resulting from conversion of forest to row crop and pasture agricultural practices were a primary factor in freshwater mussel decline in Copper Creek, a tributary to the Clinch River in Virginia. The specific impacts identified include removal of riparian vegetation, agricultural erosion problems, siltation and pathogens related to poor agricultural and silvicultural practices, and potentially high levels of nitrogenous wastes (Hanlon *et al.* 2009, p. 12).

6.1.1.4 Agricultural Activities Summary

The advent of intensive row crop agricultural practices has been cited as a potential factor in freshwater mussel decline and species extirpation in the eastern U.S. (Peacock *et al.* 2005, p. 550). Nutrient enrichment and water withdrawals, which are threats commonly associated with agricultural activities. However, chemical control using pesticides, including herbicides, fungicides, insecticides, and their surfactants and adjuvants, are highly toxic to juvenile and adult freshwater mussels (Bringolf *et al.* 2007, p. 2,092). Waste from confined animal feeding and commercial livestock operations is another potential source of contaminants that come from agricultural runoff. The concentrations of these contaminants that emanate from fields or pastures may affect Purple Lilliput, especially given the sporadic and somewhat clumped distribution of the species (also see section 6.1.3, Contaminants, above).

Agencies such as the NRCS and Soil and Water Conservation Districts provide technical and financial assistance to farmers and private landowners. Additionally, county resource development councils and university agricultural extension services disseminate information on the importance of minimizing land use impacts, specifically agriculture, on aquatic resources. These programs help identify opportunities for conservation through projects such as exclusion fencing and alternate water supply sources, which help decrease nutrient inputs and water withdrawals, and help keep livestock off of stream banks and shorelines, thus reducing erosion. However, the overall effectiveness of these programs over a large scale is unknown given Purple Lilliput’s distribution across nine states with varying agricultural intensities. Virtually all streams in the eastern US have been affected in some way by agriculture. Impacts from agricultural runoff and cultivation activities are considered a threat to the Purple Lilliput populations throughout its range.

6.1.2 Development/Urbanization

6.1.2.1 Urban Development

The term “development” refers to urbanization of the landscape, including (but not limited to) land conversion for residential, commercial, and industrial uses and the accompanying infrastructure. The effects of urbanization may include alterations to water quality, water quantity, and habitat (both in-stream and streamside) (Ren *et al.* 2003, p. 649; Wilson 2015, p. 424). Along with agricultural and resource extraction activities, human development impacts currently present threats to the Purple Lilliput throughout the range of the species.

Urban development can lead to increased variability in streamflow, typically increasing the extent and volume of water entering a stream after a storm and decreasing the time it takes for the water to travel over the land before entering the stream (Giddings *et al.* 2009, p. 1). An “impervious surface” refers to all hard surfaces like paved roads, parking lots, roofs, and even highly compacted soils like sports fields. Impervious surfaces prevent the natural soaking of rainwater into the ground and ultimately and gradually seeping into streams (Brabec *et al.* 2002, p. 499). Instead, rainwater accumulates and often flows rapidly into storm drains, which rapidly drain to local streams. This results in deleterious effects on streams in three important ways (U.S. Geological Survey (USGS) 2014, pp. 2–5):

(1) *Water Quantity*: Storm drains deliver large volumes of water to streams much faster than would naturally occur, often resulting in flooding and bank erosion that reshapes the channel and causes substrate instability, resulting in destabilization of bottom sediments. Increased, high velocity discharges can cause species living in streams (including mussels) to become stressed, displaced, or killed by fast moving water and the debris and sediment carried in it.

(2) *Water Quality*: Pollutants (e.g., gasoline, oil drips, fertilizers) that accumulate on impervious surfaces may be washed directly into streams during storm events.

(3) *Water Temperature*: During warm weather, rain that falls on impervious surfaces becomes superheated and can stress or kill freshwater species when it enters streams.

Urbanization increases the amount of impervious surfaces (Center for Watershed Protection (CWP) 2003, p. 1). The resulting storm water runoff affects water quality parameters such as temperature, pH, dissolved oxygen, and salinity, which in turn alters the water chemistry potentially making it inhospitable for aquatic biota. The rapid runoff also reduces the amount of infiltration into the soil to recharge aquifers, resulting in lower sustained streamflow and water levels, especially during drought periods (Giddings *et al.* 2009, p. 1).

Water infrastructure development, including water supply, reclamation, and wastewater treatment, results in pollution point discharges to streams. Concentrations of contaminants (including nitrogen, phosphorus, chloride, insecticides, polycyclic aromatic hydrocarbons, and personal care products) increase with urban development (Giddings *et al.* 2009, p. 2; Bringolf *et al.* 2010, p. 1,311).

Utility crossings and right-of-way (ROW) maintenance are additional aspects of development that affect stream habitats. Direct impacts from utility crossings include direct exposure or crushing of individuals, sedimentation, and habitat disturbance. The greatest cumulative impact involves cleared ROWs that result in direct runoff and increased stream temperature at the crossing location, and potentially promotes maintenance utility and all-terrain vehicle access from the ROW (which destroy banks and instream habitat, leading to increased erosion). Maintenance of these utility crossings and ROWs are additional aspects of development that can influence stream habitats. Herbicides and their surfactants used to clear ROWs also have deleterious effects to aquatic organisms (see Contaminants, section 6.1.3, below).

The Clinton River population of Purple Lilliput is threatened by development from the City of Detroit and nearby smaller urban areas, and the mussel fauna in the main stem downstream of Pontiac was apparently lost due to pollution between 1933 and 1977 (Strayer 1980, p. 144). Municipal pollution and general developmental activities associated with industrialization continue to threaten the Purple Lilliput, and destruction of habitat through channelization and paving with concrete have permanently altered streams in the Clinton River MU (van Hees *et al.* 2010, p. 606).

The St. Joseph River basin, which currently has one population of Purple Lilliput, in Lake Wilson, formerly harbored as many as six populations; urbanization and associated discharges have been considered as the primary threat to mussels in this river drainage (Watters 1988, p. 3). An improvement in the fish community downstream of Findlay, Ohio, in the Blanchard MU, as a result of construction of a new wastewater treatment plant in 2001 was observed in 2005, indicating improved water quality in downstream reaches (Ohio EPA 2007, p. 3). However, the population of the Purple Lilliput in this river is small, geographically isolated by a reservoir, and linear in extent (Hoggarth *et al.* 2000, p. 22).

There are several locations where the Purple Lilliput occurs in water bodies located on or immediately adjacent to Federal lands. These include the National Wildlife Refuges (Refuge) managed by the Service, National Parks managed by the National Park Service (NPS), and National Forests managed by the U.S. Forest Service (Forest Service). While the Purple Lilliput is not a species currently receiving any active management strategies, it likely receives some indirect benefits from occurrence on these lands (such as lack of urbanization/developmental pressure).

The Dale Bumpers White River, Felsenthal, and Pond Creek Refuges in Arkansas (Arkansas-White-Red basin) as well as Wheeler Refuge in Alabama and the Clarks River Refuge in Kentucky (Tennessee Basin) are important public land holdings where the Purple Lilliput occurs. The Purple Lilliput also occurs within rivers and streams on several refuges in the Central Arkansas Refuge complex, such as the Big Lake, Cache River and Bald Knob Refuges. The Daniel Boone National Forest in eastern Kentucky contains portions of the Licking and Kentucky Rivers (Ohio basin) and Cumberland River and tributaries (Cumberland basin). The location of Mammoth Cave National Park also provides a level of localized protection against development pressures for the Purple Lilliput population in the upper Green River, Kentucky (Ohio Basin).

A programmatic Safe Harbor Agreement (SHA) and Candidate Conservation Agreement with Assurances (CCAA) with private landowners in Arkansas focuses on those non-Federal lands adjacent to streams and upland areas that may contribute sediment and pollutant runoff; these conservation tools are intended to provide benefits to the Purple Lilliput and a suite of other protected and at-risk aquatic species. This agreement resulted from a partnership between the Arkansas Game and Fish Commission (AGFC), the Nature Conservancy's (TNC) Arkansas Field Office, Natural Resources Conservation Service (NRCS), and the Service. The Saline-Caddo-Ouachita Programmatic Safe Harbor Agreement covers 439,792 acres (ac) (177,977 hectares (ha)) of the upper Saline River MU (currently high condition), the 412,556 ac (166,955 ha) of the upper Ouachita River (Ouachita Headwaters MU, currently high condition), and the 235,010 ac (95,105 ha) of the upper Caddo River (Upper Ouachita MU, currently low condition) (Service 2015, p. 6). These MU support a diversity of aquatic habitats that may be suitable for the Purple Lilliput in their headwaters.

The TNC has targeted areas for conservation within some river and stream systems harboring extant populations of the Purple Lilliput: the upper Green River and Horse Lick Creek in Kentucky, the upper Clinch/Powell River in Tennessee and Virginia, and the Paint Rock River in Alabama. Although TNC has few riparian inholdings, they have carried out community-based and partner-oriented projects that are intended to address aquatic species and instream habitat conservation. TNC has worked with riparian landowners to help them restore and protect streambanks and riparian zones, and they collaborate with various other stakeholders in conserving aquatic resources.

Various small, isolated parcels of public land (e.g., state parks, state forests, wildlife management areas) lie along rivers and streams where Purple Lilliput occurs. However, vast tracts of riparian lands where Purple Lilliput occurs are privately-owned, and the prevalence of privately-owned lands in streams with extant populations is comparatively much larger than the species' occurrence on public land. This will necessitate substantial additional voluntary conservation or maintenance of riparian vegetation for overall protection of stream health. It also somewhat diminishes the level of importance afforded by public lands that may experience various land use restrictions. In other words, activities within riparian vegetation on lands outside or upstream of public-owned lands may be pervasive and have a profound impact on the downstream mussel populations. Habitat protection benefits on public lands may therefore easily be negated by detrimental activities upstream or immediately downstream.

Increased commercial and residential development is more frequently cited as a threat to Purple Lilliput populations in the Great Lakes and Ohio River basins. However, increased human population growth projections indicate that urban sprawl will also affect Purple Lilliput populations in the Tennessee, Cumberland, and Arkansas-White-Red basins (Terando *et al.* 2014, p. 7). A commonly cited threat to mussels is poor wastewater discharge treatments, which are generally more common in rural areas, but regardless are an indicator of anthropogenic disturbance (ESI 2009, p. 14; see section 6.1.3, Contaminants, below).

The effects of commercial and residential urbanization and development on aquatic communities at large spatial scales are poorly studied (Wheeler *et al.* 2005, p. 162). Extant populations of Purple Lilliput are not concentrated in urban areas with large human occupation on the landscape; therefore, it is the potential rapid expansion of urban and suburban growth into rural and undeveloped areas that are most likely to affect the species' populations. It is currently unknown whether the anthropogenic effects of development and urbanization are likely to impact the Purple Lilliput at the individual or population level. However, secondary impacts such as the increased likelihood of potential contaminant introduction, stream disturbance caused by impervious surfaces, barrier construction, and forest conversion are likely to act cumulatively on Purple Lilliput populations.

6.1.2.2 Transportation

A major aspect of urbanization is the resultant road development. By its nature, road development increases impervious surfaces as well as land clearing and habitat fragmentation. Roads are generally associated with negative effects on the biotic integrity of aquatic ecosystems, including changes in surface water temperatures and patterns of runoff, changes in sedimentation levels, and increased heavy metals (especially lead), salts, organics, and nutrients to stream systems (Trombulak and Frissell 2000, p. 18). The adding of salts through road de-icing results in high salinity runoff, which is toxic to freshwater mussels. In addition, a major impact of road development is improperly constructed culverts at stream crossings. These culverts act as barriers if flow through the culvert varies significantly from the rest of the stream, or if the culvert ends up being perched, and aquatic organisms, specifically mussel host fishes, cannot pass through them. Improperly installed culverts alter in-stream habitat, and can cause changes in stream depth, resulting in pools upstream and a destabilized channel downstream of the culvert.

Transportation also includes river navigation impacts. Dredging and channelization activities as a means of maintaining waterways have profoundly altered riverine habitats nationwide (Ebert 1993, p. 157). Channelization affects many physical characteristics of streams through accelerated erosion, increased bed load, reduced depth, decreased habitat diversity, geomorphic instability, and riparian canopy loss (Hartfield 1993, p. 139). All of these impacts contribute to loss of habitat for the Purple Lilliput, and alter habitats for host fish. Changes in both the water velocity, and deposition of sediments not only alters physical habitat but the associated increases in turbulence, suspended sediment, and turbidity affect mussel feeding and respiration (Aldridge *et al.* 1987, p. 25). The scope of channel maintenance activities over extensive areas alters physical habitat and degrades water quality.

6.1.3 Contaminants

Contaminants contained in point and non-point discharges can degrade water and substrate quality and adversely impact mussel populations. Although chemical spills and other point sources of contaminants may directly result in mussel mortality, widespread decreases in density and diversity may result in part from the subtle, pervasive effects of chronic, low-level contamination (Naimo 1995, p. 354). The effects of heavy metals, ammonia, and other contaminants on freshwater mussels were reviewed by Mellinger (1972), Fuller (1974), Havlik and Marking (1987), Naimo (1995), Keller and Lydy (1997), and Newton *et al.* (2003).

The effects of contaminants such as metals, chlorine, and ammonia are profound on juvenile mussels (Augspurger *et al.* 2003, p. 2,571; Bartsch *et al.* 2003, p. 2,566). Juvenile mussels may readily ingest contaminants adsorbed to sediment particles while pedal feeding (Newton and Cope 2007, p. 276). These contaminants also affect mussel glochidia, which are sensitive to some toxicants (Goudreau *et al.* 1993, p. 221; Jacobson *et al.* 1997, p. 2,386; Valenti *et al.* 2005, p. 1,243).

Mussels are noticeably intolerant of heavy metals (Havlik and Marking 1987, p. 4). Even at low levels, certain heavy metals may inhibit glochidial attachment to fish hosts. Cadmium appears to be the heavy metal most toxic to mussels (Havlik and Marking 1987, pp. 4–9), although chromium, copper, mercury, and zinc also negatively affect biological processes (Naimo 1995, p. 355; Jacobson *et al.* 1997, p. 2,389; Valenti *et al.* 2005, p. 1,243). Chronic mercury contamination from a chemical plant on the North Fork Holston River, Virginia, destroyed a diverse mussel fauna downstream of Saltville, Virginia, and potentially contributed to the extirpation of the Purple Lilliput from that river (Brown *et al.* 2005, p. 1,459).

Long-term declines and extirpation of mussels from the Clinch River in Virginia have been attributed to copper and zinc contamination originating from wastewater discharges at electric power plants, which emphasizes that despite localized improvements, these metals can stay bound in sediments, affecting recruitment and densities of the mussel fauna for decades (Price *et al.* 2014, p. 12; Zipper *et al.* 2014, p. 9). Runoff high in heavy metals (lead, cadmium, and zinc) from the extensive Tri-State Mining Area in Missouri, Kansas, and Oklahoma has been implicated with causing mussel declines in streams such as the Spring River and Center, Shoal, Tar, and Turkey Creeks (Angelo *et al.* 2007, p. 491).

To the best of our current knowledge, heavy metals and their toxicity to mussels have been documented in the Black, Spring (Missouri), Ohio, Clinch, and Tennessee Rivers (Havlik and Marking 1987, pp. 4–9). Coal plants are also located on the Ohio, Green, and Cumberland Rivers, and the effects of these facilities on water quality and the freshwater mussel fauna, including the Purple Lilliput, are likely similar.

Among pollutants, ammonia warrants priority attention for its effects on mussels. It has been shown to be lethal to juveniles at concentrations as low as 0.7 ppm total ammonia nitrogen, normalized to pH 8 (range = 0.7–19.7 ppm) and lethal to glochidia at concentrations as low as 2.4 ppm total ammonia nitrogen, normalized to pH 8 (range = 2.4–10.4 ppm) (Augspurger *et al.* 2003, p. 2,574). The un-ionized form of ammonia is usually attributed as being the most toxic to aquatic organisms, although the ammonium ion form may contribute to toxicity under certain conditions (Newton 2003, p. 1). Documented toxic effects of ammonia on freshwater bivalves include reduced survival, reduced growth, and reduced reproduction (Augspurger *et al.* 2003, p. 2,575; Mummert *et al.* 2003, p. 2,522). Ammonia has also been shown to cause a shift in glucose metabolism and to alter the metabolic utilization of total lipids, phospholipids, and cholesterol (Chetty and Indira 1994, p. 693).

Sources of ammonia are agricultural (e.g., animal feedlots and nitrogenous fertilizers), municipal (e.g., outdated water treatment plants and industrial waste products), and from natural processes (e.g., precipitation and decomposition of organic nitrogen) (Goudreau *et al.* 1993, p. 222; Augspurger *et al.* 2003, p. 2,575; Newton 2003, p. 2,543). Toxic effects of ammonia are more pronounced at higher pH and water temperatures because the level of the un-ionized form increases as a percentage of total ammonia (Mummert *et al.* 2003, p. 2,545; Newton 2003, p. 2,544). Therefore, this contaminant may become more problematic for juvenile mussels during periods of low water levels and high temperatures (Cherry *et al.* 2005, p. 378).

In stream systems, ammonia frequently is at its highest concentrations in interstitial spaces where juvenile mussels live and feed, and may occur at levels that exceed water quality standards (Frazier *et al.* 1996, p. 97; Cooper *et al.* 2005, p. 392). The EPA established ammonia water quality criteria (WQC) (EPA 1985, entire) that may not be protective of mussels (Augspurger *et al.* 2003, p. 2,571). Ammonia is considered a limiting factor for survival and recovery of some mussel populations due to its high level of toxicity and because the highest concentrations occur in their microhabitats (Augspurger *et al.* 2003, p. 2,569).

Other common contaminants associated with households and urban areas, particularly those from industrial and municipal effluents, may include heavy metals, chlorine, phosphorus, and numerous other toxic compounds. Pharmaceuticals, hormones, and other OWCs were detected downstream from urban areas and livestock production (Kolpin *et al.* 2002, p. 1,208). These OWCs (82 of the 95 tested for) originated from a wide range of residential, industrial, and agricultural sources, and some are known to have deleterious effects on aquatic organisms (Kolpin *et al.* 2002, p. 1,210). Wastewater is discharged through NPDES-permitted (and some non-permitted) sites throughout the country. In Virginia, high counts of coliform bacteria originating from wastewater treatment plants have been documented in both the Clinch River, and degradation of water quality is a primary threat to aquatic fauna (Neves and Angermeier 1990, p. 50). In the Illinois River basin in Arkansas and Oklahoma, point source discharges have been documented as the primary contributing sources of water quality degradation, accompanied by undesirable algal growths and impairments of the river's aquatic communities (Oklahoma Conservation Commission 2010, p. 63).

The toxic effects of high salinity wastewater from oil and natural gas drilling on juvenile and adult freshwater mussels have been observed in the upper Ohio River basin (Patnode *et al.* 2015, p. 55). Extraction of petroleum produces water with high chlorine concentrations, to which all stages of freshwater mussels are highly sensitive (Patnode *et al.* 2015, p. 56). The degradation of water quality as a result of land-based oil and gas drilling activities is an adverse effect on freshwater mussels, and the Purple Lilliput in the Ohio, Tennessee, Cumberland, and Arkansas-White-Red River basins.

Chemical spills occur often and are devastating for isolated populations of rare, relatively immobile species with limited potential for recolonization, such as mussels (Wheeler *et al.* 2005, p. 155). Numerous streams throughout the range of the Purple Lilliput have experienced mussel and fish kills from toxic chemical spills, especially in the upper Tennessee River system in Virginia (Neves 1987, p. 254; Jones *et al.* 2001, p. 20; Schmerfeld 2006, p. 12; Ahlstedt *et al.* 2016, p. 8). Catastrophic pollution events, coupled with pervasive sources of contaminants from municipal and industrial pollution and coal-processing wastes, have contributed to the decline of mussels in the Clinch River, Tennessee (Neves 1991, p. 260).

Sediment from the upper Clinch River was found to be toxic to juvenile mussels, which has contributed to the decline and lack of recruitment of mussels in the Virginia portion of the river (Ahlstedt and Tuberville 1997, p. 74; Price *et al.* 2014, p. 855). Chemical spills will invariably continue to occur and have the potential to reduce or eliminate Purple Lilliput populations. Spills also may damage or contaminate nearshore and depth-transitional areas where mussel beds are common (Miller and Payne 1998, p. 184).

Section 401 of the Federal CWA requires that an applicant for a Federal license or permit provide a certification that any discharges from the facility will not degrade water quality or violate water-quality standards, including those established by states. Section 404 of the CWA establishes a program to regulate the discharge of dredged and fill material into waters of the United States. Permits to fill wetlands and fill, culvert, bridge, or re-align streams or water features are issued by the U.S. Army Corps of Engineers (Corps) under Nationwide Permits, Regional General Permits, or Individual Permits.

- *Nationwide Permits* are for “minor” impacts to streams and wetlands, and do not require an intense review process. These impacts usually include stream impacts under 150 ft (45.7 m), and wetland fill projects up to 0.50 ac (0.2 ha). Mitigation is usually provided for the same type of wetland or stream affected, and is usually at a 2:1 ratio to offset losses and make the “no net loss” closer to reality.

- *Regional General Permits* are for various specific types of impacts that are common to a particular region; these permits will vary based on location in a certain region/state.

- *Individual Permit*s are for the larger, higher impact and more complex projects. These require a complex permit process with multi-agency input and involvement. Impacts in these types of permits are reviewed individually and the compensatory mitigation chosen may vary depending on project and types of impacts.

State and Federal Water Quality Programs

Current state regulations regarding pollutants are designed to be protective of aquatic organisms; however, unionids may be more susceptible to some pollutants than the test organisms commonly used in bioassays. Additionally, water quality criteria may not incorporate data available for freshwater mussels (March *et al.* 2007, pp. 2,066–2,067). A multitude of bioassays conducted on 16 mussel species (summarized by Augspurger *et al.* 2007, pp. 2,025–2,028) show that freshwater mollusks are more sensitive than previously known to some chemical pollutants, including chlorine, ammonia, copper, fungicides, and herbicide surfactants. Another study found that nickel and chlorine were toxic to a federally threatened mussel species at levels below the current criteria (Gibson 2015, p. 90). The study also found mussels are sensitive to sodium dodecyl sulfate (SDS), a surfactant commonly used in household detergents, for which water quality criteria do not currently exist. The Purple Lilliput is probably also sensitive to many of these chemical pollutants.

Several studies have demonstrated that the criteria for ammonia developed by the EPA in 1999 were not protective of freshwater mussels (Augspurger *et al.* 2003, p. 2,571; Mummert *et al.* 2003, pp. 2,548–2,552; Newton *et al.* 2003, pp. 2,559–2,560). However, the EPA revised its recommended criteria for ammonia in 2013 after having considered newer toxicity data on sensitive freshwater mollusks (August 22, 2013; 78 FR 52192). Most of the states in the range of the Purple Lilliput have not yet adopted the new ammonia criteria due to costs associated with upgrading facilities. NPDES permits are valid for 5 years; thus, even after the new criteria are adopted, it could take several years before facilities must comply with the new limits.

Despite regulations by existing authorities, such as the CWA, pollutants continue to impair the water quality in portions of the Purple Lilliput’s range. State and Federal regulatory mechanisms have helped reduce the negative effects of point source discharges since the 1970s, yet these regulations are difficult to monitor and implement. Although new water quality criteria are under development that will take into account more sensitive aquatic species, most current criteria do not. It is expected that several years will be needed to implement new water quality criteria throughout the Purple Lilliput’s range.

6.1.4 Dams and Barriers

The effects of impoundments and barriers on aquatic habitats and freshwater mussels are relatively well-documented (Watters 2000, p. 261). Dams alter and disrupt connectivity, and alter water quality, which affect Purple Lilliput species needs. The Purple Lilliput has shown the ability to adapt to a wide variety of habitats (Williams *et al.* 2008, p. 720; Haag and Cicerello 2016, p. 239). Purple Lilliput is one of the few imperiled mussel species that is adaptable, in some situations, to lentic environments, such as Wheeler Reservoir on the mainstem Tennessee River. It is puzzling it is that it only seems to have done this in a couple of locations, but not in other situations, as far as we know. This section is intended to be a summary of the effects, as opposed to a comprehensive overview, that dams and other barriers have on the Purple Lilliput.

Extinction/extirpation of North American freshwater mussels can be traced to impoundment and inundation of riffle habitats in all major river basins of the central and eastern United States (Haag 2009, p. 107). Humans have constructed dams for a variety of reasons: flood prevention, water storage, electricity generation, irrigation, recreation, and navigation (Eissa and Zaki 2011, p. 253). Dams, either natural (by beavers or by aggregations of woody debris) or man-made, have many impacts on stream ecosystems. Reductions in the diversity and abundance of mussels are primarily attributed to habitat shifts caused by impoundments (Neves *et al.* 1997, p. 63). The survival of mussels and their overall reproductive success are influenced:

● *Upstream of dams* – the change from flowing to impounded waters, increased depths, increased buildup of sediments, decreased dissolved oxygen, and the drastic alteration in resident fish populations.

● *Downstream of dams* – fluctuations in flow regimes, minimal releases and scouring flows, seasonal depletion of dissolved oxygen, reduced or increased water temperatures, and changes in fish assemblages.

As mentioned above in section 6.1.2.2, Transportation, improperly constructed culverts at stream crossings may act as barriers, and have some similar negative effects as dams on stream systems. Fluctuating flows through the culvert can vary significantly from the rest of the stream, preventing fish passage and scouring downstream habitats. For example, if a culvert sits above the streambed, aquatic organisms cannot pass through them. These barriers fragment habitats along a stream course and contribute to genetic isolation of the aquatic species inhabiting the streams.

The majority of the rivers and streams currently occupied by the Purple Lilliput in the Ohio, Cumberland, Tennessee, and Arkansas-White-Red River basins are directly affected by dams. Extensive river and stream segments in the Arkansas River basin within the range of the Purple Lilliput have been impounded by dams or adversely affected by tailwater releases, and such alterations have been attributed with reductions in native mussel distribution and diversity (Obermeyer *et al.* 1997, p. 42; Mather 2006, p. 17). Impacts of these dams to the Purple Lilliput include population isolation, hydrological instability, high shear stress, scour, and cold water releases, all of which suppress mussel recruitment (Hardison and Layzer 2001, p. 79; Smith and Meyer 2010, p. 543; Hubbs 2012, p. 8).

The construction and continued operation of dams have historically resulted in extirpation of freshwater mussels within portions of the range of the Purple Lilliput. In the Cumberland River basin in Tennessee, many adverse effects of impoundments contribute to habitat loss for mussels, including altered temperature regimes, silt deposition, unstable substrates, sedimentation, oxygen depletion, altered river morphology, dewatering, and reservoir fluctuation (Layzer *et al.* 1993, p. 68). In the South Fork Holston River, Tennessee, impoundment was identified as the biggest contributor to extirpation of a diverse and abundant native mussel fauna, including Purple Lilliput (Parmalee and Polhemus 2004, p. 233).

6.1.5 Resource Extraction

6.1.5.1 Coal Mining

Across the Purple Lilliput's range, the most intensive resource extraction impacts are from coal mining and oil and gas exploration. Activities associated with coal mining and oil and gas drilling can contribute chemical pollutants to streams. Acid mine and saline drainage (AMD) is created from the oxidation of iron-sulfide minerals such as pyrite, forming sulfuric acid (Sams and Beer 2000, p. 3). This AMD may be associated high concentrations of aluminum, manganese, zinc, and other constituents (Tennessee Department of Environment and Conservation (TDEC) 2014, p. 72). These metals, and the high acidity typically associated with AMD, can be acutely and chronically toxic to aquatic life (Jones 1962, p. 196). Implementation of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) has significantly reduced AMD from new coal mines; however, un-reclaimed areas mined prior to SMCRA continue to generate AMD in portions of the Purple Lilliput's range.

Surface mining has been identified as a source of impairment for approximately 775 mi (1,247 km) of streams in Kentucky (Kentucky Department of Environmental Protection (KDEP) 2014, p. 66). The Purple Lilliput is extirpated from the Rockcastle and Caney Fork Rivers in the upper Cumberland River basin (see Appendix B); these MUs have experienced water quality degradation resulting from acid mine drainage and intensive surface mining activity (Layzer and Anderson 1992, p. 97). Mining continues to impair water quality in streams in the Cumberland Plateau and Central Appalachian regions of Tennessee and Kentucky (upper Cumberland River basin and upper Tennessee River basin) (TDEC 2014, p. 62), and is the primary source of low pH impairment of 376 mi (605 km) of stream in Tennessee (TDEC 2014, p. 53).

High concentrations of zinc and copper were found in sediments below a coal processing plant in the Clinch River, Virginia, resulting in reduced survival of juvenile mussels (Ahlstedt and Tuberville 1997, p. 75). The negative influence of mined land on mussels in the Clinch River has also been demonstrated through elevated levels of tissue zinc concentrations and dissolved manganese, indicating chronic mussel exposure to contaminated runoff (Van Hassel 2007, p. 323).

The Tri-State Mining District (TSMD) encompasses portions of Kansas, Missouri, and Oklahoma. Within the TSMD, lead and zinc mining occurred over the past 100 years throughout the Spring River MU and in portions of the Neosho River MU. Although this resource extraction activity no longer occurs in these river systems, high levels of lead and zinc have accumulated in the TSMD, entering streams and rivers, contaminating surface waters, groundwater, sediments, and souls (ESI 2018, p. 1). Comprehensive quantitative and qualitative mussel and habitat surveys, conducted in the past 5 years within these MUs in the Arkansas-White-Red basin, indicate negative correlations between unionid community metrics and sediment toxicity (ESI 2018, p. 59). These results indicate that sediment metal concentrations as a result from lead and zinc mining have negatively affected the unionid community of the Spring River MU, including the Purple Lilliput.

The concentrations of toxic metals as a result of coal processing and mining activities, in addition to water quality degradation from abandoned mines, is a threat to the Purple Lilliput specifically in the Cumberland and Ohio River basins. Areas of past and current intensive mining activity where the Purple Lilliput occurs, such as in the Ohio River basin (particularly in Ohio and Kentucky), Cumberland basin (particularly Kentucky), and Arkansas-White-Red basin (particularly Missouri) are most vulnerable to this threat.

6.1.5.2 Natural Gas Extraction

Natural gas extraction in the Marcellus Shale region (the largest natural gas field in the United States that runs through northern Appalachia) has negatively affected water quality through accidental spills and discharges, as well as increased sedimentation due to increases in impervious surface and tree removal for drill pads and pipelines (Vidic *et al.* 2013, p. 6). The Fayetteville Shale region in Arkansas and Oklahoma is also among the most productive for natural gas in the eastern U.S. Fayetteville shale fracking and horizontal drilling activity was an imminent threat to the aquatic fauna in the region from 2006–2012 through habitat alteration and loss, but has since subsided drastically (Davidson 2019, pers. comm.). However, fracking remains a concern for the Cadron and Lake Conway-Point Remove MUs.

Water withdrawals for drilling and fracking fluids are a stressor to rivers and streams, since they reduce streamflow, as each well uses between 2–7 million gallons of source water, and areas of fracking concentration compounds consumptive water uses (Entrekin *et al.* 2011, p. 508). Disposal of insufficiently treated brine wastewater is known to adversely affect freshwater mussels (Patnode *et al.* 2015, p. 62). Contaminant spills are also a concern.

Sediment appears to be the largest impact to mussel physical habitat in streams as a result gas extraction activities. Excessive suspended sediments can impair feeding processes, leading to acute short-term or chronic long-term stress. Both excessive sedimentation and excessive suspended sediments can lead to reduced mussel fitness (Ellis 1936, p. 29; Anderson and Kreeger 2010, p. 2). This sediment is generated by construction of the well pads, access roads, and pipelines (for both gas and water). Increased benthic sediments in surface waters and stream disturbance from land clearing for well pads and supporting infrastructure (e.g., roads, pipelines, stream crossings), as well as loss of riparian area associated with gas-well installation activities, can negatively affect lotic ecosystems (Entrekin *et al.* 2011, p. 507).

The impact of pipelines crossing mussel streams through open-trenching, the preferred industry method, increases sediment load and contributes to a loss of mussel habitat through sedimentation, and the covering of appropriate substrates. Tank trucks hauling such fluids can overturn into mussel streams; it is presumed that many spills go unreported. Brine wastewater and fracking fluids discharging from natural gas facilities represent the greatest concern to water quality in streams where mussels occur. Compressor and processing plants have also been constructed. Other sediment impacts result from bank slippage and mudslides resulting from pipeline construction, access road construction, and well pad construction in mountainous terrain (Clayton 2018, pers. comm.).

6.1.5.3 Gravel Mining/Dredging

Instream sand and alluvial gravel mining has been implicated in the loss of mussel populations (Hartfield 1993, p. 138). Negative impacts associated with gravel mining include stream channel modifications such as altered habitat, disrupted flow patterns, and sediment transport. Additionally, water quality modifications result from gravel mining, including increased turbidity, reduced light penetration, increased temperature, and increased sedimentation. These habitat and water quality degradations reduce macroinvertebrate and fish populations, which suffer impacts to spawning and nursery habitat, and food web disruptions (Kondolf 1997, p. 541; Brown *et al.* 1998, p. 988). The Corps and state water quality agencies retain regulatory oversight for sand and gravel mining, but some sand, gravel, and rock mining in rivers is unmonitored.

6.1.5.4 Resource Extraction Summary

Coal mining, AMD, and the legacy effects of abandoned mine runoff are currently affecting Purple Lilliput populations in the Ohio, Cumberland, and Tennessee River basins. Fayetteville Shale activity was an imminent threat from 2006–2012, but has since subsided drastically (Davidson 2019, pers. comm.). However, the impacts of pipeline construction, well pad installation, and access road clearing are a potential future threat to Purple Lilliput populations in the Arkansas-White-Red and Lower Mississippi River basins. The presence of a large number of mine waste ponds in the Ohio and Tennessee River basins increase the risk of dam and levee failure and blowouts, resulting in mining waste covering the substrate, which could be catastrophic to Purple Lilliput populations.

Resource extraction and AMD have been cited as a contributor to the loss of mussel species in the Cumberland River basin, such as in the Rockcastle River (Haag and Cicerello 2016, p. 15). The presence of these threats may limit recovery opportunities in those MUs (Layzer and Anderson 1992, p. 97; Ahlstedt *et al.* 2003–2004, p. 39). Additionally, direct and indirect effects of water quality degradation, pollution, and chemical toxicity as a result of active or past mining activities are affecting freshwater mussel populations in the historical and current range of the Purple Lilliput in the Ohio and Cumberland basins, in addition to the Arkanasas-White-Red basin (Haag and Cicerello 2016, pp. 9–16).

Sand and gravel mining are currently affecting populations of the Purple Lilliput in the Upper and Lower Cumberland, Current, Beaver Reservoir, Illinois, Little Red, Upper Black MUs. The Cumberland River has been affected by gravel mining and dredging in the past (Sickel 1982, p. 4), resulting in permanent alteration of substrates and hydraulic patterns, and thus contributing to habitat loss for freshwater mussels. In the Oklahoma portion of the Illinois River, an assessment found four permitted gravel mining operations in the basin as well as several small unlicensed operations on river tributaries (Oklahoma Conservation Commission 2010, p. 73). An investigation of one tributary found mining had significantly impacted the riparian community and changed the stream channel to a wider, shallower, less stable morphology. In portions of the Purple Lilliput's range where mining is ongoing (i.e., the Ohio, Cumberland, Tennessee, and Arkansas-White-Red River basins), the impacts of that mining have negatively impacted the Purple Lilliput's ability to meet their resource needs, and the potential exists for additional impacts in the future.

6.1.6 Changing Climate Conditions

Changing conditions that can influence freshwater mussels include increasing or decreasing water temperatures and precipitation patterns that result in increased flooding, prolonged droughts, or reduced stream flows, as well as changes in salinity levels (Nobles and Zhang 2011, pp. 147–148). An increase in the number of days with heavy precipitation over the next 20 to 30 years is expected across the Purple Lilliput's range (U.S. Global Climate Change Research Program [USGCRP] 2017, p. 207). Although changing climate conditions have potentially affected the Purple Lilliput to date, the timing, frequency, and extent of these effects is currently unknown.

It is important to consider possible climate change impacts to Purple Lilliput and its habitat. As mentioned in the Poff *et al.* (2002, pp. ii–v) report on Aquatic Ecosystems and Global Climate Change, impacts of climate change on aquatic systems can potentially include:

- Increases in water temperatures that may alter fundamental ecological processes, thermal suitability of aquatic habitats for resident species, and their geographic distribution.
- Changes and shifts in seasonal patterns of precipitation and runoff, which can alter the hydrology of stream systems, affecting species composition and ecosystem productivity. Aquatic organisms are sensitive to changes in frequency, duration, and timing of extreme precipitation events such as floods or droughts, potentially resulting in interference of reproduction. Further, increased water temperatures and seasonally reduced water levels and streamflow can alter many ecosystem processes, including increases in nuisance algal blooms.
- Cumulative or synergistic impacts that can occur when considering how climate change may be an additional stressor to sensitive freshwater systems, which are already adversely affected by a variety of other human impacts, such as altered flow regimes and deterioration of water quality.
- Adapting to climate change may be limited for some aquatic species depending on their life history characteristics and resource needs. Reducing the likelihood of impacts would largely depend on human activities that reduce other sources of ecosystem stress to ultimately enhance adaptive capacity, which could include, but not be limited to: maintaining riparian forests, reducing nutrient loading, restoring damaged ecosystems, minimizing groundwater and stream withdrawal, and strategically locating any new reservoirs to minimize adverse effects.
- Changes in presence or combinations of native and nonnative, invasive species could result in specific ecological responses to changing climate conditions that cannot be easily predicted at this time (e.g., increased temperatures that are more favorable to a

nonnative, invasive species compared to a native species).
- Shifts in mussel community structure, which can stem from climate-induced changes in water temperatures since sedentary freshwater mussels have limited refugia from disturbances such as droughts and floods, and since they are thermo-conformers whose physiological processes are constrained by water temperature within species-specific thermal preferences (Galbraith *et al.* 2010, p. 1,176).

Regardless of this assessment, small populations are already at an increased risk for extinction given the biological restrictions associated with small populations and reduced distribution (Furedi 2013, p. 3). While it is likely that climate change may further magnify the factors contributing to the decline of the species (e.g., fragmentation), the precise locations and extent of these magnifications that may be influenced specifically by changing climate conditions are difficult to predict.

Within the range of the species, shifts in the Purple Lilliput's species-specific physiological thresholds in response to altered precipitation patterns and resulting thermal regimes are possible. Additionally, nonnative, invasive species expansion because of climatic changes have the potential for long-term detriment to the Purple Lilliput and its habitat. Other potential impacts are associated with changes in food web dynamics and the genetic bottleneck that can occur with low effective population sizes (Nobles and Zhang 2011, p. 148). The influences of these changes on the Purple Lilliput are possible in the future (see Scenario 3, section 7.5, below). However, the effects of landscape-level changes on sedentary species such as freshwater mussels may be difficult to observe and quantify, requiring systematic collection of data over an extended time period (Ahlstedt *et al.* 2016, p. 4).

The best available information does not indicate that changing climate conditions within the range of the Purple Lilliput are likely to have adverse effects at the population- or rangewide scales, but the populations in Oklahoma may be more vulnerable due to increasing temperatures and decreasing precipitation levels, which are predicted to be more severe than the rest of Purple Lilliput's range. Therefore, climate change is considered a secondary factor influencing the viability of the Purple Lilliput and is not currently thought to be a primary factor in its occurrence and distribution.

In summary, changing climate conditions are an increasing concern across the United States. The greatest concerns to consider for the Purple Lilliput and its habitat include the potential for alteration of thermal regimes, which can contribute to increased risk of stress to individuals. At some point in the future beyond the 20- to 30-year timeframe analyzed in this report, if changes in habitat connectivity and other water quality impacts, the Purple Lilliput may be affected by climate change. However, at this time, the best available information does not indicate that changing climate conditions are playing a role in influencing the viability of the Purple Lilliput across its range.

6.1.7 Forest Conversion

Silvicultural activities, when performed according to strict Forest Practices Guidelines (FPG) or BMPs, can retain adequate conditions for aquatic ecosystems; however, when FPGs or BMPs are not followed, these activities can also cause measurable impacts and contribute to the myriad of stressors facing aquatic systems throughout the eastern U.S. (Warrington *et al.* 2017, p. 8). Both small- and large-scale forestry activities have an impact depending on the physical, chemical, and biological characteristics of adjacent streams (Allan 1995, p. 107).

Clearing large areas of forested wetlands and riparian systems eliminates shade once provided by the tree canopies, exposing streams to more sunlight and increasing the in-stream water temperature (Wenger 1999, p. 35). The increase in stream temperature and light after deforestation alters macroinvertebrate and other aquatic species richness and abundance composition in streams to various degrees depending a species tolerance to temperature change and increased light in the aquatic system (Kishi *et al.* 2004, p. 283; Couceiro *et al.* 2007, p. 272; Caldwell *et al.* 2014, p. 2,196).

Sediment runoff from cleared forested areas is a known stressor to aquatic systems (e.g., Webster *et al.* 1992, p. 232; Jones III *et al.* 1999, p. 1,455; Broadmeadow and Nisbet 2004, p. 286; Aust *et al.* 2011, p. 123). The physical characteristics of stream channels are affected when large quantities of sediment are added or removed (Watters 2000, p. 263). Mussels and fishes are potentially affected by changes in suspended and bed material load, bed sediment composition associated with increased sediment production and runoff, channel changes in form, stream crossings, and inadequately buffered clear-cut areas, all of which can be sources of sediment entering streams (Taylor *et al.* 1999, p. 13).

Many forestry activities are not required to obtain a CWA 404 permit, as silviculture activities such as harvesting for the production of fiber and forest products are exempted (EPA 2018, p. 1). Because forestry activities often include the construction of logging roads through the riparian zone, this can directly degrade nearby stream environments (Aust *et al.* 2011, p. 123). Logging roads constructed in wetlands adjacent to headwater drains and streams fall into this exemption category, but may affect the aquatic system for years, as these roads do not always have to be removed immediately. Roads remain as long as the silviculture operation is ongoing, thus wetlands, streams, or ditches draining into the more sensitive areas may be heavily affected by adjacent fill and runoff if BMPs or FMPs fail or are not maintained, causing sedimentation to travel downstream into more sensitive in-stream habitats. Stream crossings tend to have among the lowest BMP implementation rates (Warrington *et al.* 2017, p. 9). Requirements maintain that flows are not to be restricted by logging roads, but culverts are only required per BMPs and FMPs and are not always adequately sized or spaced, or properly installed.

Forestry practices that do not follow BMPs and FMPs can influence a river or stream’s natural flow regime, resulting in altered habitat connectivity. Logging staging areas, logging ruts, and not replanting are all associated impacts that are a threat to downstream aquatic species. BMPs and FMPs typically require foresters to ensure that discharge shall not take, or jeopardize the continued existence of an endangered or threatened species, or adversely modify or destroy the critical habitat of such species, and to ensure that adverse impacts to the aquatic environment are minimized. However, foresters are not required to consult with appropriate state or Federal agencies regarding unlisted sensitive species, though consultation typically results in beneficial measures that best reduce potential impacts prior to moving forward with management activities.

Currently, forestry BMP and FMP manuals suggest planning road systems and harvest operations to minimize the number of stream crossings. Proper construction and maintenance of crossings reduces soil erosion and sedimentation with the added benefit of increasing harvest operation efficiency (National Council for Air and Stream Improvement (NCASI) 2015, p. 2).

Siltation and erosion from natural forest conversion to monoculture and intensive forestry practices without BMPs is a well-documented stressor to aquatic systems throughout the eastern U.S. (Warrington *et al.* 2017, p. 8). Forest conversion has been documented in all basins in which the species occurs, especially in the Cumberland and Tennessee basins, and the lack of riparian buffers is particularly detrimental to benthic aquatic fauna (Jones III *et al.* 1999, p. 1,460). However, in comparison to other agricultural, resource extraction, and human development stressors, which have led to impaired water quality and habitat degradation, forest conversion is not currently thought to be a substantial threat throughout the range of the species.

6.2 Invasive and Nonnative Species

Approximately 42 percent of federally endangered or threatened species are estimated to be significantly affected by nonnative, nuisance species across the nation, and nuisance species are significantly impeding recovery efforts for them in some way (National Invasive Species Council Management Plan [NISCMP] 2018, p. 2). When a nonnative species is introduced into an ecosystem, it may have many advantages over native species, such as easy adaptation to varying environments and a high tolerance of living conditions that allow it to thrive in its new habitat. There may not be natural predators to keep the nonnative species in check; therefore, it can potentially live longer and reproduce more often, further reducing the biodiversity in the system. The native species may become an easy food source for invasive species, or the invasive species may carry diseases that extirpate populations of native species. Examples of nonnative species that affect freshwater mussels like the Purple Lilliput are the Asian Clam, Zebra Mussel (*Dreissena polymorpha*), Quagga Mussel (*Dreissena bugenis*), Black Carp (*Mylopharyngodon piceus*), Didymo (a.k.a. rock snot; *Didymosphenia geminata*), and Hydrilla (a.k.a. water-thyme; *Hydrilla verticillata*).

The Asian Clam alters benthic substrates, may filter mussel sperm or glochidia, competes with native species for limited resources, and causes ammonia spikes in surrounding water when they die off en masse (Scheller 1997, p. 2). The Asian Clam is hermaphroditic, enabling fast colonization and is believed to practice self-fertilization, enabling rapid colony regeneration when populations are low (Cherry *et al.* 2005, p. 378). Reproduction and larval release occur biannually in the spring and in the late summer. A typical settlement of the Asian Clam occurs with a population density ranging from 100 to 200 clams per square meter, which may not be detrimental to native unionids; however, populations can grow as large as 3,000 clams per square meter, which at this density influence both food resources and competition for space for the Purple Lilliput. Asian Clams are prone to have die-offs that reduce available dissolved oxygen and increase ammonia, which can cause stress and mortality to the Purple Lilliput (Cherry *et al.* 2005, p. 377).

Dreissenid mollusks, such as the Zebra Mussel and Quagga Mussel, are a threat to native freshwater mussels. These nonnative mollusks are known to occur in the Great Lakes, Ohio, Tennessee, Arkansas-White-Red, and the Lower Mississippi River basins. Mussels, such as the Purple Lilliput, are adversely affected by dreissenids through direct colonization, reduction of available habitat, changes in the biotic environment, or a reduction in food sources (MacIsaac 1996, p. 292). Zebra Mussels are listed by Congress (by statute) as Injurious Wildlife under the Lacey Act (16 U.S.C. 3371-3378; 18 U.S.C. 42-43), (50 CFR §16). Zebra Mussels are also known to alter the nutrient cycle in aquatic habitats, affecting other mollusks and fish species (Strayer *et al.* 1999, p. 22).

Since its introduction in the Great Lakes in 1986, Zebra Mussel colonization has resulted in the decline and regional extirpation of freshwater mussel populations in lakes and rivers across North America (Schloesser *et al.* 1996, p. 303; Schloesser *et al.* 1998, p. 300). One of the direct consequences of the invasion of Zebra and Quagga Mussels is the local extirpation of native freshwater mussel populations from: (1) attaching to the shells of native mussels, which can kill them (dreissenid mussels are sessile, and cling to hard surfaces); (2) affecting vertical and lateral movements of mussels, due to heavy infestations that can prevent valve closure; and (3) outcompeting native mussels and other filter feeding invertebrates for food. This problem has been particularly acute in some areas of the U.S. that have a very rich diversity of native freshwater mussel species, such as the Ohio and Tennessee River basins.

The two nonnative plant species that are most problematic for the Purple Lilliput are Hydrilla and Didymo, although an additional species known as Golden Alga (*Prymnesium parvum*), a marine algae, has spread into the upper Ohio River basin and is a potential threat to mussel populations, particularly during low-flow years and if coupled with brine discharges (Anderson and Kreeger 2010, p. 9). Hydrilla is an aquatic plant that alters stream habitat, decreases flows, and contributes to sediment buildup in streams (NISCMP 2018, p. 2). High sedimentation can cause suffocation, reduce stream flow, and make it difficult for mussels' interactions with host fish necessary for development.

Hydrilla can quickly dominate native vegetation, forming dense mats at the surface of the water and dramatically altering the balance of the aquatic ecosystem. Hydrilla covers spawning areas for native fish and can cause reductions in stream oxygen levels (Colle *et al.* 1987, p. 410). Hydrilla is widespread in the Lower Mississippi, Arkansas-White-Red, Ohio, Cumberland, and Tennessee River basins. Second, Didymo or "rock snot" is a nonnative alga (diatom) that can alter the habitat and change the flow dynamics of a site (Jackson *et al.* 2016, p. 970). Invasive plants grow uncontrolled and can smother habitat, affect flow dynamics, alter water chemistry, increase water temperatures, and can even dry out completely, especially in drought conditions (Colle *et al.* 1987, p. 416).

Black Carp, a molluscivore, has been reported in Arkansas, Illinois, Mississippi, and Missouri (Nico *et al.* 2005, p. 155), Louisiana, Tennessee, and Kentucky (Nico and Neilson 2018, USGS Nonindigenous Aquatic Species Database). The species is present in the lower Ohio, Cumberland, Lower Mississippi, and Tennessee River basins. Based on diet studies of the species within their native range in east Asia, there is potential that the Black Carp will negatively impact native North American aquatic communities by direct predation, thus reducing populations of native mussels and snails, many of which are considered endangered or threatened (Nico *et al.* 2005, p. 193). A diet study found wild caught Black Carp in the Mississippi River from 2009–2017 had a 13.7 percent incidence for unionids (26.6 percent for mollusks) (Poulton *et al.* 2019, p. 94). The black carp is also listed as Injurious Wildlife under the Lacey Act.

Given their size and diet preferences, Black Carp have the potential to restructure benthic communities by direct predation and removal of algae-grazing snails. Mussel beds consisting of smaller individuals and juvenile recruits are probably most vulnerable to being consumed by black carp (Nico *et al.* 2005, p. 192). Furthermore, because Black Carp attain a large size (well over 3.28-ft (1-m) long), and their life span is reportedly over 15 years, they are expected to persist for many years. Therefore, they have the potential to cause harm to native molluscs by way of predation to multiple age classes (Nico *et al.* 2005, p. 77).

The Aquatic Nuisance Species (ANS) Task Force, co-chaired by the Service and the National Oceanic and Atmospheric Administration (NOAA), encourages state and interstate planning entities to develop management plans describing detection and monitoring efforts of aquatic nuisance and nonnative species, prevent efforts to stop their introduction and spread, and control efforts to reduce their impacts. Management plan approval by the ANS Task Force is required to obtain funding under Section 1204 of the ANS Prevention and Control Act. Regardless of financial incentives, plans are a valuable and effective tool for identifying and addressing ANS problems and concerns in a climate of many jurisdictions and other interested entities. Each state within the range of the Purple Lilliput has either a plan approved by or submitted to the ANS Task Force, or a plan under development. These plans have been effective in terms of raising awareness at the state level of the severity of ecological damage that nonnative and nuisance species are capable of, but many are in early stages of implementation.

Asian Clams are a ubiquitous presence in rivers and streams of eastern North America. Asian Clams are present throughout the range of the Purple Lilliput, and the competitive interactions and effects of their massive die-offs have been documented for many mussel species, but the complete impacts of these nonnative bivalves on native unionids is not completely understood. The arrival and proliferation of the Zebra Mussel in the Ohio River in the early 1990s corresponded with a substantial decline in native freshwater mussel populations (Watters and Flaute 2010, p. 1). The decline and extirpation of native freshwater mussels in the Great Lakes and its tributaries has been attributed to Zebra Mussel invasion (Schloesser *et al.* 2006, p. 307). Zebra and Quagga Mussel densities are highly variable annually, and may depend on discharge rates, water temperatures, settlement location, and predator presence (Cope *et al.* 2006, p. 185).

There are nonnative species present throughout the range of the Purple Lilliput. These nonnative species discussed above affect Purple Lilliput individuals through competitive interactions, water quality degradation, predation, and habitat alteration. Low condition Purple Lilliput populations may be affected by the nonnative vegetation, fish, and mollusks described in this section due to their limited resiliency.

6.3 Genetic Isolation

Purple Lilliput exhibit several inherent traits that influence population viability, including relatively small population size and low fecundity at many locations compared to other mussels (see Appendix A). Purple Lilliput prefer sites with clean water and stable substrates (see sections 4.1.1–4.1.3). Small population size puts the species at greater risk of extirpation from stochastic events (e.g., drought) or anthropomorphic changes and management activities that affect habitat. In addition, small Purple Lilliput populations may have reduced genetic diversity, be less genetically fit, and more susceptible to disease during extreme environmental conditions compared to large populations (Frankham 1996, p. 1,505).

Populations that have a small effective population size (number of breeding individuals) and that are geographically spread out and isolated from one another are more vulnerable than more robust populations. Factors such as low effective population size, genetic isolation, relatively low levels of fecundity and recruitment, and limited juvenile survival could all affect the ability of this species to maintain current population levels and to rebound if a reduction in population occurs (e.g., predation, toxic releases or spills, poor environmental conditions that inhibit successful reproduction).

Fragmentation (i.e., the breaking apart of habitat segments, independent of habitat loss (Fahrig 2003; p. 299)) and isolation contribute to the extinction risk that mussel populations face from stochastic events (see Haag 2012, pp. 336–338). Streams are naturally dynamic, frequently creating or shifting areas of quality habitat over a particular period. A number of factors, most of which interact to create stable patches of suitable and unsuitable mussel habitat, bring about habitat fragmentation (natural and human-induced) in stream systems. Some causes, like barriers, directly and permanently fragment habitat. Other sources, such as drought, water quality, host fish movement, substrate stability, and adjacent land use lead to increasing stream fragmentation in subtle and interdependent ways.

In dendritic landscapes, such as streams and rivers, these may lead to multiple fragments of variable size (Fagan 2002, p. 3,247). In contrast to landscapes where multiple routes of movement among patches are possible, pollution or other habitat degradation at specific points in dendritic landscapes can completely isolate portions of the system (Fagan 2002, p. 3,246). Connectivity between patches (mussel beds or occupied habitat) is important in landscapes where these patches of suitable habitat are created or destroyed frequently. Where populations are small, local extinction caused by demographic stochasticity (e.g., changes in the proportion of males and females, the reproductive potential of females, survival of individuals) happens often, and populations must be re-established by colonization from other patches. Given that these conditions may apply to many lotic mussel populations, connectivity of mussel populations and their required resources is an important factor to consider for Purple Lilliput persistence (Newton *et al.* 2008, p. 428).

Impoundments result in the genetic isolation of mussel populations as well as fishes that act as hosts (Vaughn 2012, p. 6; also see section 6.1.4, above). Perched or improperly maintained culverts at stream crossings can also act as barriers (see section 6.1.2 and 6.1.4, above), and have similar effects as dams on stream systems. Fluctuating flows through a culvert can differ significantly from the rest of the stream, preventing fish passage and scouring downstream habitats.

6.4 Enigmatic Population Declines

Mussel populations in the U.S. have experienced declines in the absence of obvious severe point or non-point source pollution or severe habitat loss and destruction (Haag 2019, p. 1). These declines, documented since the 1960s, are termed enigmatic population declines, due to their mysterious and currently puzzling nature (Haag 2012, p. 341). Despite speculation and repeated aquatic organism surveys and water quality monitoring, the causes of these events are unknown. In some cases the instream habitat often remain basically intact and continue to support other aquatic organisms such as fish and crayfish.

For example, the entire mussel fauna has collapsed almost completely in the Red MU (Red River), Harpeth MU (Harpeth River), and Stones MU (Stones River), all of which historically supported Purple Lilliput, but populations within these MUs are now considered extirpated (Haag 2019, pp. 7–8). Other rivers and streams affected by apparent enigmatic declines are the Rockcastle River in the Rockcastle MU, Buck Creek in the Upper Cumberland-Lake Cumberland MU, and Little South Fork Cumberland River in the South Fork Cumberland MU (Haag 2019, pp. 7–8). These have had enigmatic mussel declines, but the Purple Lilliput is still considered extant in those MUs (Service 2019a, unpublished data).

6.5 Factors Currently Believed To Have Limited Effects on Purple Lilliput Populations

At this time, our analysis of the best available scientific and commercial information suggests that host fish, disease, parasites, and predation are not likely resulting in population- or rangewide-level negative impacts to the Purple Lilliput. Some of these impacts may be influencing Purple Lilliput individuals in specific locations, and examples are given below. Disease or other pathogens may be a factor in freshwater mussel declines, but the environmental conditions that facilitate these declines are poorly known (Grizzle and Brunner 2009, p. 454).

6.5.1 Parasites

Mussel parasites include water mites, trematodes, leeches, bacteria, and some protozoa (Grizzle and Brunner 2009, p. 433). Although these organisms are generally not suspected to be a major limiting factor for mussel populations in general, reproductive output can be negatively correlated with mite abundance, and physiological condition is negatively correlated with trematode abundance (Gangloff *et al.* 2008, p. 28). Trematodes live directly in mussel gonads and may negatively affect gametogenesis (i.e., the process in which cells undergo meiosis to form gametes). It is possible mussels are more susceptible to parasites after anthropogenic factors reduce their fitness (Henley 2018, pers. comm.).

6.5.2 Predation

Native Americans extensively harvested freshwater mussels for food (Morrison 1942, p. 348; Bogan 1990, p. 112), though among mussel predators, the muskrat (*Ondatra zibethicus*) is probably cited most often (Tyrrell and Hornbach 1998, p. 301). Based on a study of muskrat predation on imperiled mussels in the upper North Fork Holston River in Virginia, Neves and Odom (1989, p. 939) concluded that this predation could limit the recovery potential of endangered mussel species or contribute to the local extirpation of already depleted mussel populations. However, they only recovered one individual of the Purple Lilliput in their study (Neves and Odom 1989, p. 939). A lack of available data on muskrat predation of the Purple Lilliput is indicative that it is probably not a substantial threat to the species. Predation by muskrats may represent a seasonal or localized threat to the Purple Lilliput, but since muskrat predation is size-selective, other mussel species that attain greater sizes are likely preferred.

Although other mammals such as raccoon, mink, otter, hogs, rats, turtles, and aquatic birds occasionally feed on mussels, the threat from these species is not currently deemed significant (Tyrrell and Hornbach 1998, p. 301). Some species of native fish, such as Freshwater Drum (*Aplodinotus grunniens*) and Redear Sunfish (*Lepomis microlophus*), feed on mussels. Based on the current available information, we determined the overall threat posed by vertebrate and invertebrate predators of the Purple Lilliput is insignificant compared to other stressors that currently influence the species.

6.6 Overall Summary of Factors Affecting the Species

Factors discussed in this chapter that negatively affect or have the potential to negatively affect Purple Lilliput include those that are systemic and threats impacting its resource needs throughout its range, including: habitat alteration and water quality impairment from a variety of sources including poorly-managed agriculture and development; enigmatic declines, and more site-specific threats, such as invasive species. The topics discussed in this chapter are reflective of the best available scientific and commercial information as it pertains to the Purple Lilliput.

Impacts to freshwater mussels and benthic riverine aquatic organisms, in general, often involve multiple interrelated actions, involve compounded stressors, and rarely lack a single causative agent; therefore, they are not easy to observe and may be difficult to quantify after they occur. While factors such as climate change, disease, or predation may affect the species currently or in the future, the best available information does not suggest these limit the mussel’s access to needed habitat resources.

The threats to the Purple Lilliput result in effects to individuals and populations at a more rapid rate. The combined impacts of habitat alteration, water quality degradation, resource extraction, agricultural activities, and nonnative species have led to localized extirpations of the Purple Lilliput, and a cumulative loss of 45 percent of populations. Although the species is considered extirpated from North Carolina and Georgia, substantial range reductions have not been observed to date, such that the species continues to be represented throughout all of the basins from which it has been documented.

CHAPTER 7 - FUTURE CONDITIONS

This chapter summarizes our evaluation of what the species' likely future conditions will be under different scenarios, and applies these forecasts to the concepts of resiliency, representation, and redundancy to describe future Purple Lilliput viability.

The Purple Lilliput occurs in rivers and streams of differing widths and lengths and a variety of habitats in the Great Lakes, Ohio, Cumberland, Tennessee, Arkansas-White-Red, and Lower Mississippi River basins (Williams *et al.* 2008, p. 720). Overall, the Purple Lilliput has greater numbers of populations in small streams and rivers, such as in the Tippecanoe, Paint Rock, and Current River MUs, where multiple tributaries are currently occupied, as compared to large rivers, such as the mainstem Ouachita, and Tennessee rivers (Appendix A). The Purple Lilliput is currently found only in streams, small lakes, and small-medium rivers in the Great Lakes and Cumberland River basins, where there are no large river populations remaining. Wide variation in river and stream occupation by Purple Lilliput is difficult to characterize succinctly, and there is a large number of extant Purple Lilliput populations (146). So, while we use population level condition categories for future condition scenarios, similar to current condition, we provide examples primarily at the MU scale throughout this chapter.

7.1 Future Scenario Considerations

The factors influencing the viability of Purple Lilliput include: (1) physical habitat fragmentation and loss, (2) water quality degradation, (3) invasive and nonnative species, and (4) genetic isolation (see Figure 6-1, above). Each of these factors are expected to continue into the future at varying degrees, depending on the populations and locations across the landscape (e.g., some sources of habitat degradation or loss are likely to be more influential in some populations than others). We attempted to discern this variance by using the best available information on proposed projects and modeling efforts (e.g., climate change/representative concentration pathway (RCP[9]) models).

7.2 Future Scenarios

We forecast the Purple Lilliput's future conditions, in terms of resiliency, representation, and redundancy, under three plausible future scenarios. These three scenarios forecast the Purple Lilliput's viability over approximately 20 to 30 years, which is a range representing two generations. We concentrated on this duration because: (1) the species lives 5–10 years, and (2) long-term trend information on Purple Lilliput abundance and threats is not available across the species' range to contribute to meaningful alternative timeframes. Given there are currently 146 populations and 65 MUs under consideration, we describe the threats that may occur at the

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[9] RCP stands for Representative Concentration Pathway. It refers to a greenhouse gas concentration (not emissions) trajectory adopted by the Intergovernmental Panel on Climate Change (IPCC) in its 5th Assessment Report ((IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.). Four pathways were selected by the IPCC for climate modeling and research, all describing potential future climate outcomes, and all considered possible depending on the amount of greenhouse gases that are emitted in the future.

basin scale as opposed to each of the populations, i.e., the Great Lakes, Ohio, Cumberland, Tennessee, Arkansas-White-Red, and Lower Mississippi River basins, which are the six major basins the species currently inhabits and historically inhabited.

Where possible, we also provide examples at the MU scale, which include one or more populations, to demonstrate potential impacts to the species, rather than for each population (Figures 7-1, 7-2, 7-3). Most of the factors currently affecting Purple Lilliput populations are influencing the species at the basin and MU level, not just at the population level (see Chapter 6, above). Further, local stressors and threats to each population are difficult to predict under future scenarios. The factors that influence the species either remain constant from current conditions (scenario 1), improve (scenario 2), or become worse (scenario 3).

Resiliency of Purple Lilliput MUs depends on future water quality, clean water availability, substrate suitability, abundance and distribution of host fish species, and habitat connectivity. We expect Purple Lilliput MUs to experience changes to these resource needs in different ways under the different scenarios. We project the expected future resiliency of each MU based on events likely to occur under each scenario. We did not include an assessment of reproduction for the future scenarios; rather, the abundance of the populations in the future reflects whether reproduction, and more importantly, recruitment, are occurring. We also project an overall condition for each MU as either High, Medium, Low, or Very Low (the latter condition equating to extirpation or functionally extirpated; see Table 7-1 for definitions).

Table 7-1. Population and Habitat condition categories used to determine the overall projected future conditions of Purple Lilliput populations and MUs.

Future Condition Category	Description
High	**Populations and MUs -** Resilient populations with evidence of recruitment and multiple age classes represented. Likely to maintain viability and connectivity among populations. Populations are not linearly distributed (i.e., occur in tributary streams within a management unit). These populations are expected to persist in 20 to 30 years and beyond and withstand stochastic events. (*Thriving; capable of expanding range*.)
	Habitats - Water quality meets designated uses and contiguous reaches with clean, mixed sand, gravel, and cobble substrates without excessive silt are predominant. Stable habitats available for population expansion.
Medium	**Populations and MUs** - Spatially restricted populations with limited levels of recruitment or age class structure. Resiliency is less than under high conditions, but the majority (approximately 75 percent) are expected to persist beyond 20 to 30 years. (*Stable; not necessarily thriving or expanding its range.)*
	Habitats - Mixed sand, gravel, and cobble substrates free of excessive silt are maintained in stable shoals, and naturally variable water levels are maintained in currently occupied rivers and streams. Lowered water quality and habitat degradation may occur but not at a level that negatively affects both the density and extent of mussel distribution.
Low	**Populations and MUs** - Small and highly restricted populations, with no evidence of recent recruitment or age class structure, and limited detectability. These populations have low resiliency, are not likely to withstand stochastic events, and potentially will no longer persist in 20 to 30 years. Populations are linearly distributed within a management unit. (*Surviving, observable; but population likely declining*.)

Future Condition Category	Description
	Habitats - Loss of mussel habitat or water quality degradation within the formerly occupied river or stream reach has been measured or observed.
Very Low	**Populations and MUs** - Populations are expected to no longer occur in a river/stream or management unit in the future (20–30 years). A population may be below detectable levels despite consistent survey effort within its formerly occupied range. (*No survival or survival uncertain; no longer observable*.)
	Habitats - Contiguous mussel habitat with clean, silt-free substrates have been lost or covered in sediment. Water quantity and quality limits colonization and reintroduction potential.

For each scenario, we used best judgement based on the best available scientific and commercial information to determine the likelihood that a particular condition would apply in 20 to 30 years. For example, we used state, city, and county development planning documents, peer-reviewed literature projections, mussel expert advice and input, and our best professional judgement. We used the scale in Table 7-2, below, to estimate these likelihoods.

Table 7-2. Explanation of confidence terminologies used to estimate the likelihood of a particular future condition category.

Confidence Terminology	Explanation
Highly likely	We are more than approximately 90 percent certain this condition category will occur.
Moderately likely	We are approximately 50 to 90 percent certain this condition category will occur.
Somewhat likely	We are less than approximately 50 percent certain this condition category will occur.

7.3 Scenario 1

Under this scenario, factors influencing current Purple Lilliput populations and MUs are assumed to remain constant into the future.

Factors influencing Purple Lilliput MUs are assumed to remain constant into the future for the next 20 to 30 years, including existing habitat degradation and beneficial conservation actions, and climate and hydrological conditions. This scenario assumes the current levels of translocation and monitoring capacity are consistent (i.e., population augmentation is not currently taking place).

Scenario 1 assumes that existing patterns and rates of land use change continue across the species' range (Lawler *et al.* 2014, p. 56), including urban growth and changes in agricultural practices (Newton *et al.* 2008, p. 434; Terando *et al.* 2014, p. 4; Lasier *et al.* 2016, p. 672). This scenario also assumes that existing regulatory mechanisms and voluntary conservation measures indirectly benefiting the species remain in place and no new/additional conservation measures are added. See Figure 7-1 below.

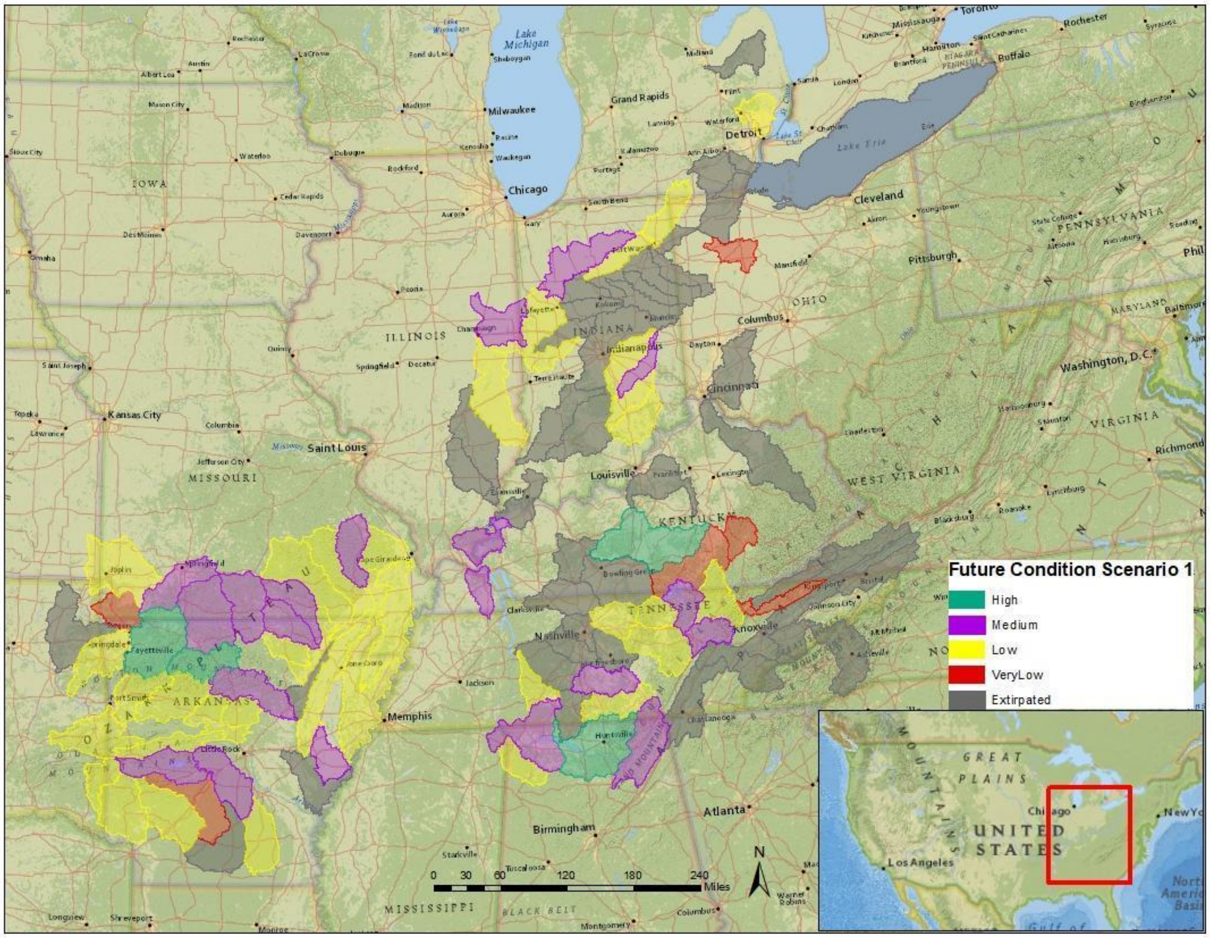

Figure 7-1. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC8s) of Purple Lilliput under Future Condition Scenario 1. Currently occupied MUs are represented with very low (i.e., no survival or survival uncertain; no longer observable), low, medium, and high condition categories (as described in Chapter 7; Service 2018, unpublished data).

Great Lakes basin

Nonnative species, such as Asian Clam, Zebra Mussel, and Quagga Mussel, continue to negatively influence MUs basin-wide. Zebra Mussels are well established in Lake Erie, to which the Blanchard, Clinton, and St. Joseph MUs drain. Asian Clam abundance and distribution is widespread within the range of the species and competes for food and nutrients needed for mussel growth and development.

There is a small to moderate reduction in water discharge due to drought conditions, and negative changes in physical habitat features due to increasing urbanization, contaminants, and agricultural practices in the Blanchard and Clinton MUs. Water quality declines are evident within this basin, and MUs are all currently identified as low condition due to untreated or poorly treated wastewater discharges, development, and high risk of contaminant spills.

Diminishment of clean water conditions through agricultural practices, which increase pressure on groundwater aquifers, makes individual Purple Lilliput more susceptible to drought (which can expose aquatic habitat, isolate mussels during sperm and juvenile mussel dispersal, increase predation, and concentrate contaminants), more susceptible to temperature increases, and, in extreme situations, can impede the delivery of sufficient dissolved oxygen. Lower water levels and discharge also foster the concentration of contaminants. The pervasive impacts of water quality degradation can affect these MUs, which are linear or confined to a small glacial lake (Lake Wilson), small in extent, and low density. Under this scenario, the currently small, isolated, linear Blanchard River MU is lost, resulting in extirpation of the species from the State of Ohio.

Ohio River basin

There is a small to moderate reduction in water discharge due to drought conditions, and negative changes in physical habitat features due to agricultural practices, human population growth, and resource extraction activities in small streams and rivers that affect individuals (e.g., Tippecanoe, Eel, Muscatatuck, and Vermilion MUs). Increased ground and surface water withdrawals for agriculture and consumptive human uses makes individual Purple Lilliput more susceptible to drought (which can expose aquatic habitat, isolate mussels during sperm and juvenile mussel dispersal, increase predation, and concentrate contaminants), more susceptible to temperature increases, and, in extreme situations, can impede the delivery of sufficient dissolved oxygen. Lower water levels and discharge also foster the concentration of contaminants.

Water quality declines are evident due to untreated or poorly treated wastewater discharges, development, resource extraction, and high risk of contaminant spills (e.g., Upper Green, Flatrock-Haw, Driftwood MUs). Habitat degradation continues due to development and extensive agriculture in riparian areas. Streamside development and agriculture causes sedimentation that fills in the interstitial spaces needed by juvenile mussels and host fish eggs. Habitat fragmentation, where there are dams both upstream and downstream of Purple Lilliput populations within MUs, may limit the mussel's access to suitable habitat and isolate individuals, which in turn limits the amount of genetic exchange. This habitat degradation has the potential to affect individuals initially, but over time, results in impacts to entire MUs as the habitat is no longer suitable to meet the mussel's resource needs.

Nonnative species, such as Asian Clam, Zebra Mussel, and Quagga Mussel begin to negatively influence MUs basin-wide. Asian Clam abundance and distribution is widespread within the range of the species and competes for food and nutrients needed for mussel growth and development. Black Carp are predators on mussels, and competition for space and resources from Asian Clams, Zebra Mussels, and Quagga Mussels result in reduced fitness of Purple

Lilliput in the lower Ohio River basin MUs, such as the Lower Ohio Bay and Upper East Fork White MUs.

Cumberland River basin

Water quality degradation from agriculture and resource extraction continues in the Cumberland River basin, which harbors MUs that are confined to small streams and rivers. Habitat and water quality impacts from agriculture and oil and gas drilling continue to affect these MUs (Ahlstedt *et al.* 2014, p. 15). High levels of stream conductivity, and general limited habitat availability due to the prevalence of bedrock substrates limit colonization potential and species expansion in Obey, South Fork Cumberland MUs (Moles *et al.* 2007, p. 81; Hitt *et al.* 2016, p. 55). Large hydropower, flood control, and water supply impoundments in the Caney Fork, Old Hickory Dam, and Cordell Hull MUs cause substantial fragmentation and isolation within the Cumberland basin, and lack of connectivity affects host fish colonization and expansion opportunities.

Tennessee River basin

Small to moderate reductions in water discharge occur due to drought and agricultural and resource extraction activities in small streams and rivers, resulting in habitat loss through increased sedimentation and siltation, which covers substrates used for settlement. Wastewater and runoff from land use activities have increased concentrations of contaminants such as ammonia and chlorine. Discharge reductions and water extraction activities also result in periodic loss of connectivity the Emory, Upper Elk, Upper Duck, Buffalo, and Bear MUs. Impacts from periodic loss of connectivity can be exacerbated if they occur during reproductively active periods or juvenile mussel dispersal (limiting distribution in the stream).

Water quality declines are evident in large rivers and reservoirs due to untreated or poorly treated wastewater discharges, resource extraction, and high risk of contaminant spills, affecting the Guntersville Lake, Wheeler, Lake, Pickwick Lake MUs, which are mainstem Tennessee River reservoirs created by dams. Habitat degradation continues due to development and extensive agriculture in riparian areas. This degradation results in direct habitat loss, increased sediment that fills substrate spaces required for juvenile mussel development and host fish eggs, and excessive storm water flows that erode substrate habitat. MUs isolated by smaller impoundments (such as mill dams), and larger hydropower, flood control, and water supply reservoirs limit genetic exchange; nonnative species (such as Asian Clam) continue to impact the Upper Elk and Upper Duck MUs through competitive interactions for food and nutrients.

Arkansas-White-Red basin

Water quality declines are evident in MUs currently identified as medium condition due to untreated or poorly treated wastewater discharges, development, resource extraction, and high risk of contaminant spills (e.g., James, North Fork White, Eleven Point, Spring, South Fork Spring MUs). The pervasive impacts of water quality degradation can affect these entire MUs.

Habitat degradation continues in large-river MUs due to development, navigational impacts such as dredging and increases in river commerce traffic, and extensive agriculture in riparian areas. In the Spring River, streamside development and agriculture causes sedimentation that fills in the interstitial spaces needed by juvenile mussels and host fish eggs. This habitat degradation has the potential to affect individuals initially, but over time, results in impacts to MUs.

Nonnative species, such as Asian Clam and Zebra Mussel, continue to negatively influence MUs basin-wide. Asian Clam abundance and distribution is widespread within the range of the species and competes for food and nutrients needed for mussel growth and development. Competition for space and resources from Zebra and Quagga Mussels result in reduced fitness of Purple Lilliput in the Arkansas and White River basin.

Habitat fragmentation is a common issue for many of the populations in the Arkansas-White-Red River basin. Large impoundments on the Arkansas, White, and Little Red Rivers, where there are dams both upstream and downstream of Purple Lilliput MUs, limit the mussel’s access to suitable habitat and contributes to isolation, which in turn limits the amount of genetic exchange.

Lower Mississippi River basin

Habitat alteration occurs in this basin through channelization, bank erosion, widened channels, uniform flows, unstable sediments, and meander cutoffs; this threat continues as the greatest threat to the Purple Lilliput in this basin. Agricultural impacts and human development have led to high levels of suspended solids, ammonia, and other contaminants degrading water quality and habitat.

Nonnative species, such as Asian Clam and Black Carp, continue to negatively influence MUs basin-wide. Asian Clam abundance and distribution is widespread within the range of the species and competes for food and nutrients needed for mussel growth and development. Black Carp are predators on mussels and recent collections of juveniles have been collected in ditches along the Castor River Diversion Channel in the Little River Ditches and Whitewater MUs.

Habitat fragmentation is a common issue for many of the Purple Lilliput MUs in the Lower Mississippi River basin. Impoundments on the Ouachita, St. Francis, and Caddo Rivers, where there are dams both upstream and downstream of Purple Lilliput MUs, may limit the mussel’s access to suitable habitat contributes to isolation, which in turn limits the amount of genetic exchange.

7.3.1 Resiliency

Under Scenario 1, factors currently influencing Purple Lilliput MUs remain constant into the future. In total, 9 of 65 Purple Lilliput MUs (14 percent) deteriorate in resiliency. In contrast, 56 MUs (86 percent) maintain resiliency over time as some existing regulatory and voluntary conservation measures continue to be implemented to counteract existing threats. Notably, the Upper Green MU is able to maintain its high resiliency under this scenario, largely due to the removal of Lock and Dam 6 and the potential for additional dam removals on the Green River.

However, the effect of current levels of river and MU fragmentation, sedimentation, oil and gas exploration, and increases in numbers and individuals of nonnative species continue to result in habitat loss, water quality degradation, and competition for food resources and suitable substrates, which leads to reduced recruitment and lowered mussel abundance and survival. Genetic isolation, caused by habitat fragmentation and distance between MUs, remains a concern, especially in the Great Lakes and Cumberland basins. Improvements in dissolved oxygen and reduction of hypolimnetic flow releases from hydropower dams continue to aid Upper Elk, Upper Duck, and Pickwick MUs.

Under this scenario, the Purple Lilliput is potentially extirpated (very low condition) from the Indian, Upper Cumberland-Lake Cumberland, Rockcastle, Clinch and Blanchard MUs. It is also potentially extirpated (very low condition) from Coon Creek, Ouachita River, and South Fork Saline Rivers; however, other populations remain in the MUs, so the species is expected to persist at the MU level. Two populations and MUs in the Ohio River basin are extirpated. A total of 5 MUs (8 percent) are estimated to decline to very low condition and may be extirpated under this scenario. We estimate that 6 out of the remaining 60 MUs (10 percent) would be in high condition, 22 MUs (37 percent) in medium condition, and 32 MUs (53 percent) in low condition (Figure 7-1).

7.3.2 Representation

The Purple Lilliput generally retains representation over time, although 32 of the remaining 60 MUs (53 percent) would be in low condition; a total of 28 MUs (47 percent) would remain in high or medium condition. The high and medium condition MUs under this scenario (*e.g.*, Beaver Reservoir, Wheeler Lake, James, Buffalo, Upper Saline, Upper St. Francis, Upper Duck, Lower Tennessee, Obey, Upper Green and Tippecanoe) would maintain representation in the Ohio, Cumberland, Tennessee, Arkansas-White-Red, and lower Mississippi River basins. All of the basins in which the species currently occurs would remain occupied. However, the loss of the Blanchard River MU within the Great Lakes basin, results in extirpation from the State of Ohio.

7.3.3 Redundancy

Under Scenario 1, redundancy for the Purple Lilliput is reduced from current conditions. The loss of the species from Indian, Upper Cumberland-Lake Cumberland, Rockcastle, Clinch, and Blanchard MUs; as well as Coon Creek, Ouachita River, and South Fork Saline River populations contributes to a loss in redundancy from the Great Lakes, Cumberland, Tennessee, Arkansas-White-Red, and lower Mississippi River basins. The best available information suggests that 5 of 65 MUs (8 percent) are likely in very low condition and extirpated. The 32 low condition MUs (53 percent) increases the species vulnerability (potentially beyond the 20- to 30-year time frame) in the Great Lakes, Ohio, Cumberland, Tennessee, Arkansas-White-Red, and lower Mississippi River basins.

7.4 Scenario 2

Under this scenario, factors that negatively influence most of the extant populations and MUs are reduced by additional conservation, beyond the continued implementation of existing regulatory or voluntary conservation actions.

Conservation measures may include: implementation of additional BMPs, increased environmental regulations or enforcement of existing regulation improvements in aquatic connectivity, and active species management, such as captive propagation or translocation efforts using brood stock from all three basins. Under Scenario 2, there is an optimistic species response to the factors influencing mussel viability, and conservation measures are implemented for targeted translocation, propagation, or augmentation. Additionally, restoration efforts using existing resources and capacity are successful, and monitoring costs decrease. See Figure 7-2, below, for MU conditions under Scenario 2.

Scenario 2 presumes all MUs are able to maintain or improve their current condition. This scenario assumes some reintroductions to currently unoccupied historical range or potential augmentation to populations or MUs experiencing reduced resource needs, or with limited capability to expand their range due to impoundments. Areas receiving added conservation are those that would have the greatest chance of becoming resilient in the future, potentially occurring in areas that are most likely to have land owners (such as the Service, National Park Service, and Forest Service) that would maintain and improve habitat quality.

This scenario assumes the pattern of urban growth would continue to increase to differing degrees across the species' range (Lawler *et al.* 2014, p. 56). Increased urban growth often reduces the amount of land available for agriculture (Newton *et al.* 2008, p. 434; Terando *et al.* 2014, p. 4; Lasier *et al.* 2016, p. 672). This scenario (similar to Scenario 1) also assumes that existing regulatory mechanisms and voluntary conservation measures that are indirectly benefiting the species would remain in place. However, the difference from Scenario 1 is that additional conservation is implemented across the Purple Lilliput's range to benefit the long-term conservation of the species.

Scenario 2 assumes some actions of positive intervention are thoughtfully designed and executed as feasible and appropriate conservation plans. Such plans may be implemented by a combination of Federal, state, and local governments, including river authorities, municipalities, and other "water regulators" along with non-governmental organization (NGO) conservation groups, private landowners, and other stakeholders informed by biologists with expertise in the conservation of freshwater mussels and their habitats. Also, increased enforcement of environmental regulations helps address contamination issues, and mitigation of resources lost due to impacts provides opportunities for conservation funds, such as translocation or propagation activities.

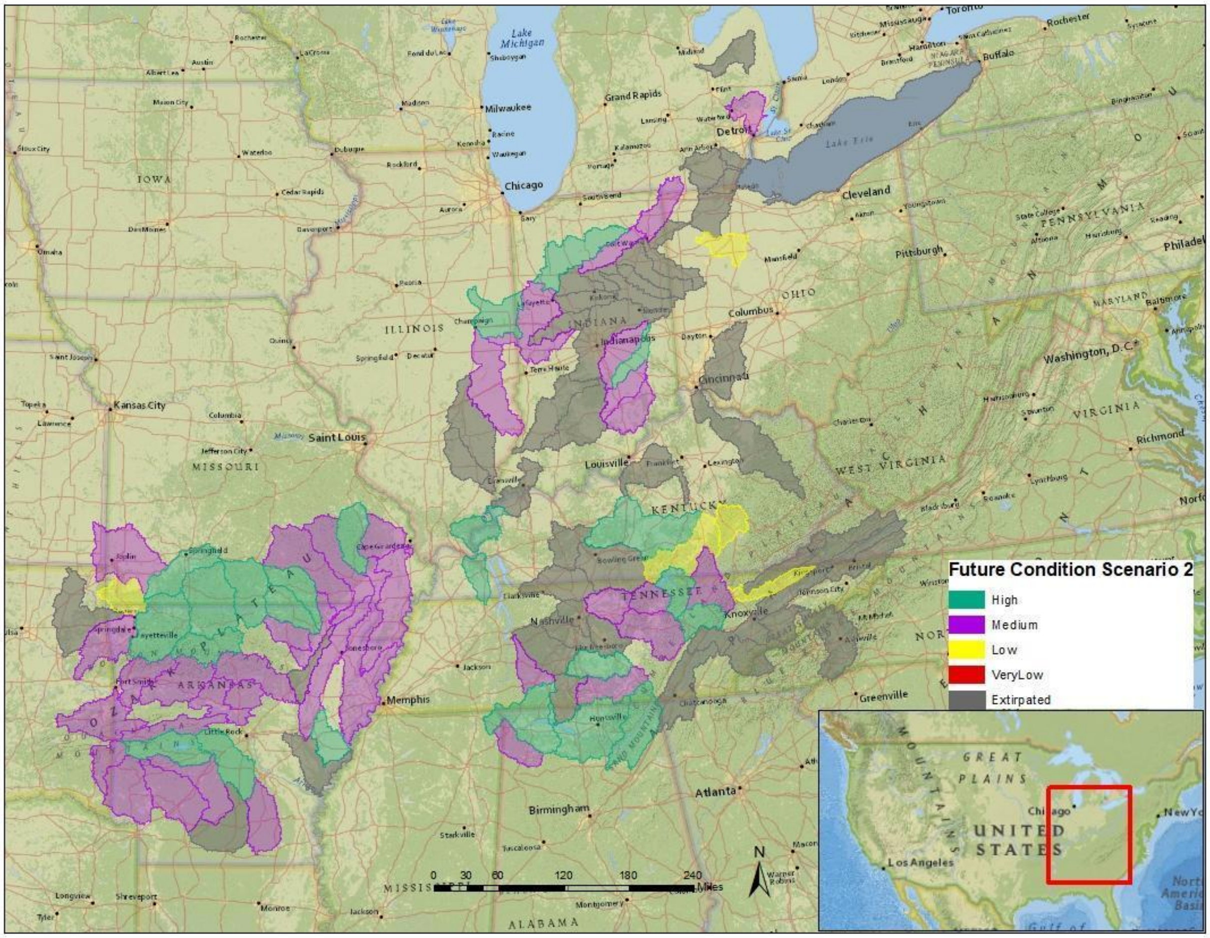

Figure 7-2. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC8s) of Purple Lilliput under Future Condition Scenario 2. Currently occupied MUs are represented with very low (i.e., no survival or survival uncertain; no longer observable), low, medium, and high condition categories (as described in Chapter 7; Service 2018, unpublished data).

Great Lakes basin

Studies are conducted on nonnative species, such as Asian Clam, Zebra Mussel, and Quagga Mussel, its interactions with native unionids that lead to better understanding of how to reduce the effects of their spread basin-wide, thereby reducing competition for food and nutrients in mussel beds.

Negative changes in physical habitat features due to increasing urbanization, contaminants, and agricultural practices in the Blanchard and Clinton Rivers are lessened through education and outreach initiatives. Watershed partnerships are better funded through EPA grants or other available funding sources, which increases riparian buffer restoration opportunities and resource awareness. Water quality improvements are made in highly developed areas, such as the Clinton River MU, due to improved treatment of wastewater discharges.

Within the Great Lakes basin, the natural hydrograph in Blanchard and Clinton MUs, and the existing water levels in the St. Joseph MU (Lake Wilson) are maintained to the maximum extent possible, making individuals less susceptible to drought and temperature increases, as well as providing sustained delivery of sufficient dissolved oxygen and nutrients. Some increase in replication to other glacial lakes in the Great Lakes basin is possible due to the discovery of additional populations, MUs, or translocation into appropriate habitats.

Ohio River basin

Seasonally variable water levels are maintained in tributaries to the maximum extent possible, and improvements in physical habitat are achieved due to environmental outreach and awareness, which reduces water quality degradation. The Purple Lilliput is able to withstand impacts from climate change, such as prolonged drought or flooding, due to increases in the abundance of individuals in small streams. Opportunities for improvements in habitat connectivity are achieved through barrier removal, allowing for range expansion. Improvements in connectivity benefit periodically isolated small stream and river MUs to larger river MUs that the species formerly occupied such as in the White, Wabash and Vermilion Rivers in the Ohio Basin (e.g., Upper East Fork White and Vermilion MUs).

Water quality improves due to better treatment of wastewater discharges, especially in rural areas. Targeted programs are developed and implemented to improve water quality through BMPs concerning agricultural practices and development, and measurable success is achieved. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.), are monitored and enforcement of violations is conducted in a timely manner, potentially reducing long-term issues. Risks of MU loss due to contaminant spills is lessened through improved connectivity and presence of non-linear MUs.

Habitat degradation due to development and extensive agriculture in riparian areas is mitigated through using existing funds or establishment of conservation funds for Purple Lilliput species restoration initiatives. The costs of monitoring large river MUs decrease due to advances in technology, leading to better annual estimates of mussel bed distribution (for instance, environmental deoxyribonucleic acid (eDNA), or sonar exploration of river beds and mussel habitat), and areas that can be targeted for survey efforts. These advances potentially lead to the recovery, downstream dispersal, or rediscovery of populations or MUs where the species is currently considered extirpated (e.g., Barren, Little Miami, Salamonie, Mississinewa, Upper and Lower White MUs [Appendix B]).

Studies are conducted on nonnative species (Asian Clam, Zebra Mussel, Quagga Mussel) that leads to better understanding of how to reduce the impacts of their spread basin-wide, thereby decreasing competition for food and nutrients in mussel beds.

Cumberland River basin

Habitat degradation due to resource extraction, increased development, and extensive agriculture in the Cumberland River basin is curtailed. MUs throughout this basin are currently confined to small streams and rivers but formerly occurred in large rivers such as the Cumberland River, which in turn facilitated dispersal into larger tributaries. Examples from Kentucky and Tennessee are the Rockcastle, Red, Harpeth, and Caney Fork MUs (Appendix A). Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are regulated, monitored, and enforcement of violations are conducted in a timely manner, potentially reducing long-term contamination issues.

Habitat impacts, fragmentation, and water quality degradation is mitigated through existing funds or establishment of conservation funds to offset human development impacts resulting from agricultural and mining activities, which can be used for Purple Lilliput species restoration initiatives and thus enable propagation or translocation of Cumberland River basin Purple Lilliput brood stock for stocking into appropriate habitat within its formerly occupied range.

Additional restoration efforts could address sediment and erosion problems in order to increase the amount of available habitat for stocking in the Cumberland River basin. The Purple Lilliput can be reintroduced into former portions of its range in the Cumberland River basin through successful captive propagation efforts and partnerships, and additional resources are exerted to target Cumberland River basin survey efforts in portions of the species former range.

Tennessee River basin

Similar to the Ohio River basin, water levels and suitable aquatic habitats are maintained in tributary populations to the maximum extent possible, and improvements in physical habitat are achieved due to environmental outreach and awareness. The species is able to withstand minor impacts from climate change such as prolonged drought or flooding. Opportunities for improvements in habitat connectivity are achieved, allowing for increases in abundance and Purple Lilliput expansion, connecting stream and small river MUs to medium and large river MUs. Population restoration/augmentation is possible in the Emory, Upper Elk, Upper Duck, Buffalo, and Bear MUs.

Water quality improves in reservoir MUs in the Tennessee River (Guntersville, Wheeler, Wilson MUs) due to better treatment of wastewater discharges, similar to the Ohio River basin, especially in rural areas. Education and outreach initiatives are better funded through partnerships, which improves riparian buffer restoration on river banks where substantial erosion of fine sediments, which affects resource needs for the Purple Lilliput, is currently occurring. Targeted programs are developed to improve water quality through agricultural and human development BMPs. Impacts from resource extraction activities such as water withdrawal, stream contamination, and deposition of fine sediment, are regulated, monitored, and enforcement of violations are conducted in a timely manner, potentially reducing long-term contamination issues.

Studies are conducted on the nonnative Asian Clam and its interactions with native unionids. This research would lead to better understanding of how to reduce the effects of the Asian Clam spread basin-wide, thereby reducing competition for food and nutrients in mussel beds (similar to the Ohio and Cumberland River basins).

Arkansas-White-Red basin

Similar to the other basins, water quality improves in large river populations (Spring and White River MUs) due to better treatment of wastewater discharges, especially in rural areas. Education and outreach initiatives are better funded through partnerships, which improves riparian buffer restoration on river banks where erosion is occurring. Targeted programs are developed to improve water quality through agricultural and development BMPs.

Habitat degradation due to resource extraction, development, and extensive agriculture in riparian areas is mitigated through using existing funds or establishment of conservation funds for Purple Lilliput species restoration initiatives. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are regulated, monitored, and enforcement of violations are conducted in a timely manner, potentially reducing long-term contamination issues.

The costs of monitoring large river mussel MUs decrease due to advances in technology, leading to better annual estimates of mussel bed distribution (for instance, eDNA, or sonar exploration of river beds and mussel habitat), and areas that can be targeted for survey efforts. Opportunities for improvements in habitat connectivity are achieved, allowing for increases in abundance and Purple Lilliput expansion, connecting stream and small river MUs to medium and large river MUs. Population restoration/augmentation is possible in the Spring, Upper Black, Illinois Poteau, and Strawberry MUs.

Studies are conducted on Asian Clam and its interactions with native unionids that lead to better understanding of how to reduce the effects of their spread basin-wide, thereby reducing competition for food and nutrients in mussel beds (similar to the Ohio and Cumberland River basins).

Mississippi River basin

Water quality improves due to better treatment of wastewater discharges, especially in rural areas. Targeted programs are developed to improve water quality through agricultural and development BMPs. Impacts from agricultural activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are regulated, monitored, and enforcement of violations are conducted in a timely manner, potentially reducing long-term contamination issues. Risks of MU loss from contaminant spills (resulting in suboptimal water quality conditions) are lessened through the presence of non-linear MUs, and potential expansion into formerly occupied tributaries within MUs or adjacent MUs.

Habitat impacts, fragmentation, and water quality degradation is mitigated through existing funds or establishment of conservation funds to offset agricultural and mining impacts, which can be used for Purple Lilliput species restoration initiatives. These initiatives would enable propagation or translocation of Mississippi River basin Purple Lilliput brood stock for stocking into appropriate habitat within its formerly occupied range.

Additional restoration efforts could address sediment and erosion problems in order to increase the amount of available habitat for stocking in the Mississippi River basin. The Purple Lilliput can be reintroduced into former portions of its range in the Mississippi River drainage through successful captive propagation efforts and partnerships, and additional resources are exerted to target Mississippi River basin survey efforts in portions of the species former range.

Improved management of nonnative species such as Asian Clam is implemented and studies are conducted that lead to a better understanding of how to reduce the effects of their spread basin-wide, thereby reducing the risk of predation, and decreasing competition for food and nutrients in mussel beds (similar to the Ohio, Tennessee, and Arkansas-White-Red River basins).

7.4.1 Resiliency

Under Scenario 2, factors that negatively influence most of the extant MUs are reduced by additional conservation. There is an improvement in resiliency from current condition (positive change in condition category) for 38 of 65 (58 percent) of the Purple Lilliput MUs. The other 27 MUs (42 percent) maintain resiliency over time as regulatory and voluntary conservation measures continue to be implemented and increase, counteracting existing threats. The effects of current levels of river and stream fragmentation, sedimentation, and wastewater discharges are reduced, resulting in: increased suitable habitat conditions and connectivity within MUs, protection of suitable substrates, and improved non-point source water treatment for maintenance of water quality standards. These overall improved conditions lead to improved recruitment and increased mussel abundance and survival.

Programs targeted to improve water quality through agricultural and development BMPs are developed and implemented. Impacts from resource extraction activities, such as gas extraction and coal mining, are monitored and violations are enforced in a timely manner, potentially reducing long-term contamination issues. Under this scenario, which is considered to be highly optimistic based on the current level of threats, none of the currently 65 extant MUs are likely to become extirpated. However, it is important to keep in mind that some of the [current] low current condition MUs may already be not viable, especially those that are restricted by impoundments both upstream and downstream. Improvements to MUs result in non-linear distributions, which improves resilience to stochastic events. Under Scenario 2, we estimate that 23 out of 65 MUs (35 percent) would be in high condition, 42 (65 percent) in medium condition, and none in low condition (noting that none in low condition is likely overly optimistic). There are also no very low condition populations. The Purple Lilliput would remain extant in all basins and MUs where it currently exists (Figure 7-2).

7.4.2 Representation

The Purple Lilliput retains representation over time, with 65 high and medium MUs maintained among all six currently occupied basins (Great Lakes, Ohio, Cumberland, Tennessee, Arkansas-White-Red, and lower Mississippi). Representation could potentially increase within the Cumberland basin through propagation efforts into the South Fork Cumberland MU or other suitable locations. Populations within MUs across the species range under this scenario are not linearly distributed, and natural or human-assisted improvements in MU and habitat connectivity reduce the risk of genetic isolation. Regardless, it is possible the Purple Lilliput could potentially still decline in portions of its range, especially in the Great Lakes basin, due to loss of individuals from the concentration of competition and factors that spread non-native species.

7.4.3 Redundancy

The Purple Lilliput maintains and potentially improves redundancy. The best available information suggests that no populations become extirpated under Scenario 2. Natural or human-assisted population expansion into portions of its formerly occupied range occurs in all six basins. If Purple Lilliput densities within currently occupied basins are suitable, expanded distribution is achieved due to within-basin augmentation through translocation around barriers. This is potentially accomplished through augmentation, within-basin reintroductions and improved conservation, including in the Great Lakes and Cumberland River basins, which currently have low redundancy.

7.5 Scenario 3

Under this scenario, factors that influence the current extant populations and MUs of Purple Lilliput are likely to become worse from the implementation of known existing and projected development, resource extraction, hydroelectric projects, etc. Additional risks to the species and its habitat (e.g., climate change) are more challenging to predict with accuracy at this time.

In general, this scenario assumes that all existing threats and associated sources of threats are worse in the future, leading to reductions in water quality in those areas that are already poor and increased habitat degradation of areas that are not fully supporting resource needs (i.e., appropriate food, nutrients, and water quality condition) for aquatic life. The abundance and distribution of host fishes decline. Climate conditions such as sustained droughts and flooding may result in desiccation, scour, and increased sedimentation and deposition in high quality mussel habitats. This scenario assumes that existing regulatory mechanisms and voluntary conservation measures that are benefiting the species would remain in place, although funding and staffing constraints likely prohibit additional protections (see Figure 7-3).

Under Scenario 3, the Purple Lilliput's response to multiple impacts acting synergistically on the landscape result in declines coupled with limited propagation capacity or limited capacity for reintroductions or augmentations. Monitoring capabilities also decrease due to cost and time. In general, this scenario considers a future where conditions are worse for the species across its entire range compared to current conditions (Chapter 5) and Scenario 1. In this scenario, there is some reduction or negative effects to all of the species' resource and demographic needs (clean water reduction, decline in water quality, reduced connectivity between populations, etc.), but not necessarily significant or "worst case scenario" in those MUs where substantial impacts would be unlikely.

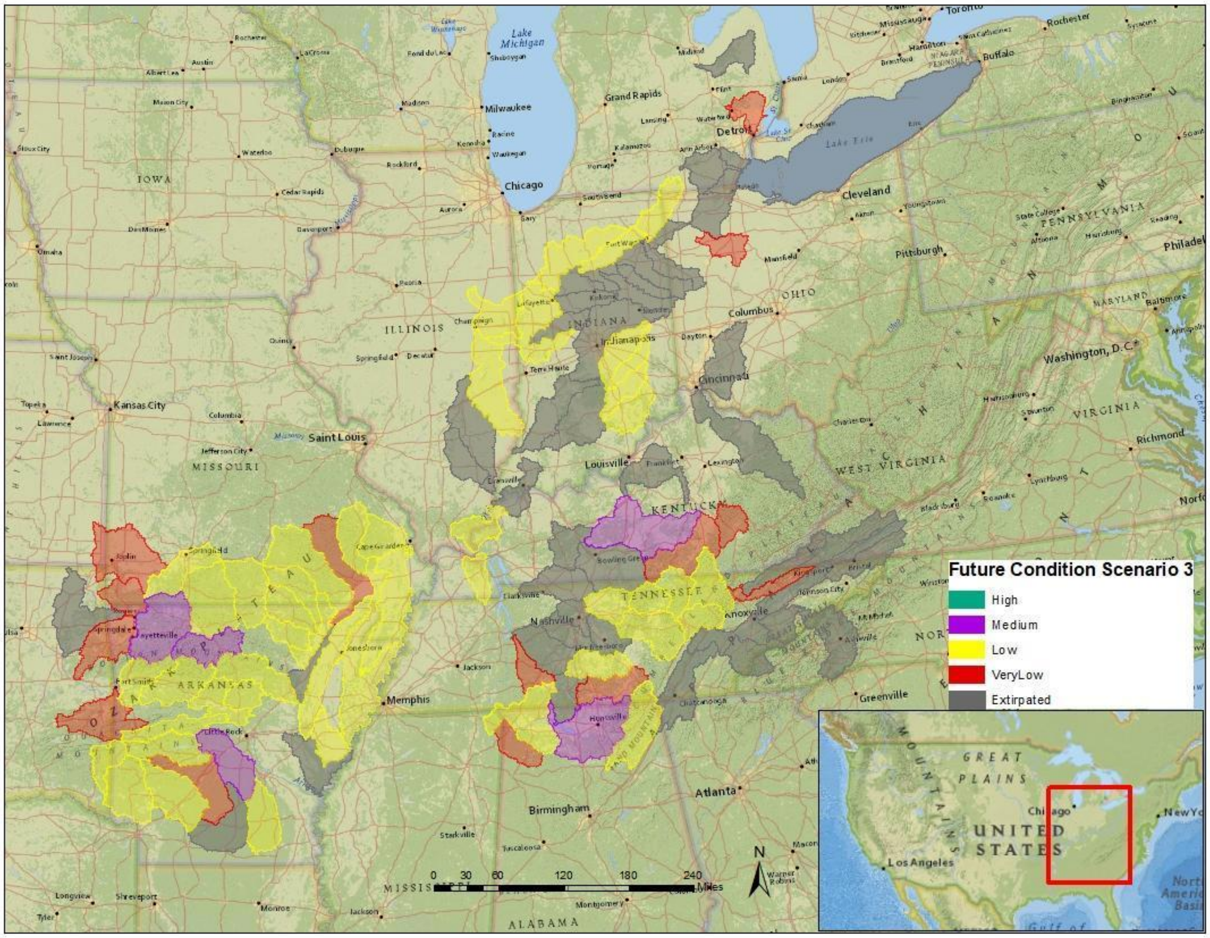

Figure 7-3. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC8s) of Purple Lilliput under Future Condition Scenario 3. Currently occupied MUs are represented with very low (i.e., no survival or survival uncertain; no longer observable), low, medium, and high condition categories (as described in Chapter 7; Service 2018, unpublished data).

Great Lakes

Nonnative species, such as Asian Clam, Zebra Mussel, and Quagga Mussel, continue to negatively influence Purple Lilliput basin-wide. Zebra Mussels are well established in Lake Erie, to which the Blanchard, Clinton, and St. Joseph River MUs drain. Zebra Mussels are able to spread from currently occupied glacial lakes to others, including Lake Wilson, which harbors the last Purple Lilliput population in the St. Joseph MU. The expansion of Zebra Mussel limits recovery potential in other lakes. Asian Clam abundance and distribution increases and results in increased competition for food and nutrients needed for Purple Lilliput growth and development.

Dramatic reduction in clean water and water levels occur through agricultural practices and human development pressures, taxing groundwater aquifers, and making individuals more susceptible to drought, which can expose aquatic habitat, isolate mussels during sperm and juvenile mussel dispersal, increase predation, and concentrate contaminants. These conditions also make individuals more susceptible to temperature increases, and impedes the delivery of sufficient dissolved oxygen. The possibility for construction of more small impoundments for water supply or irrigation further lowers water levels, alters the natural hydrograph, and results in increased isolation, concentration of contaminants, increasing the likelihood of a single stochastic event negatively affecting a MU.

The pervasive impacts of water quality and quantity degradation affect the three remaining MUs, which are linear or confined to a small lake (Lake Wilson), small in extent, and low density. Loss of physical habitat features due to increasing urbanization, contaminants, and agricultural practices in the Blanchard and Clinton MUs results in the extirpation of these populations. Consequently, this results in extirpation of the species from the State of Ohio and increases the isolation of the last remaining population in the Great Lakes basin (i.e., Lake Wilson, St. Joseph MU).

Ohio River basin

Reductions in water discharge in tributaries lead to alterations in seasonally variable water levels and changes to the physical habitat requirements of the species (i.e., reduced frequency of events that help keep clean-swept substrates). Consequently, these changes lead to reduced connectivity and Purple Lilliput recruitment, which affects MUs in small streams and rivers. The species may struggle to adapt to prolonged drought or periodic flooding, which results in desiccation, scour, and increased sedimentation and deposition in shoal and shoreline habitats occupied by the Purple Lilliput. Habitat fragmentation increases, reducing connectivity more than what would occur under Scenario 1, further reducing opportunities for Purple Lilliput expansion.

If all MUs containing small streams and rivers persist, they become more restricted and genetically isolated from medium and large river MUs, such as in the Tippecanoe, Eel, Muscatatuck, and Vermilion MUs. Additionally, population restoration through augmentation is not possible or extremely difficult and costly due to lack of sufficient available brood stock.

Water quality deteriorates due to lack of treatment of wastewater discharges, especially in rural areas; however, the degree of water quality decline is substantially worse than that experienced under Scenario 1. There is little to no water quality improvement through BMPs concerning agricultural practices and development. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are exacerbated by increased localized concentrations of row-crop agriculture, abandoned mines and oil and gas exploration, increasing long-term water contamination issues that influence the survival of the Purple Lilliput. Risks of MU losses due to contaminant spills are increased compared to Scenario 1 through the presence of linear populations within MUs (e.g., Upper Green, Flatrock-Haw, Lower Ohio Bay, and Upper East Fork White MUs).

Habitat degradation continues and becomes worse due to human population growth and associated land-use changes. There is an increase in the extent of habitat degradation in riparian areas due to increased agricultural activities without adequate BMPs. The costs of monitoring increases, reducing the capabilities of gathering annual estimates of species abundance and distribution. Nonnative species such as Asian Clam, Zebra Mussel, Quagga Mussel, and Black

Carp spread significantly across the basin, invading new streams and rivers within the Purple Lilliput's range, and increasing competition for Purple Lilliput resource needs and predation on the species.

Cumberland River basin

Habitat degradation becomes worse in the Cumberland River basin due to development, increased concentrated agricultural activities, and resource extraction intensity. Habitat fragmentation increases through the construction of farm ponds, which alters hydrology, concentrates contaminants, and also lowers the water table. This results in additional sedimentation and water contamination, and increased isolation of populations due to lack of available physical habitat, impoundment, and water quality impacts (Caney Fork, Old Hickory Dam, and Cordell Hull MUs).

Due to such small and isolated individuals, recruitment failure is possible, and as a result of predominantly linear occurrence, the risk of stochastic events is exacerbated in the Obey, South Fork Cumberland, Rockcastle, Upper Cumberland-Lake Cumberland MUs. Nonnative species, such as Asian Clam, increase competition for Purple Lilliput resource needs within appropriate mussel habitat.

Tennessee River basin

Decreases in seasonal discharge variability occurs in small streams and rivers, leading to alterations in the natural flow regime and changes in physical habitat, which results in reduced connectivity of aquatic habitat and, in turn, Purple Lilliput recruitment. Due to small population sizes within MUs, the species is unable to withstand minor impacts from drought or periodic flooding, which result in desiccation, scour, and increased sedimentation and deposition in shoal and shoreline habitats occupied by the Purple Lilliput. Habitat fragmentation increases significantly compared to current conditions and Scenario 1, reducing connectivity and opportunities for Purple Lilliput expansion. Stream and small river MUs; such as the Emory, Upper Elk, Upper Duck, Buffalo, Bear, become more restricted and genetically isolated from Guntersville Lake, Wheeler Lake, and Pickwick Lake large river and reservoir MUs.

Water quality deteriorates due to untreated wastewater discharges, especially in rural areas. There is no initiative to improve water quality through BMPs concerning agricultural practices and human population growth and development. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are exacerbated by greater localized concentrations of abandoned mines, increasing long-term water contamination issues that have an influence on the survival of the Purple Lilliput (e.g., Upper Clinch MU).

Water temperature effects below hydropower dams are exacerbated by climatic changes in rainfall. The lack of consistent seasonal rainfall (*e.g.*, drought) reduces river discharge into upstream reservoirs, resulting in alteration of seasonal dam release schedules by the Tennessee Valley Authority (TVA), which no longer provides water quality improvement strategies in the Upper Duck, Upper Elk, Pickwick, and Bear MUs. Risks of contaminant spills remain high and elevate the likelihood of water quality contamination and direct effects to mussels due to the presence of only linear MUs.

Habitat degradation continues and becomes worse in large river MUs due to human population growth, sedimentation, and navigational impacts such as dredging and increases in river commerce traffic. Activities that formerly only affected individuals or populations, such as barge traffic and fleeting, are now negatively influencing entire MUs, due to increasing rarity of the species. There is an increase in the magnitude of agricultural activities in riparian areas to accommodate population growth. This results in loss of appropriate habitat patches and habitat heterogeneity, which increases the likelihood of Purple Lilliput isolation and extirpation from large rivers. The cost of monitoring mussels in large river MUs increases due to reductions in staffing of agency partners and reliance on private industry for data and survey information, reducing the capabilities of gathering annual estimates of species abundance and distribution in the Tennessee River (e.g., Guntersville Lake, Wheeler, Lake, Pickwick Lake MUs).

Nonnative species (such as Asian Clam, Zebra Mussel, Quagga Mussel, and Black Carp) spread throughout the basin, invading new streams and rivers within the Purple Lilliput range and increasing competition for Purple Lilliput resource needs and predation on the species.

Arkansas-White-Red

Water quality deteriorates due to untreated wastewater discharges, especially in rural areas. There is no initiative to improve water quality through BMPs concerning agricultural practices and human population growth and development. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are exacerbated by greater localized concentrations of abandoned mines, increasing long-term water contamination issues that have an influence on the survival of the Purple Lilliput (e.g., Spring River MU).

Habitat fragmentation is a common issue for many of the Arkansas-White-Red River basin MUs and it continues to worsen due to human development and agricultural stressors. More impoundments limit the mussel's access to suitable habitat and isolate MUs, which in turn limits the amount of genetic exchange.

Habitat degradation continues in large-river MUs due to development, navigational impacts such as dredging and increases in river commerce traffic, and extensive agriculture in riparian areas. In the Spring River MU in Arkansas, streamside development and agriculture causes sedimentation that fills in the interstitial spaces needed by juvenile mussels and host fish eggs. This habitat degradation negatively impacts entire MUs. Nonnative species (such as Asian Clam, Zebra Mussel, and Quagga Mussel) continue to negatively influence populations basin-wide. Asian Clam abundances and distribution increases and results in increased competition for food and nutrients needed for Purple Lilliput growth and development. Black Carp expand and increase the potential for concentration of predators in large river MUs (e.g., Current River, Dardanelle Reservoir MU).

Lower Mississippi

Habitat alteration occurs in this basin through channelization, bank erosion, widened channels, unstable sediments, and meander cutoffs; this threat continues as the greatest threat to the species and remaining populations in this basin. These impacts are exacerbated and occur at a much more rapid rate than under Scenario 1, with no opportunity for education, outreach, or restoration initiatives. Water quality degradation through high levels of suspended solids continues, which affects respiration and smothers invertebrates, and resulting in direct mortality of Purple Lilliput in this basin.

Habitat fragmentation is a common issue for many of the MUs in the Lower Mississippi River basin and it continues to worsen under this scenario. More impoundments, constructed predominantly for agricultural uses, limit the mussel's access to suitable habitat and isolate more populations, which in turn limits the amount of genetic exchange between MUs. There is an increase in the magnitude of agricultural activities in riparian areas to accommodate human population growth. This results in loss of appropriate habitat patches and habitat heterogeneity, which increases the likelihood of Purple Lilliput isolation from large rivers.

Nonnative species (such as Asian Clam, Zebra Mussel, Quagga Mussel, and Black Carp) continue to negatively influence MUs across the basin. Asian Clam abundances and distribution increases and results in increased competition for food and nutrients needed for Purple Lilliput growth and development. Black Carp spread from currently occupied large river MUs into tributaries throughout the basin, increasing predation on the Purple Lilliput (e.g., Upper Saline, Lower Saline, Lower St. Francis, and Upper St. Francis MUs).

7.5.1 Resiliency

Under Scenario 3, where conditions become worse, 13 of 65 (20 percent) of the Purple Lilliput MUs deteriorate in resiliency (negative change in condition category from current condition). Despite these reductions, as many as 6 MUs remain in medium condition, and 46 MUs (71 percent) maintain some low resiliency over time. Despite substantial impacts, 44 percent of remaining MUs are expected to be in medium or low condition, and the Purple Lilliput exhibits lowered resiliency, but continued persistence, across 5 of the 6 basins in which it currently occurs (Ohio, Cumberland, Tennessee, Arkansas-White-Red, and Lower Mississippi). Under this Scenario, the Great Lakes basin is the most imperiled, and only one severely isolated MU, the St. Joseph (Lake Wilson), remains.

Current threats continue along with elevated (compared to Scenario 1) impacts to MUs from changing climate conditions. Significant changes may not be observed at first due to continued implementation of existing regulatory and voluntary conservation measures that help reduce (but not eliminate) habitat and water quality degradation. Increased levels of river and stream fragmentation through isolation and sedimentation result in degraded habitat and connectivity within MUs, and deposition of fine sediments into suitable substrates. The magnitude and scale of wastewater discharges and oil and gas exploration result in lack of non-point source water treatment, which leads to recruitment failure and decreased mussel abundance and survival.

Targeted programs to improve water quality through BMPs concerning agricultural practices and anthropogenic land uses are not developed. There is an increase of impacts from resource extraction activities, such as oil and gas drilling in the Ohio and Cumberland basins, which contributes to long-term water contamination issues. Decreases in dissolved oxygen and changes to thermal regimes such as the increased potential of hypolimnetic flow releases from dams suppress populations in some rivers previously negatively affected in the Tennessee basin (e.g., Upper Elk, Upper Duck, and Bear MUs).

Regardless of ongoing regulatory and voluntary conservation measures, 13 of 65 MUs (20 percent) deteriorate in resiliency from current condition and have the potential to drop below detectable levels or become extirpated (very low condition). Genetic isolation is an increasing concern due to fragmentation, with MUs becoming more linearly distributed, decreasing resilience to stochastic events. The number of MUs (52) that continue to be represented across the species' range is strongly dependent on public lands with aquatic species conservation incorporated into long-term planning strategies. The Tippecanoe, Upper Green, Upper Duck, and Ouachita MUs, which have resource protection measures such Federal managed lands and BMPs, offer refugia from threats and result in the best conservation opportunities.

7.5.2 Representation

The Purple Lilliput loses some representation over time compared to current condition and Scenario 1, with no high condition MUs in any of the six remaining occupied basins, and one MU remaining in the Great Lakes basin. The Cumberland basin is represented by only low condition MUs, but is aided by replication and multiple MUs occupied (Lower Cumberland-Old Hickory Lake, Upper Cumberland-Cordell Hull, Caney, South Fork Cumberland, and Obey).

Some MUs within the Ohio (Driftwood, Flatrock-Haw, Upper East Fork White), Cumberland (South Fork Cumberland, Obey, Cordell Hull), Tennessee (Upper Duck, Emory, Lower Tennessee), Arkansas-White-Red (James, Frog-Mulberry), and Lower Mississippi (Upper Ouachita) basins are linearly distributed due to reductions in population and habitat connectivity, thus resulting in fragmentation and a potential for genetic isolation in these MUs.

With 46 MUs (71 percent) in low condition and the potential extirpation (very low condition) of 13 populations (20 percent), the species would be less represented across its range as compared to current or Scenario 1 conditions. However, as many as 6 MUs would be in medium condition across 4 basins (Ohio, Tennessee, Arkansas-White-Red, Lower Mississippi), indicating that the species maintains representation overall despite substantial habitat and water quality impacts.

7.5.3 Redundancy

The Purple Lilliput loses some redundancy compared to current conditions and to a greater degree than what is presented for Scenario 1. The best available information suggests that up to 13 MUs (20 percent) would decline to very low condition become extirpated. Loss of MUs in all portions of its currently occupied range occur in all six basins in Scenario 3, and there are no longer any high condition populations to use for brood stock for translocation or captive propagation efforts. Only low condition MUs remain in the Great Lakes and Cumberland basins. However, with 52 MUs (80 percent) remaining in low and medium condition, despite reductions in redundancy, and limited opportunities for species restoration in the Great Lakes and Cumberland basins, the species maintains redundancy such that 4 of the 6 currently occupied basins retain a medium condition MU (Ohio, Tennessee, Arkansas-White-Red, Lower Mississippi), and are projected to continue to persist.

CHAPTER 8 - OVERALL SYNTHESIS

The goal of this assessment is to describe the current and potential future conditions of the Purple Lilliput in terms of resiliency, representation, and redundancy by using the best available commercial and scientific information. To capture the uncertainty associated with the degree and extent of potential future risks and their impacts on the species' needs, we assessed potential future conditions using three plausible scenarios. These scenarios were based on a variety of negative and positive influences on the species across its current 9-state range, allowing us to predict potential changes in habitat used by the Purple Lilliput. The results of our analysis describe a range of possible conditions in terms of the number and distribution of Purple Lilliput populations (Table ES-1).

Historical Range and Abundance - The historical range of the Purple Lilliput included streams and rivers across 13 states, including Oklahoma, Arkansas, Missouri, Michigan, Indiana, Illinois, Ohio, Kentucky, Virginia, Tennessee, Georgia, North Carolina, and Alabama. This range encompassed six major basins: the Great Lakes, Ohio, Cumberland, Tennessee, Arkansas-White-Red, and Lower Mississippi. The best available information suggests that at least 272 populations and 135 MUs occurred over this range; however, it is also possible that more populations were present and undetected prior to the use of more intensive contemporary survey methods.

Current Viability Summary - The current range extends over nine states; the species is now considered extirpated in Georgia and North Carolina, both of which are represented by only one historical collection record each. This current range encompasses the six major river basins that the species is known to occur historically. Overall, the Purple Lilliput is presumed extirpated from 127 of 272 (47 percent) of its historically occupied populations, including 12 populations in the Great Lakes basin, 42 populations in the Ohio River basin, 19 populations in the Cumberland River basin, 39 populations in the Tennessee River basin, 10 populations in the Arkansas-White-Red basin, and 5 populations in the Lower Mississippi basin (Appendix B). Of the current populations, 23 (16 percent) are estimated to be highly resilient, 36 (25 percent) are moderately resilient, and 86 (60 percent) have low resiliency. The risks facing the Purple Lilliput populations varied among scenarios and are summarized below (see Table 8-1 and Table ES-1).

Future Condition Scenarios - An important assumption of the predictive analysis presented herein is that future population resiliency is largely dependent on water quality, seasonally variable water levels, instream habitat conditions, and condition of riparian vegetation (see Resource Needs, Chapter 4). Our assessment predicts that if conditions remain the same or worsen into the future, a range of 5 (Scenario 1) to 13 (Scenario 3) MUs would experience negative changes to their resource needs, and potentially resulting in no highly resilient MUs (Scenario 3).

Alternatively, the scenario that suggests additive conservation measures beyond those currently implemented (Scenario 2) could result in the continued persistence of all 65 MUs in the future. The risks facing the Purple Lilliput populations varied among scenarios and are summarized below (see Table 8-1 and Table ES-1).

Given Scenario 1, lowered resiliency and redundancy is expected. Under this scenario, we predict that 6 (9 percent) of the current high condition MUs would remain in high condition, 22 MUs (34 percent) would be in medium condition, and 32 MUs (49 percent) would be in low condition. Redundancy would be reduced with likely extirpation of 5 out of 65 (8 percent) of the currently extant MUs. Only the Great Lakes and Cumberland basins (2 of the 6 basins currently occupied by the species) would not contain a highly resilient MU. Representation would remain at current levels, with all 6 (100 percent) of the currently occupied basins continuing to harbor high or medium condition Purple Lilliput MUs.

Given Scenario 2, we predict higher levels of resiliency in some portions of the Purple Lilliput's range than was estimated for Scenario 1; representation and redundancy would remain the same level as current conditions with the species continuing to occur within all currently occupied MUs and states across the species 9-state range. Twenty-three MUs (35 percent) are predicted to be high condition, compared to the current 7 MUs in high condition. Scenario 2 also predicts 42 MUs (65 percent) in medium condition and no MUs in low condition; no MUs would become extirpated. All six currently occupied major river basins would remain occupied, and the existing levels of redundancy and representation could improve. It is possible that this scenario is the least likely to occur in the future as compared to Scenario 1 or 3 only because it will take many years (potentially beyond the 20- to 30-year time frame analyzed in this report) for all of the beneficial effects of management actions that are necessary to be implemented and realized on the landscape.

Given Scenario 3, we predict a decrease in resiliency, and slight decreases in representation and redundancy across the species range. Redundancy would remain across all six major basins that it currently inhabits, but the Great Lakes basin would have only one remaining isolated MU (St. Joseph), thus increasing its vulnerability to extirpation. No high condition populations would remain, and 13 (20 percent) of the currently extant MUs are likely to become extirpated. The resiliency of the remaining 52 MUs is expected to be reduced to 6 MUs (10 percent) in medium condition and 46 MUs (71 percent) in low condition. Representation would be reduced to 52 MUs, across 6 major river basins, and 10 states (as compared to the current 9 states) occupied by the species. However, with 52 MUs (80 percent) remaining in low and medium condition, despite reductions in redundancy, and limited opportunities for species restoration in the Great Lakes and Cumberland basins, the species maintains redundancy such that 4 of the 6 currently occupied basins retain a medium condition MU (Ohio, Tennessee, Arkansas-White-Red, Lower Mississippi), and are projected to continue to persist.

Overall Summary - Estimates of current and future resiliency for the Purple Lilliput (Table 8-1, below) are moderate given that 23 (19 percent) of the populations are estimated to be highly resilient and 36 (25 percent) of the populations are estimated to be moderately resilient. The Purple Lilliput faces a variety of factors negatively influencing the species throughout its range, including habitat degradation or loss (i.e., declines in water quality, reduced water levels, riparian and instream fragmentation, and genetic isolation from development, urbanization, contaminants, agricultural activities, impoundments, changing climate conditions, resource extraction, and forest conversion), as well as impacts associated with invasive and nonnative species.

These negative influences, which are expected to be exacerbated by continued growing human populations that demand associated development, energy, infrastructure, and water needs, as well as (but to a lesser degree than the former) climate change, are important factors in our assessment of the future viability of the Purple Lilliput. Given current and future decreases in resiliency, populations become more vulnerable to extirpation from stochastic events (particularly the small populations that are linearly distributed), in turn, resulting in concurrent losses in representation and redundancy.

Predictions of the Purple Lilliput's habitat conditions and population factors in the future suggest between 137 (95 percent) and 118 (81 percent) of currently extant populations remain under future condition scenarios. Also, between 60 (92 percent) and 52 (80 percent) of MUs are expected to persist under these scenarios. With over 100 populations and 50 MUs remaining into the future under multiple scenarios, the Purple Lilliput maintains representation despite reductions in resiliency, and there is some loss of populations and MUs, but all basins are predicted to remain occupied.

If additional conservation or beneficial management actions are implemented and effective, more populations and MUs beyond our predictions may persist, largely due to the species' ability to adapt to a variety of habitat conditions. Although the species is considered extirpated from North Carolina and Georgia, and its current status in Virginia and Oklahoma is unknown, substantial range reductions have not been observed to date, such that the species continues to be represented in all of the basins it has been documented. Additionally, all factors currently influencing the viability of populations currently appear to be affecting the species throughout its range.

Regardless of our analyses, the Purple Lilliput is considered rare, critically imperiled, or the current status of populations within the states of Virginia, Michigan, Ohio, and Oklahoma is uncertain (Badra 2004, p. 31; Mather 2005, p. 233; Watters *et al.* 2009, p. 302; Jones 2015, p. 315). In this SSA, populations in Oklahoma and Virginia are tentatively considered extirpated due to the lack of live or fresh dead specimens collected since 2000. The Great Lakes basin has only three populations within Michigan and Ohio and all are considered to be low condition with limited resiliency (Table 8-1). These populations are on the periphery of the range of the Purple Lilliput, and are imperiled due to a variety of factors including nonnative species, habitat alteration and loss, water quality degradation, impoundment, and resulting isolation (Watters 2000, p. 269). These synergistic effects make the last remaining low condition Great Lakes basin populations in Ohio and Michigan vulnerable to a stochastic event under any current or future scenario.

Table 8-1. Summary of Purple Lilliput mussel population size, extent, threat level, current conditions, and potential future conditions.

Major River Basin	**Contiguous Population (occupied waterbody)**	**Population Size (small, medium, large)**	**Threat Level (low, moderate, high)**	**Current Condition**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Great Lakes							
Great Lakes	Blanchard River	Small	Moderate	Low	Very Low	Low	Very Low
	Clinton River	Small	High	Low	Low	Medium	Very Low
	Lake Wilson	Small	Low	Low	Low	Medium	Low
Ohio							
Ohio	Green River	Large	Moderate	High	High	High	Medium
	Russell Creek	Small	Low	Medium	Low	High	Low
	Big Grand Pierre Creek	Medium	Moderate	Medium	Medium	High	Low
	Jordan Creek	Large	Moderate	High	High	High	Medium
	Middle Fork North Fork Vermilion River	Medium	Moderate	Medium	Medium	High	Low
	North Fork Vermilion river	Medium	Moderate	Medium	Medium	High	Low
	Middle Fork Vermilion River	Small	Moderate	Low	Low	Medium	Low
	Little Pine Creek	Small	Moderate	Low	Low	Medium	Low
	Big Pine Creek	Small	Moderate	Low	Low	Medium	Low
	North Fork Coal Creek	Small	Moderate	Low	Low	Medium	Low
	Brushy Fork	Small	Moderate	Low	Low	Medium	Low

Major River Basin	Contiguous Population (occupied waterbody)	Population Size (small, medium, large)	Threat Level (low, moderate, high)	Current Condition	Scenario 1	Scenario 2	Scenario 3
Ohio	Kuhn Lake	Medium	Moderate	Medium	Medium	High	Low
	Sechrist Lake	Small	Moderate	Low	Low	Medium	Low
	Grassy Creek	Medium	Moderate	Medium	Medium	High	Low
	Tippecanoe	Large	Moderate	High	High	High	Medium
	Lake Maxinkuckee	Small	Moderate	Low	Low	Medium	Low
	Big Monon Ditch	Small	Moderate	Low	Low	Medium	Low
	Vernon Fork Muscatatuck River	Small	Moderate	Low	Low	Medium	Low
	Graham Creek	Small	Moderate	Low	Low	Medium	Low
	Big Creek	Small	Moderate	Low	Low	Medium	Low
	Clifty Creek	Small	Moderate	Low	Low	Medium	Low
	Flatrock River	Small	Moderate	Medium	Medium	High	Low
	Brandywine Creek	Small	Moderate	Low	Low	Medium	Very Low
	Little Blue River	Medium	Moderate	Medium	Medium	High	Low
	Sugar Creek	Small	Moderate	Low	Low	Medium	Very Low
	Cedar Lake	Small	Moderate	Low	Low	Medium	Low
	Round Lake	Small	Moderate	Low	Low	Medium	Low
	Shriner Lake	Small	Moderate	Low	Low	Medium	Low
	Eel River	Small	Moderate	Low	Low	Medium	Low
	Paw Paw Creek	Small	Moderate	Low	Low	Medium	Low
Cumberland							
Cumberland	Peyton Creek	Small	Moderate	Low	Low	Medium	Low
	Goose Creek	Small	Moderate	Low	Low	Medium	Low

Major River Basin	Contiguous Population (occupied waterbody)	Population Size (small, medium, large)	Threat Level (low, moderate, high)	Current Condition	Scenario 1	Scenario 2	Scenario 3
Cumberland	Little Goose Creek	Small	Moderate	Low	Low	Medium	Low
	Flynn Creek	Small	Moderate	Low	Low	Medium	Low
	Hickman Creek	Small	Moderate	Low	Low	Medium	Low
	Smith Fork	Small	Moderate	Low	Low	Medium	Low
	Buck Creek	Small	High	Low	Very Low	Low	Very Low
	Horse Lick Creek	Small	High	Low	Very Low	Low	Very Low
	Little South Fork Cumberland River	Small	High	Low	Low	Medium	Low
	Wolf River	Medium	Moderate	Medium	Medium	High	Low
Tennessee							
Tennessee	Cypress Creek	Medium	Moderate	Medium	Medium	High	Low
	Town Creek (Colbert/ Lawrence Co.)	Small	Low	Medium	Medium	High	Low
	Big Nance Creek	Small	Low	Low	Low	Medium	Low
	Shoal Creek	Small	Moderate	Low	Low	Medium	Very Low
	Tennessee River (Pickwick Reservoir)	Large	High	High	High	High	Medium
	Buffalo River	Small	Moderate	Low	Low	Medium	Very Low
	Bear Creek	Small	Moderate	Low	Low	Medium	Very Low
	East Fork Clarks River	Small	Low	Medium	Medium	High	Low
	Town Creek	Small	Low	Medium	Medium	High	Low
	Tennessee River	Small	Moderate	Low	Low	Medium	Low

Major River Basin	**Contiguous Population (occupied waterbody)**	**Population Size (small, medium, large)**	**Threat Level (low, moderate, high)**	**Current Condition**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Tennessee	Second Creek	Large	Low	High	High	High	Medium
	First Creek	Small	Low	Medium	Medium	High	Low
	Goldfield Branch	Large	Low	High	High	High	Medium
	Fox Creek	Small	Low	Medium	Medium	High	Low
	Spring Creek	Large	Low	High	High	High	Medium
	Round Island Creek	Small	Moderate	Low	Low	Medium	Low
	Limestone Creek	Small	Moderate	Low	Low	Medium	Low
	Piney Creek	Small	Moderate	Low	Low	Medium	Low
	Flint River	Small	Low	Medium	Medium	High	Low
	Hurricane Creek (1) (Flint trib)	Large	Low	High	High	High	Medium
	Lick Fork	Small	Low	Medium	Medium	High	Low
	Larkin Fork	Small	Low	Medium	Medium	High	Low
	Estill Fork	Medium	Low	High	High	High	Medium
	Hurricane Creek (2) (Paint Rock trib)	Medium	Low	High	High	High	Medium
	Little Paint Creek	Medium	Low	High	High	High	Medium
	Paint Rock River	Large	Low	High	High	High	Medium
	Tennessee River	Large	Moderate	High	High	High	Medium
	Clinch River	Small	Moderate	Low	Very Low	Low	Very Low
	Elk River	Small	Moderate	Low	Low	Medium	Very Low
	Clear Creek	Small	Low	Medium	Medium	High	Low
	Big Rock Creek	Small	Moderate	Low	Low	Medium	Very Low
	Duck River	Large	Moderate	High	High	High	Medium

Major River Basin	**Contiguous Population (occupied waterbody)**	**Population Size (small, medium, large)**	**Threat Level (low, moderate, high)**	**Current Condition**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Arkansas-White-Red							
Arkansas-White-Red	Coon Creek	Small	Low	Low	Very Low	Low	Very Low
	Shoal Creek	Small	Moderate	Low	Low	Medium	Very Low
	Indian Creek	Small	Moderate	Low	Very Low	Low	Very Low
	James River	Large	Moderate	Medium	Medium	High	Low
	Finley Creek	Small	Moderate	Low	Low	Medium	Very Low
	Flat Creek	Small	Moderate	Low	Low	Medium	Very Low
	Swan Creek	Small	Low	Medium	Medium	High	Low
	Bull Creek	Medium	Low	Medium	Medium	High	Low
	Bryant Creek	Medium	Low	Medium	Medium	High	Low
	North Fork White River	Small	Low	Medium	Medium	High	Low
	Eleven Point	Small	Low	Medium	Medium	High	Low
	West Fork Fourche Creek	Small	Moderate	Low	Low	Medium	Low
	Black River	Small	Moderate	Low	Low	Medium	Very Low
	Jacks Fork River	Small	Moderate	Low	Low	Medium	Low
	Big Barren Creek	Small	Moderate	Low	Low	Medium	Low
	Current River	Small	Moderate	Low	Low	Medium	Low
	Little Black River	Small	Moderate	Low	Low	Medium	Very Low
	North Prong Little Black River	Small	Moderate	Low	Low	Medium	Low
	South Fork Spring River	Medium	Moderate	Medium	Medium	High	Low
	Spring River	Small	Moderate	Medium	Medium	High	Low

Major River Basin	**Contiguous Population (occupied waterbody)**	**Population Size (small, medium, large)**	**Threat Level (low, moderate, high)**	**Current Condition**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Arkansas-White-Red	Upper White River	Large	Low	High	High	High	Medium
	War Eagle Creek	Large	Moderate	High	High	High	Medium
	Illinois River	Small	Moderate	Low	Low	Medium	Very Low
	Frog Bayou	Small	Moderate	Low	Low	Medium	Very Low
	Mulberry River	Small	Moderate	Low	Low	Medium	Low
	Cadron Creek	Small	Moderate	Low	Low	Medium	Low
	East Fork Illinois Bayou	Small	Moderate	Low	Low	Medium	Low
	Middle Fork Illinois Bayou	Small	Moderate	Low	Low	Medium	Low
	Illinois Bayou	Small	Moderate	Low	Low	Medium	Low
	Big Piney Creek	Small	Moderate	Low	Low	Medium	Very Low
	Archey Fork Little Red River	Large	Moderate	High	High	High	Medium
	South Fork Little Red River	Small	Moderate	Medium	Medium	High	Medium
	Turkey Creek	Small	Moderate	Low	Low	Medium	Low
	Beech Fork Little Red River	Small	Moderate	Low	Low	Medium	Low
	Middle Fork Little Red River	Large	Moderate	High	High	High	Medium
	Big Creek	Small	Moderate	Low	Very Low	Medium	Very Low
	Jones Creek	Small	Moderate	Low	Low	Medium	Low
	East Fork Cadron Creek	Small	Moderate	Low	Low	Medium	Low
	North Fork Cadron Creek	Medium	Moderate	Medium	Low	Medium	Low

Major River Basin	**Contiguous Population (occupied waterbody)**	**Population Size (small, medium, large)**	**Threat Level (low, moderate, high)**	**Current Condition**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Arkansas-White-Red	East Fork Point Remove Creek	Medium	Moderate	Medium	Low	Medium	Low
	West Fork Point Remove Creek	Small	Moderate	Low	Low	Medium	Low
	Black Fork Fourche LaFave River	Small	Moderate	Low	Low	Medium	Low
	South Fourche LaFave River	Medium	Moderate	Medium	Medium	High	Low
	Jones Creek	Small	Moderate	Low	Low	Medium	Very Low
	Ross Creek	Small	Moderate	Low	Low	Medium	Very Low
	Poteau River	Small	Moderate	Low	Low	Medium	Very Low
	Mountain Fork Little River	Small	Moderate	Low	Low	Medium	Low
	Saline River	Small	Moderate	Low	Low	Medium	Low
	Strawberry River	Small	Moderate	Low	Low	Medium	Low
	Buffalo River	Large	Moderate	High	High	High	Medium
Lower Mississippi							
Lower Mississippi	Crooked Creek	Small	Moderate	Low	Low	Medium	Low
	Castor River	Small	Moderate	Low	Low	Medium	Low
	Ditch 28	Small	Low	Medium	Medium	High	Low
	St. Francis River	Medium	Moderate	Medium	Medium	High	Low
	Tyronza River	Small	Moderate	Low	Low	Medium	Low
	National Ditch	Medium	Moderate	Medium	Medium	High	Low
	Varney River	Small	Moderate	Low	Low	Medium	Low
	Cache River	Small	Moderate	Low	Low	Medium	Low

Major River Basin	**Contiguous Population (occupied waterbody)**	**Population Size (small, medium, large)**	**Threat Level (low, moderate, high)**	**Current Condition**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Lower Mississippi	East Fork Flat Creek	Medium	Moderate	Medium	Medium	High	Low
	Caddo River	Small	Moderate	Low	Very Low	Medium	Very Low
	Ouachita River	Small	Moderate	Low	Very Low	Low	Very Low
	South Fork Ouachita River	Large	Moderate	High	High	High	Medium
	Ouachita River Headwaters	Small	Moderate	Low	Low	Medium	Very Low
	Middle Fork Saline River	Small	Moderate	Low	Low	Medium	Very Low
	Little Alum Creek	Small	Moderate	Medium	Medium	High	Low
	Alum Fork Saline River	Large	Moderate	High	High	High	Medium
	South Fork Saline River	Small	Moderate	Low	Very Low	Low	Very Low
	North Fork Saline River	Large	Moderate	High	High	High	Medium
	Upper Saline River	Large	Moderate	High	High	High	Medium
	Little Missouri River	Small	Moderate	Low	Low	Medium	Low
	Lower Saline River	Small	Moderate	Low	Low	Medium	Low

LITERATURE CITED

NOTE: SOME OF THE WORKS CITED ARE NOT WITHIN THE MAIN BODY OF THE DOCUMENT BUT INSTEAD IN THE APPENDICES.

[ADEM] Alabama Department of Environmental Management. 2002. Final siltation TMDL development for 22 segments in the Lower Tennessee River basin.

Ahlstedt, S.A. 1995–96. Status survey for federally listed endangered freshwater mussel species in the Paint Rock River system, northeastern Alabama, U.S.A. Walkerana 8(19):63–80.

Ahlstedt, S.A., and J.D. Tuberville. 1997. Quantitative reassessment of the freshwater mussel fauna in the Clinch and Powell Rivers, Tennessee and Virginia. Pp. 72–97 in: K.S. Cummings, A.C. Buchanan, C.A. Mayer, and T.J. Naimo, eds. Conservation and management of freshwater mussels II: initiatives for the future. Proceedings of a UMRCC symposium, October 1995, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Ahlstedt, S.A., J.R. Powell, R.S. Butler, M.T. Fagg, D.W. Hubbs, S.F. Novak, S.R. Palmer, and P.D. Johnson. 2004. Historical and current examination of freshwater mussels (Bivalvia: Margaritiferidae, Unionidae) in the Duck River basin Tennessee. Final Report: Tennessee Wildlife Resource Agency contract FA–02–14725–00.

Ahlstedt, S.A., S. Bakaletz, M.T. Fagg, D.W. Hubbs, M.W. Treece, and R.S. Butler. 2003–2004. Current status of freshwater mussels (Bivalvia: Unionidae) in the Big South Fork National River and Recreation Area of the Cumberland River, Tennessee and Kentucky (1999-2002): Evidence of faunal recovery. Walkerana 14(31):33–77.

Ahlstedt, S., R. Butler, Z. Couch, S. Brunderman, M. Compton, and E. Brett. 2014. Current status of freshwater mussel populations in the Little South Fork Cumberland River drainage, McCreary and Wayne counties, Kentucky (2013): Continuing collapse of a once fabulous fauna. Final report to the US Fish & Wildlife Service Kentucky Field Office and Kentucky Waterways Alliance. 16 pp.

Ahlstedt, S.A., M.T. Fagg, R.S. Butler, J.F. Connell, and J.W. Jones. 2016. Quantitative Monitoring of Freshwater Mussel Populations from 1979–2004 in the Clinch and Powell Rivers of Tennessee and Virginia, with Miscellaneous Notes on the Fauna. Freshwater Mollusk Biology and Conservation 19:1–18.

Ahlstedt, S.A., J.R. Powell, R.S. Butler, M.T. Fagg, D.W. Hubbs, S.F. Novak, S.R. Palmer, and P.D. Johnson. 2017. Historical and current examination of freshwater mussels (Bivalvia: Margaritiferidae: Unionidae) in the Duck River basin, Tennessee, U.S.A. Malacological Review 45:1–163.

Aldridge, D.W., Payne, B.S., and Miller, A.C. 1987. The effects of intermittent exposure to suspended solids and turbulence on three species of freshwater mussels. Environmental Pollution 45(1):17–28.

Allan, J.D. 1995. Stream Ecology: Structure and Function of Running Waters. Chapman and Hall. New York.

Allen, W.R. 1921. Studies of the biology of freshwater mussels: III. Distribution and movements of Winona Lake mussels. Proceedings of the Indiana Academy of Science. 31:227–238.

Amyot, J.-P. and J.A. Downing. 1997. Seasonal variation in vertical and horizontal movement of the freshwater bivalve Elliptio complanata (Mollusca: Unionidae). Freshwater Biology 37: 345-354.

Anderson, R.M., and D.A. Kreeger. 2010. Potential for impairment of freshwater mussel populations in Delaware River Basin Commission special protection waters as a consequence of natural gas exploratory well development. 14 pp.

Angelo, R.T., M.S. Cringan, E. Hays, C.A. Goodrich, E.J. Miller, M.A. VanScoyoc, and B.R. Simmons. 2009. Historical changes in the occurrence and distribution of freshwater mussels in Kansas. Great Plains Research 19:89–126.

Augspurger, T., A.E. Keller, M.C. Black, W.G. Cope, and F.J. Dwyer. 2003. Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. Environmental Toxicology and Chemistry 22(11):2,569–2,575.

Augspurger, T., F.J. Dwyer, C.G. Ingersoll, and C.M. Kane. 2007. Advances and opportunities in assessing contaminant sensitivity of freshwater mussel (Unionidae) early life stages. Environmental Toxicology and Chemistry 26:2,025–2,028.

Aust, W.M., Carroll, M.B., Bolding, M.C., and C.A. Dolloff. 2011. Operational forest stream crossings effects on water quality in the Virginia Piedmont. Southern Journal of Applied Forestry 35:123–130.

Badra, P.J. 2004. Freshwater mussel surveys of Great Lakes tributary rivers in Michigan. Report 2004-22 prepared by the Michigan Natural Features Inventory to the Michigan Department of Environmental Quality. 39 pp.

Barling, R.D., and I.D. Moore. 1994. Role of buffer strips in management of waterway pollution: A review. Environmental Management 18(4):543–558.

Barnhart, M.C., W.R. Haag, and W.N. Roston. 2008. Adaptations to host infection and larval parasitism in Unionoida. Journal of the North American Benthological Society 27(2):370–394.

Bartsch, M.R., T.J. Newton, J.W. Allran, J.A. O’Donnell, and W.B. Richardson. 2003. Effects of pore-water ammonia on situ survival and growth of juvenile mussels (*Lampsilis cardium*) in the St. Croix riverway, Wisconsin, USA. Environmental Toxicology and Chemistry 22(11):2,561–2,568.

Berg, D.J., T.D. Levine, J.A. Stoeckel, and B.K. Lang. 2008. A conceptual model linking demography and population genetics of freshwater mussels. Journal of the North American Benthological Society 27(2):395–408.

Bogan, A.E. 1990. Stability of recent unionid (Mollusca: Bivalvia) communities over the past 6000 years. Pp. 112–136 in: W. Miller, III, ed. Paleocommunity temporal dynamics: the long-term development of multispecies assemblies. The Paleontological Society Special Publication No. 5.

Bonner, T.H., E.L. Oborny, B.M. Littrell, J.A. Stoeckel, B.S. Helms, K.G. Ostrand, P.L. Duncan, and J. Conway. 2018. Multiple freshwater mussel species of the Brazos River, Colorado River, and Guadalupe River basins. CMD 1 - 6233CS. Final Report to Texas Comptroller of Public Accounts. February 28, 2018. 306 pp.

Brabec, E., S. Schulte, and P.L. Richards. 2002. Impervious surfaces and water quality: a review of current literature and its implications for watershed planning. Journal of Planning Literature 16(4):499–514.

Branson, B.A. 1984. The mussels (Unionaceae: Bivalvia) of Oklahoma - Part 3: Lampsilini. Proceedings of the Oklahoma Academy of Science 64:20–36.

Bringolf, R.B., W.G. Cope, C.B. Eads, P.R. Lazaro, M.C. Barnhart, and D. Shea. 2007. Acute and chronic toxicity of technical-grade pesticides to glochidia and juveniles of freshwater mussels (Unionidae). Environmental Toxicology and Chemistry 26(10):2,086–2,093.

Bringolf, R.B., R.M. Heltsley, T.J. Newton, C.B. Eads, S.J. Fraley, D. Shea, and W.G. Cope. 2010. Environmental occurrence and reproductive effect of the pharmaceutical fluoxetine in native freshwater mussels. Environmental Toxicology and Chemistry 29(6):1,311–1,318.

Broadmeadow, S. and T.R. Nisbet. 2004. The effects of riparian forest management on the freshwater environment: a literature review of best management practices. Hydrology and Earth System Sciences 8(3):286–305.

Brown, A.V., M.M. Lyttle, and K.B. Brown. 1998. Impacts of gravel mining on gravel bed streams. Transactions of the American Fisheries Society 127(1998):979–994.

Brown, M.E., M. Kowalewski, R.J. Neves, D.S. Cherry, and M.E. Schreiber. 2005. Freshwater mussel shells as environmental chronicles: Geochemical and taphonomic signatures of mercury-related extirpations in the North Fork Holston River, Virginia. Environmental Science and Technology 39(2005):1,455–1,462.

Bruenderman, S.A., J.S. Faiman, and A.C. Buchanan. 2001. Survey for the Curtis Pearly Mussel, *Epioblasma florentina curtisi* (Utterback 1914) and other mussel species in the Little Black River, Missouri. MDC report, Columbia, MO. 78 pp.

Caldwell, P. C. Segura, S.G. Laird, G. Sun, S.G. McNulty, M. Sandercock, J. Boggs, and J.M. Vose. 2014. Short-term stream water temperature observations permit rapid assessment of potential climate change impacts. Hydrological Processes 29(9):2,196–2,211.

Campbell, D., and P. Harris. 2006. Report on molecular systematics of poorly-known freshwater mollusks of Alabama. Alabama Department of Conservation and Natural Resources, Montgomery, Alabama. 34 pp.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Shartley, V.H. Smith. 1998. Non point Pollution of Surface Waters with Phosphorus and Nitrogen. Ecological Applications 8(3):559–568.

[CBD] Center for Biological Diversity. 2010. Petition to List 404 Aquatic, Riparian and Wetland Species from the Southeastern United States as Threatened or Endangered Under the Endangered Species Act. Submitted on behalf of CBD, Alabama Rivers Alliance, Clinch Coalition, Dogwood Alliance, Gulf Restoration Network, Tennessee Forests council, West Virginia Highlands Conservancy, Tierra Curry, and Noah Greenwald. Dated April 20, 2010. Pp. 538–540.

Chen, L.Y., A.G. Heath, and R.J. Neves. 2001. Comparison of oxygen consumption of freshwater mussels (Unionidae) from different habitats during declining dissolved oxygen concentration. Hydrobiologia 450:209–215.

Cherry, D.S., J.L. Scheller, N.L. Cooper, and J.R. Bidwell. 2005. Potential effects of Asian clam (*Corbicula fluminea*) die-offs on native freshwater mussels (Unionidae) I: water-column ammonia levels and ammonia toxicity. Journal of the North American Benthological Society 24(2):369–380.

Chetty, A.N., and K. Indira. 1994. Alterations in the tissue lipid profiles of *Lamellidens marginalis* under ambient ammonia stress. Bulletin of Environmental Contamination and Toxicology 53:693–698.

Christian, A.D., J.L. Harris, W.R. Posey, J.F. Hockmuth, and G.L. Harp. 2005. Freshwater mussel (Bivalvia: Unionidae) assemblages of the lower Cache River, Arkansas. Southeastern Naturalist 4(3):487-512.

Cicerello, R.R. 1999. A survey of the freshwater mussels (Mollusca: Unionoidea) of the Green River, Green River Lake Dam to Mammoth Cave National Park, Kentucky. Kentucky State Nature Preserves Commission, Frankfort. 42 pp.

Cicerello, R.R., M.L. Warren, Jr., and G.A. Schuster. 1991. A distributional checklist of the freshwater unionids (Bivalvia: Unionoidea) of Kentucky. American Malacological Bulletin 8(2):113–129.

Clark, C.F. 1977. The freshwater naiads of Ohio, Part I: St. Joseph River of the Maumee.

Sterkiana (65-66):14–36.

Clench, W.J., and Van Der Schalie. 1944. Notes on naiads from the Green, Salt, and Tradewater rivers in Kentucky. Michigan Academy of Science, Arts, and Letters. 29:223–228.

Clayton, J.L. 2018. Email communications in 2018, between Andrew Henderson, USFWS and Janet Clayton, West Virginia Division of Natural Resources (WVDNR).

Cochran, T.G., Jr., and J.B. Layzer. 1993. Effects of commercial harvest on unionid habitat use in the Green and Barren Rivers, Kentucky. Pp. 61–65 *in:* K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, October 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Colle, D.E., J.V. Shireman, W.T. Haller, J.C. Joyce, and D.E. Canfield. 1987. Influence of *Hydrilla* on harvestable sport-fish populations, angler use, and angler expenditures at Orange Lake, Florida. North American Journal of Fisheries Management 7:410–417.

Cooper, N.L., J.R. Bidwell, and D.S. Cherry, D.S. 2005. Potential effects of Asian clam (*Corbicula fluminea*) die-offs on native freshwater mussels (Unionidae) II: porewater ammonia. Journal of the North American Benthological Society 24(2):381–394.

Cope, W.G., M.R. Bartsch, and J.E. Hightower. 2006. Population dynamics of Zebra mussels *Dreissena polymorpha* (Pallas, 1771) during the initial invasion of the upper Mississippi River, USA. Journal of Molluscan Studies 72:179–188.

[Corps] U.S. Army Corps of Engineers. 2016. White River basin comprehensive watershed study: Cache River basin watershed management plan. 88 pp.

Couceiro, S., Hamada, N., Luz, S., Forsberg, B., and Pimentel, T. 2007. Deforestation and sewage effects on aquatic macroinvertebrates in urban streams in Manaus, Amazonas, Brazil. Hydrobiologia. 575:271–284.

Cummings, K.S., and M.K. Berlocher. 1990. The naiades or freshwater mussels (Bivalvia: Unionidae) of the Tippecanoe River, Indiana. Malacological Review 23:83-98.

Cummings, K.S., C.A. Mayer, and L.M. Page. 1988. Survey of the freshwater mussels (Mollusca: Unionidae) of the Wabash River drainage. Phase II: upper and middle Wabash River. Illinois Natural History Survey Technical Report 1988(8). 47 pp.

Cummings, K.S., C.A. Mayer, and L.M. Page. 1992. Survey of the freshwater mussels (Mollusca: Unionidae) of the Wabash River drainage. Final Report. Illinois Natural History Survey Technical Report 1992. 201 pp.

Cummings, K. S., C. A. Mayer, and R. E. Szafoni. 1998. Endangered freshwater mussels (Mollusca: Unionidae) in the North Fork Vermilion River, Illinois with comments on the federallyendangered clubshell Pleurobema clava (Lamarck, 1819). Transactions of the Illinois Academyof Sciences 91:91-102.

[CWP] Center for Watershed Protection. 2003. Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research Monograph No. 1. Ellicott City, Maryland. 158 pp.

Daniels, L.E. 1903. A check list of Indiana Mollusca, with localities. WB Burford.

Davidson, C. 2019. Personal communication on May 24, 2019, between Andrew Henderson, USFWS and Chris Davidson, USFWS. Subject: Fayetteville Shale – Threats to Purple Lilliput.

Davidson, C., and M. Wine. 2004. Threats assessment for the Speckled Pocketbook (*Lampsilis streckeri*) and Yellowcheek Darter (*Etheostoma moorei*) in the Upper Little Red River watershed, Arkansas. U.S. Fish & Wildlife Service Arkansas Field Office Report. 35 pp.

Davidson, C.L., J.N. Stoeckel, and C. Hilburn. 2000. Location and notes on freshwater mussels (Bivalvia: Unionacea) inhabiting Big Piney Creek within the Ozark-St. Francis National Forest, Arkansas. Annual Proceedings of the Texas Chapter of the American Fisheries Society 22:19–28.

Davidson, C.L., T. Brady, and T. Fotinos. 2014. Status and distribution of freshwater mussels (Bivalvia: Unionacea) inhabiting Little River from the Arkansas-Oklahoma state line to Millwood Lake, Arkansas. U.S. Fish & Wildlife Service Arkansas Field Office Report. 34 pp.

Diamond, J.M., D.W. Bressler, and V.B. Serveiss. 2002. Assessing relationships between human land uses and the decline of native mussels, fish, and macroinvertebrates in the Clinch and Powell River watershed, USA. Environmental Toxicology and Chemistry 21(6):1147–1155.

Dimmock, R.V. and A.H. Wright. 1993. Sensitivity of Juvenile Freshwater Mussels to hypoxic, thermal and acid stress. The Journal of the Elisha Mitchell Scientific Society 109(4):183–192.

Dinkins, G.R., and H.D. Faust. 2015. Assessment of native mussels in selected reaches within the Obed Wild and Scenic River. Unpublished report prepared for the National Park Service 40 pp.

Downing, J.A., Y. Rochon, and M. Perusse. 1993. Spatial aggregation, body size, and reproductive success in the freshwater mussel *Elliptio complanata*. Journal of the North American Benthological Society 12:148-156.

Ebert, D.J. 1993. Dredging. Pp. 157–164. in: C.F. Bryan, and D.A. Rutherford, eds. Impacts on warm water streams: Guidelines for evaluation. Southern Division, American Fisheries Society, Little Rock, Arkansas.

Eissa, A.E. and M.M. Zaki. 2011. The impact of global climatic changes on the aquatic environment. Procedia Environmental Sciences 4:251–259.

Ellis, M.M. 1936. Erosion silt as a factor in aquatic environments. Ecology 17:29–42.

Entrekin, S., M. Evans-White, B. Johnson, and E. Hagenbuch. 2011. Rapid expansion of natural gas development poses a threat to surface waters. Frontiers in Ecology and the Environment 9:503-511.

Enviroscience. 2016. Phase I and phase II freshwater mussel surveys for installation of a silt collector in the Blanchard River (group 2), Hancock County, Ohio, July 2016. Unpublished report prepared for Hull & Associates, Inc. 18 pp.

[EPA] U.S. Environmental Protection Agency. 1985. Ambient water quality criteria for ammonia. Office of Water Regulations and Standards, Criteria and Standards Division, EPA 440/5-85-001, Washington, DC.

[EPA] U.S. Environmental Protection Agency. 2013. 78 FR 52192, Rec. Criteria for ammonia

[EPA] U.S. Environmental Protection Agency. 2016. Nutrient Pollution – The Sources and Solutions: Agriculture. https://www.epa.gov/nutrientpollution/sources-and-solutions-agriculture (Accessed: October 1, 2018).

[EPA] U.S. Environmental Protection Agency. 2018. Section 404 of the Clean Water Act. *https://www.epa.gov/cwa-404/exemptions-permit-requirements* (Accessed: October 1, 2018).

[ESI] Ecological Specialists, Inc. 1995. A unionid status and distributional survey in the Salamonie and Mississinewa rivers. Indiana Department of Natural Resources, Indianapolis, and U.S. Fish and Wildlife Service, Bloomington, Indiana. 102 pp.

[ESI] Ecological Specialists, Inc. 1998. Final Report: Unionid survey upstream and downstream of 16 point sources in the Tippecanoe River. Prepared for U.S. Fish and Wildlife Service, Bloomington, Indiana. 90 pp.

[ESI] Ecological Specialist, Inc. 2009. Amended report: Analysis of threats to the distribution of unionid mussels in the Elk River, West Virginia, Clay, Braxton, and Kanawha counties. Unpublished report prepared for the U.S. Fish and Wildlife Service, Elkins, West Virginia Field Office. 110 pp.

[ESI] Ecological Specialists, Inc. 2018. Final Report: Tri-state mining district unionid assessment, Missouri, Kansas, and Oklahoma. Unpublished report prepared for the U.S. Fish and Wildlife Service. 106 pp.

Etnier, D.A. and W.C. Starnes. 1993. The fishes of Tennessee. The University of Tennessee Press, Knoxville, Tennessee. 681 pp.

Fagan, W.F. 2002. Connectivity, fragmentation, and extinction risk in dendrictic metapopulations. Ecology 83(12):3,243–3,249.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Reviews of Ecology, Evolution, and Systematics 34(2003):487–515.

Fobian, T.B., M.L. Buntin, J.T. Holifield, T.A. Tarpley, J.T. Garner, and P.D. Johnson. 2014. Freshwater mussels (Unionidae) in the Paint Rock River (Jackson, Madison, and Marshall Counties), Alabama. Southeastern Naturalist 13(2):347-366.

Frankham, R. 1996. Relationship of genetic variation to population size in wildlife. Conservation Biology 10(6):1,500–1,508.

Frazier B.E., Naimo T.H., and M.B. Sandheinrich. 1996. Temporal and vertical distribution of total ammonia nitrogen and un-ionized ammonia nitrogen in sediment pore water from the upper Mississippi River. Environmental Toxicology Chemistry 15:92–99.

Fuller, S.L.H. 1974. Clams and mussels (Mollusca: Bivalvia). Pp. 215–273 in: C.W. Hart, Jr., and S.L.H. Fuller, eds. Pollution ecology of freshwater invertebrates. Academic Press, New York.

Funk, W.C., B.R. Forester, S.J. Converse, C. Darst, and S. Morey. 2018. Improving conservation policy with genomics: a guide to integrating adaptive potential U.S. Endangered Species Act decisions for conservation practitioners and geneticists. Conservation Genetics 20:115-134.

Furedi, M. 2013. An examination of the effects of climate change on species in Pennsylvania. Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy, Pittsburgh, Pennsylvania. 83 pp.

Galbraith, H.S., D.E. Spooner, and C.C. Vaughn. 2010. Synergistic effects of regional climate patterns and local water management on freshwater mussel communities. Biological Conservation 143:1,175–1,183.

Gammon, J.R., and C.W. Gammon. 1993. Changes in the fish community of the Eel River resulting from agriculture. Proceedings of the Indiana Academy of Science 102:67–82.

Gangloff, M.M., K.K. Lenertz, and J.W. Feminella. 2008. Parasitic mite and trematode abundance are associated with reduced reproductive output and physiological condition of freshwater mussels. Hydrobiologia 610:25–31.

Garner, J. 2018. Email communication with Andrew Henderson on November 25, 2018.

Garner, J.T., and S.W. McGregor. 2001. Current status of freshwater mussels (Unionidae, Margaritiferidae) in the Muscle Shoals area of Tennessee River in Alabama (Muscle Shoals revisited again). American Malacological Bulletin 16(1/2):155–170.

Gascho-Landis, A.M., and J.A. Stoeckel. 2015. Multi-stage disruption of freshwater mussel reproduction by high suspended solids in short and long-term brooders. Freshwater Biology 61(2):229–238.

Gatenby, C.M., R.J. Neves, and B.C. Parker. 1996. Influence of sediment and algal food on cultured juvenile freshwater mussels. Journal of the North American Benthological Society 15(4):597–609.

Gibson, K.J. 2015. Acute Toxicity Testing on Freshwater Mussels (Bivalvia: Unionidae) and Freshwater Snails (Gastropoda: Caenogastropoda). Unpublished Master's Thesis, Troy University, Troy, Alabama. 129 pp.

Giddings, E.M.P., A.H. Bell, K.M. Beaulieu, T.F. Cuffney, J.F. Coles, L.R. Brown, F.A. Fitzpatrick, J. Falcone, L.A. Sprague, W.L. Bryant, M.C. Peppler, C. Stephens, and G. McMahon. 2009. Selected physical, chemical, and biological data used to study urbanizing streams in nine metropolitan areas of the United States, 1999-2004: U.S. Geological Survey Data Series 423. 11 pp. + data tables.

Godwin, J.C. 2002. Monitoring of federally listed and rare mussels in the Paint Rock River. Report prepared by the Alabama Natural Heritage Program for the Alabama Department of Conservation and Natural Resources, Montgomery. 80 pp.

Goodrich, C., and H. van der Schalie. 1932. I. On an increase in the naiad fauna of Saginaw Bay, Michigan, II. The naiad species of the Great Lakes. Occasional Papers of the Museum of Zoology 238. 16 pp.

Goodrich, C., and H. van der Schalie. 1944. A revision of the Mollusca of Indiana. American Midland Naturalist 32(2):257–326.

Gordon, M.E., and J.B. Layzer. 1989. Mussels (Bivalvia: Unionidea) of the Cumberland River: Review of life histories and ecological relationships. U.S. Fish and Wildlife Service Biological Report 89(15). 99 pp.

Goudreau, S., R.J. Neves, and R.J. Sheehan. 1993. Effects of wastewater treatment plant effluents on freshwater mollusks in the upper Clinch River, Virginia, U.S.A. Hydrobiologia 252(3):211–230.

Grabarkiewicz, J. and T. Crail. 2006. Freshwater mussels of the Maumee drainage, 2nd edition. 66 p.

Grizzle, J.M., and C.J. Brunner. 2009. Infectious diseases of freshwater mussels and other freshwater bivalve mollusks. Reviews in Fisheries Science 17(4):425–467.

Haag, W.R. 2009. Past and future patterns of freshwater mussel extinctions in North America during the Holocene. Holocene extinctions (2009):107–128.

Haag, W.R. 2012. North American Freshwater Mussels: Natural History, Ecology, and Conservation. Cambridge University Press, Cambridge, New York.

Haag, W.R. 2019. Reassessing enigmatic mussel declines in the United States. Freshwater Mollusk Biology and Conservation 22:1–18.

Haag, W.R., and J.L. Staton. 2003. Variation in fecundity and other reproductive traits in freshwater mussels. Freshwater Biology 48:2,118–2,130.

Haag W.R. and A.L. Rypel. 2011. Growth and longevity in freshwater mussels: evolutionary and conservation implications. Biological Reviews 86(1):225–247.

Haag, W.R., and R.R. Cicerello. 2016. A distributional atlas of the freshwater mussels of Kentucky. Scientific and Technical Series Number 8. Kentucky State Nature Preserves Commission, Frankfort, Kentucky. 299 pp.

Haggerty, T.M., and J.T. Garner. 2008. Distribution of the Armored Snail (*Marstonia pachyta*) and Slender Campeloma (*Campeloma decampi*) in Limestone, Piney, and Round Island Creeks, Alabama. Southeastern Naturalist 7(4):729–736.

Hambrick, P.S. and H.W. Robison. 1979. Life history aspects of the Paleback Darter, *Etheostoma pallididorsum* (Pisces: Percidae), in the Caddo River system, Arkansas. Southwestern Naturalist 24(3):475–484.

Hanlon, S.D. and J.F. Levine. 2004. Notes on the life history and demographics of the Savannah Lilliput (*Toxolasma pullus*) (Bivalvia: Unionidae) in University Lake, North Carolina. Southeastern Naturalist 3(2):289–296.

Hanlon, S.D., M.A. Petty, and R.J. Neves. 2009. Status of native freshwater mussels in Copper Creek, Virginia. Southeastern Naturalist 8(1):1–18.

Hartfield, P.W. 1993. Headcuts and their effect on freshwater mussels. Pp. 131–141 *in:* K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, October 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Hardison, B.S., and J.B. Layzer. 2001. Relations between complex hydraulics and the localized distribution of mussels in three regulated rivers. Regulated Rivers: Research and Management 17:77–84.

Harmon, J.L. 1992. Naiades (Bivalvia: Unionidae) of Sugar Creek, East Fork White River drainage, in central Indiana. Malacology Data Net 3(1–4):31–42.

Harris, J.L., W.R. Posey, C.L. Davidson, J.L. Farris, and S.R. Oetker. 2009. Unionoida (Mollusca: Margaritiferidae, Unionidae) in Arkansas, Third Status Review. Journal of the Arkansas Academy of Science 63(10):50–86.

Havlik, M.E., and L.L. Marking. 1987. Effects of contaminants on naiad mollusks (Unionidae): a review. Unpublished report, U.S. Fish and Wildlife Service Resource Publication 164. 20 pp.

Headlee, T.J. 1906. Ecological notes on the mussels of Winona, Pike, and Center lakes of Kosciusko County, Indiana. The Biological Bulletin 11(6):305–318.

Henley, W.F. 2018. Email communications with Bill Henley, Virginia Polytechnic Institute and State University (VPI), June 12, 2018.

Hill, D.M. 1986. Cumberlandian mollusk conservation program, activity 3: Identification of fish hosts. Tennessee Valley Authority, Office of Natural Resources and Economic Development, Knoxville, Tennessee. 55 pp.

Hitt, N.P., M. Floyd, M. Compton, and K. McDonald. 2016. Threshold responses of Blackside Dace (*Chrosomus cumberlandensis*) and Kentucky Arrow Darter (*Etheostoma spilotum*) to stream conductivity. Southeastern Naturalist 15(1):41–60.

Hoggarth, M.A. 1992. The Unionidae and Corbiculidae of the Little Miami River system in southwestern Ohio. Walkerana 6(16):247–293.

Hoggarth, M.A. 2012. A report on a mussel survey of the Blanchard River at Interstate Route 75 bridge in Findlay, Hancock County, Ohio. Report prepared for Stantec Consulting Services, Inc. 19 pp.

Hoggarth, M.A., D.L. Rice, and T.L. Grove. 2000. The correlation of mussels with fish in the upper Blanchard River in Hardin and Hancock counties, Ohio, with special regard to the Rayed Bean (*Villosa fabalis*). Pp. 19–26 *in*: Tankersley, R.A., D.I. Warmholts, G.T. Watters, and B.T. Armitage, eds. Freshwater Mollusk Symposium Proceedings—Part I: Proceedings of the conservation, captive care and propagation of freshwater mussels symposium, March 1998. Ohio Biological Survey, Columbus.

Hoos, A.B., J.A. Robinson, R.A. Aycock, R.R. Knight, and M.D. Woodside. 2000. Sources, instream transport, and trends of nitrogen, phosphorus, and sediment in the lower Tennessee River basin, 1980–96: U.S. Geological Survey Water-Resources Investigations Report 99–4139. 96 pp.

Houp, R.E., and K.L. Smathers. 1995. Extended monitoring of mussels (Bivalvia: Unionidae) in the Rockcastle River at Billows, Kentucky, an historical site. Transactions of the Kentucky Academy of Science 56(3-4):114–116.

Howells, R.G, R.W. Neck, and H.D. Murray. 1996. Freshwater Mussels of Texas. Texas Parks and Wildlife Press. 224 pp.

Hubbard, W.D., D.C. Jackson, and D.J. Ebert. 1993. Channelization. Pp. 135–55 *in:* E.F. Bryan and D.A. Rutherford, eds. Impacts on warm-water streams: guidelines for evaluation. Warm-water Stream Committee, Southern Division, American Fisheries Society, Little Rock, Arkansas.

Hubbs, D.W. 2012. Orangefoot Pimpleback and Catspaw survey, Tennessee and Cumberland Rivers, Tennessee. Report prepared for Kentucky Waterways by Tennessee Wildlife Resources Agency, Project 7367. 52 pp.

Hubbs, D., D. McKinney, D. Sims, S. Lanier, and P. Black. 2006. Aggregate extraction impacts on unionid mussel species richness and density. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies (2006):169–173.

Hutson, C., and C. Barnhart. 2004. Survey of endangered and special concern mussel species in the Sac, Pomme de Terre, St. Francis, and Black River systems of Missouri, 2001-2003. Endangered species grant final report to the MDC. 379 pp.

[IDEM] Indiana Department of Environmental Management. 2001a. Flatrock-Haw Creek watershed restoration action strategy. Office of Water Management Report. 46 pp.

[IDEM] Indiana Department of Environmental Management. 2001b. Driftwood River watershed restoration action strategy. Office of Water Management Report. 52 pp.

[IDEM] Indiana Department of Environmental Management. 2008. Clifty Creek watershed comprehensive management plan. Office of Water Quality Report. 126 pp.

Illinois Natural History Survey. 2017. Mollusk collection Purple Lilliput record database query. Champaign, Illinois.

Integrated Taxonomic Information System. 2017. (*https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=80051#null*). Accessed October 1, 2018.

[IPCC] Intergovernmental Panel on Climate Change. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. 151 pp.

Irwin, K.L., and J.B. Alford. 2018. Survey of native mussels in the upper Duck and Harpeth River drainages, Tennessee. University of Tennessee Report submitted to the Tennessee Wildlife Resources Agency. 134 pp.

Isley, F.B. 1925. The freshwater mussel fauna of eastern Oklahoma. Proceedings of the Oklahoma Academy of Sciences 4:43–118.

Isom, B.G. 1969. The mussel resource of the Tennessee River. Malacologia 7(2–3):397–425.

Isom, B.G., and P. Yokley, Jr. 1968. The mussel fauna of Duck River in Tennessee, 1965. American Midland Naturalist 80(1):34–42.

Isom, B.G., Yokley, P., and C.H. Gooch. 1973. Mussels of the Elk River basin in Alabama and Tennessee 1965-1967. American Midland Naturalist 89(2):437–442.

Jackson, L.J., L. Corbett, and G. Scrimgeour. 2016. Environmental constraints on *Didymosphenia geminata* occurrence and bloom formation in Canadian Rocky Mountain lotic systems. Canadian Journal of Fisheries and Aquatic Sciences 73:964–972.

Jacobson, P.J., R.J. Neves, D.S. Cherry, and J.L. Farris. 1997. Sensitivity of glochidial stages of freshwater mussels (Bivalvia: Unionidae) to copper. Environmental Toxicology and Chemistry 16:2,384–2,392.

Jacobson, R.B., and A.T. Primm. 1994. Historical land-use changes and potential effects of stream disturbance in Ozark Plateaus, Missouri. USGS Open File Report 94–333.

Johnson, L.E., J.M. Bossenbroek, and C.E. Kraft. 2006. Patterns and pathways in the post-establishment spread of non-indigenous aquatic species: the slowing invasion of North American inland lakes by the Zebra Mussel. Biological Invasions 8:475–489.

Jones, J.R.E. 1962. Fish and river pollution. Elsevier. 212 pp.

Jones, J.W. 2015. Freshwater mussels of Virginia (Bivalvia: Unionidae): An introdution to their life history, status, and conservation. Virginia Journal of Science 66(3):309–331.

Jones, J.W., and R.J. Neves. 2007. Freshwater mussel status: Upper North Fork Holston River, Virginia. Northeastern Naturalist 14(3)471–480.

Jones, J.W., R.J. Neves, M.A. Patterson, C.R. Good, and A. DiVittorio. 2001. A status survey of freshwater mussel populations in the upper Clinch River, Tazewell County, Virginia. Banisteria 17:20–30.

Jones J.W., E.W. Hallerman, and R.J. Neves. 2006. Genetic management guidelines for captive propagation of freshwater mussels (Unionoidea). Journal of Shellfish Research 25(2):527–535.

Jones III, E.B.D., G.S. Helfman, J.O. Harper, and P.V. Bolstad. 1999. Effects of Riparian Forest Removal on Fish Assemblages in Southern Appalachian Streams. Conservation Biology 13(6):1,454–1,465.

[KDEP] Kentucky Department for Environmental Protection. 2014. Integrated Report to Congress on the condition of water resources in Kentucky, 2014, volume 1. Division of Water, Frankfort, Kentucky. 104 pp. + appendices.

Keller, A.E., and M. Lydy. 1997. Biomonitoring and the hazards of contaminants to freshwater mollusks. Unpublished report in: Freshwater mollusks as indicators of water quality: a workshop. U.S. Geological Survey Biological Resources Division and National Water Quality Assessment Program.

Kishi, D., M. Murakami, S. Nakano, and Y. Taniguchi. 2004. Effects of forestry on the thermal habitat of Dolly Varden (*Salvelinus malma*). Ecological Research 19:283–290.

Kolpin, D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barber, and H.T. Buxton. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999–2000: a national reconnaissance. Environmental Science and Technology 36(6):1,202–1,211.

Kondolf, G.M. 1997. Hungry water: Effects of dams and gravel mining on river channels. Environmental Management 21(4):533–551.

Kraemer, L.R. 1970. The mantle flap in three species of Lampsilis (Pelecypoda: Unionidae). Malacologia 10:225–282.

Kraemer, L.R. 1984. Aspects of the functional morphology of some fresh-water bivalve nervous systems: Effects on reproductive processes and adaptation of sensory mechanisms in the Sphaeriacea and Unionacea. Malacologia 25:221–239.

Lasier, P.J., M.L. Urich, S.M Hassan, W.N. Jacobs, R.B. Bringolf, K.M. Owens. 2016. Changing agricultural practices: Potential consequences to aquatic organisms. Environmental Monitoring and Assessment 2016 (12):188–672.

Lawler, J.J., D.J. Lewis, E. Nelson, A.J. Plantinga, S. Polasky, J.C. Withey, D.P. Helmers, S. Martinuzzi, D. Pennington, and V.C. Radeloff. 2014. Projected land-use change impacts on ecosystem services in the United States. Proceedings of the National Academy of Sciences 2014:55–57.

Layzer, J.B., and R.M. Anderson. 1992. Impacts of the coal industry on rare and endangered aquatic organisms of the upper Cumberland River basin. Kentucky Department of Fish and Wildlife Resources, Frankfort, and Tennessee Wildlife Resources Agency, Nashville. 118 pp.

Layzer, J.B., M.E. Gordon, and R.M. Anderson. 1993. Mussels: the forgotten fauna of regulated rivers. A case study of the Caney Fork River. Regulated Rivers: Research and Management 8:63–71.

Lea, I. 1831. Observations on the Naiads, and Descriptions of New Species of That and Other Families. Transactions of the American Philosophical Society 4(1834):63–121.

Lopes-Lima, M., L.E. Burlakova, A.Y. Karateyev, K. Mehler, M. Seddon, and R. Sousa. 2018. Conservation of freshwater bivalves at the global scale: diversity, threats, and research needs. Hydrobiologia 810 (1):1–14.

MacIsaac, H.G. 1996. Potential abiotic and biotic impacts of Zebra mussels on the inland waters of North America. American Zoologist 36:287–299.

March, F.A., F.J. Dwyer, T. Augspurger, C.G. Ingersoll, N. Wang, and C.A. Mebane. 2007. An evaluation of freshwater mussel toxicity data in the derivation of water quality guidance and standards for copper. Environmental Toxicology Chemistry 10:2,066–2,074.

Martin, E. and C. Apse. 2014. Northeast Aquatic Connectivity: An Assessment of Dams on Northeastern Rivers. The Nature Conservancy and Northeast Association of Fish and Wildlife Agencies. Brunswick, Maine. 102 pp.

Mather, C.M. 2005. The freshwater mussels of Oklahoma. Final report to the Oklahoma Department of Wildlife Conservation. 278 pp.

McGregor, S.W., and D.N. Shelton. 1995. A qualitative assessment of the unionid fauna of the headwaters of the Paint Rock and Flint Rivers of North Alabama and adjacent areas of Tennessee. Report by the Geological Survey of Alabama to the Alabama Department of Conservation and Natural Resources. 34 pp.

McGregor, S.W., and J.T. Garner. 2004. Changes in the freshwater mussel (Bivalvia: Unionidae) fauna of the Bear Creek system of northwest Alabama and northeast Mississippi. American Malacological Bulletin 18(1/2):61–70.

McMurray, S.E., and J.S. Faiman. 2018. Changes in the distribution and status of the freshwater mussel (Bivalvia: Unionida) fauna of the James River basin, Missouri. Southwestern Naturalist 63:102-111.

McMurray, S.E., and J.S. Faiman. 2019. Freshwater mussels of the North Fork River and Bryant Creek, Missouri. MDC report. 25 pp.

McLeod, J.M, H.L. Jelks, S. Pursifull, and N.A. Johnson. 2017. Characterizing the early life history of an imperiled freshwater mussel (*Ptychobranchus jonesi*) with host-fish determination and fecundity estimation. Freshwater Science 36(2):338–350.

Mellinger, P.J. 1972. The comparative metabolism of cadmium, mercury, and zinc as environmental contaminants in the freshwater mussel, *Margaritifera margaritifera*. Ph.D dissertation, Oregon State University, Corvallis. 129 pp.

Miller, A.C., and B.S. Payne. 1998. Effects of disturbances on large-river mussel assemblages. Regulated Rivers: Research and Management 14:179–190.

Mirarchi, R.E., J.T. Garner, M.F. Mettee, and P.E. O’Neil, eds. 2004. Alabama Wildlife. Volume 2. Imperiled aquatic mollusks and fishes. The University of Alabama press, Tuscaloosa, AL. 255 pp.

[MDC] Missouri Department of Conservation. 2001. Jacks Fork River watershed inventory and assessment. 198 pp.

[MDC] Missouri Department of Conservation. 2001. St. Francis River watershed inventory and assessment. 216 pp.

[MDC] Missouri Department of Conservation. 2003. Current River watershed inventory and assessment. 198 pp.

[MDC] Missouri Department of Conservation. 2000. Eleven Point River watershed inventory and assessment. 199 pp.

[MDC] Missouri Department of Conservation (no date). Elk River watershed inventory and assessment. 93 pp.

[MDC] Missouri Department of Conservation (no date). James River watershed inventory and assessment. 116 pp.

[MDC] Missouri Department of Conservation (no date). North Fork White River watershed inventory and assessment. 216 pp.

[MDC] Missouri Department of Conservation (no date). White River watershed inventory and assessment. 149 pp.

Moles, K.R., N.T. Welte, and J.B. Layzer. 2007. Mussel fauna of the Wolf River, Fentress and Pickett counties, Tennessee. Journal of the Tennessee Academy of Science 82(3–4):77–82.

Moles, K.R., and J.B. Layzer. 2008. Reproductive ecology of *Actinonaias ligamentina* (Bivalvia: Unionidae) in a regulated river. Journal of the North American Benthological Society 27(1):212–222.

Morowski, D., L.J. James, and R.D. Hunter. 2009. Freshwater mussels in the Clinton River, southeastern Michigan: an assessment of community status. Michigan Academician Report. 13 pp.

Morrison, J.P.E. 1942. Preliminary report on mollusks found in the shell mounds of the Pickwick Landing basin in the Tennessee River Valley. Pp. 337–392 in: W.S. Webb and D.L. DeJarnette, eds. An archeological survey of Pickwick basin in the adjacent portions of the states of Alabama, Mississippi, and Tennessee. Bureau of American Ethnology, Bulletin No. 129.

Mummert, A.K., R.J. Neves, T.J. Newcombe, and D.S. Cherry. 2003. Sensitivity of juvenile freshwater mussels (*Lampsilis fasciola*, *Villosa iris*) to total and un-ionized ammonia. Environmental Toxicology and Chemistry 22(11):2,545–2,553.

Myers-Kinzie, M.L., S.P. Wente, and A. Spacie. 2001. Occurrence and distribution of freshwater mussels in small streams of Tippecanoe County, Indiana. Proceedings of the Indiana Academy of Science 110:141–150.

Naimo, T.J. 1995. A review of the effects of heavy metals on freshwater mussels. Ecotoxicology 4:341–362.

NatureServe. 2019. Species report for *Toxolasma lividum*. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available at: <http://explorer.natureserve.org> (Accessed: May 20, 2019).

[NCASI] National Council for Air and Stream Improvement, Inc. 2015. 2 pp.

Neel, J.K., and W.R. Allen. 1964. The mussel fauna of the upper Cumberland basin before its impoundment. Malacologia 1(3):427–459.

Newton, T.J., J.W. Allran, J.A. O'Donnell, M.R. Bartsch, and W.B. Richardson. 2003. Effects of ammonia on juvenile unionid mussels (*Lampsilis cardium*) in laboratory sediment toxicity tests. Environmental Toxicology and Chemistry 22(11):2,554–2,560.

Newton, T.J., D.A. Woolnough, and D.L. Strayer. 2008. Using landscape ecology to understand and manage freshwater mussel populations. Journal of the North American Benthological Society 27(2):424–439.

Neves, R.J. 1987. Recent die-offs of freshwater mussels in the United States: an overview. Pp. 7–18 *in:* R.J. Neves (ed.). Proceedings of the workshop on die-offs of freshwater mussels in the United States, June 1986, Davenport, Iowa. Virginia Polytechnic Institute and State University, Blacksburg.

Neves, R.J. 1991. Mollusks. Pp. 251–319 *in:* K. Terwilliger, coordinator. Virginia’s endangered species. Proceedings of a symposium, April 1989, Blacksburg, Virginia. McDonald and Woodward Publishing Co., Blacksburg.

Neves, R.J. 1993. A state-of-the unionid address. Pp. 1–10 *in*: K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, October 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Neves, R.J., and M.C. Odom. 1989. Muskrat predation on endangered freshwater mussels in Virginia. Journal of Wildlife Management 53(4):934–941.

Neves, R. J., and P. L. Angermeier. 1990. Habitat alteration and its effects on native fishes in the upper Tennessee River system, east-central USA. Journal of Fish Biology 37:45–52.

Neves, R.J., A.E. Bogan, J.D. Williams, S.A. Ahlstedt, and P.W. Hartfield. 1997. Status of Aquatic Mollusks in the Southeastern United States: A Downward Spiral of Diversity;

Chapter 3 (Pp. 44–86) in Aquatic Fauna in Peril: The Southeastern Perspective, edited by G.W. Benz and D.E. Collins (1997), Special Publication 1. Southeast Aquatic Research Institute. Lenz Design and Communications, Decatur, Georgia. 554 pp.

Newton, T.J. 2003. The effects of ammonia on freshwater unionid mussels. Environmental Toxicology and Chemistry 22:3,543–3,544.

Newton, T.J., J.W. Allran, J.A. O'Donnell, M.R. Bartsch, and W.B. Richardson. 2003. Effects of ammonia on juvenile unionid mussels (*Lampsilis cardium*) in laboratory sediment toxicity tests. Environmental Toxicology and Chemistry 22:2,554–2,560.

Newton, T.J. and W.G. Cope. 2007. Biomarker responses of unionid mussels to environmental contaminants. Pp. 257-284 *in*: J.L. Farris and J.H. Van Hassel, eds. Freshwater Bivalve Ecotoxicology. CRC Press, Boca Raton, Florida.

Nichols, S.J., and D. Garling. 2000. Food‐web dynamics and trophic‐level interactions in a multispecies community of freshwater unionids. Canadian Journal of Zoology 78:871–882.

Nico, L.G., J.D. Williams, and H.L. Jelks. 2005. Black carp: biological synopsis and risk assessment of an introduced fish. American Fisheries Society Special Publication No. 32. 337 pp.

Nico, L.G., and M.E. Neilson. 2018. *Mylopharyngodon piceus* (Richardson, 1846): U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida, *https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=573*. Revision Date: August 6, 2018, Peer Review Date: April 1, 2016, Access Date: August 26, 2018.

[NISCMP] National Invasive Species Council Management Plan. 2018. *https://www.doi.gov/sites/doi.gov/files/uploads/2016-2018-nisc-management-plan.pdf*

Nobles, T., and Y. Zhang. 2011. Biodiversity Loss in Freshwater Mussels: Importance, Threats, and Solutions. Chapter 6 (pp. 137–162) in Biodiversity Loss in a Changing Planet, edited by O. Grillo and G. Venora (2011). InTech, Rijeka, Croatia. 328 pp.

Norman, D.E. 1994. Headwater Diversion Channel watershed inventory and assessment. Missouri Department of Conservation Fisheries Report. 87 pp.

Obermeyer, B.K., D.R. Edds, C.W. Prophet, and E.J. Miller. 1997. Freshwater mussels (Bivalvia: Unionidae) in the Verdigris, Neosho, and Spring River basins of Kansas and Missouri, with emphasis on species of concern. American Malacological Bulletin 14(1):41–55.

[ODNR] Ohio Department of Natural Resources; Ohio Division of Wildlife. 2015. Ohio's State Wildlife Action Plan. Columbus, Ohio, USA.

Ohio Environmental Protection Agency. 2007. Biological and water quality study of the Blanchard River (Putnam, Hancock, Seneca, Allen, Wyandot, and Hardin Counties, Ohio). OEPA Technical Report EAS/2007–6–2. 277 pp.

Oesch, R.D., 1984. Missouri Naiades: a guide to the mussels of Missouri. Missouri Department of Conservation. 271 pp.

Ohio Mussel Survey Protocol. 2018. Ohio Department of Natural Resources (ODNR), Division of Wildlife and U.S. Fish and Wildlife Service, Ohio Ecological Services Field Office. *https://wildlife.ohiodnr.gov/portals/wildlife/pdfs/licenses%20&%20permits/OH%20Mussel%20Survey%20Protocol.pdf* (Accessed October 1, 2018).

Oklahoma Conservation Commission. 2010. Watershed based plan for the Illinois River watershed. Oklahoma Conservation Commission Water Quality Division, Oklahoma City, Oklahoma. 171 pp.

Ortmann, A.E. 1918. The Nayades (freshwater mussels) of the upper Tennessee drainage, with notes on synonymy and distribution. Proceedings of the American Philosophical Society 57(6):521-626.

Ortmann, A.E. 1921. The anatomy of certain mussels from the upper Tennessee. The Nautilus 34(3):81–91.

Ortmann, A.E. 1925. The naiad fauna of the Tennessee River system below Walden Gorge. American Midland Naturalist 9(8):321–372.

[OSUM] Ohio State University Museum Mollusk Collection. 2018. Museum Database Query by Andrew Henderson, U.S. Fish and Wildlife Service, Asheville, North Carolina.

Parmalee, P.W. 1988. A comparative study- of late prehistoric and modern molluscan faunas of the Little Pigeon River system, Tennessee. American Malacological Bulletin 6(2):165–178.

Parmalee, P.W., and A.E. Bogan. 1998. The freshwater mussels of Tennessee. The University of Tennessee Press, Knoxville, Tennessee. 328 pp.

Parmalee, P.W., and H.D. Faust. 2006. Diversity and relative abundance of preimpoundment freshwater mussel (Bivalvia: Unionidae) populations in the lower Holston River, Tennessee. Journal of the Tennessee Academy of Science 81(3–4):73–78.

Parmalee, P.W., and R.R. Polhemus. 2004. Prehistoric and pre-impoundment populations of freshwater mussels (Bivalvia: Unionidae) in the South Fork Holston River, Tennessee. Southeastern Naturalist 3(2):231 –240.

Parmalee, P.W., and W.E. Klippel. 1984. The Naiad Fauna of the Tellico River, Monroe County, Tennessee. American Malacological Bulletin 3(1):41–44.

Patnode, K.A., R.M. Anderson, L. Zimmermann, E. Hittle, and J.W. Fulton. 2015. Effects of high salinity wastewater discharges on unionid mussels in the Allegheny River, Pennsylvania. Journal of Fish and Wildlife Management 6(1):55–70.

Peacock, E., W.R. Haag, and M.L. Warren, Jr. 2005. Prehistoric decline in freshwater mussels coincident with the advent of maize agriculture. Conservation Biology 19(2):547–551.

Pilsbry, H.A., and S.N. Rhoads. 1896. Contributions to the zoology of Tennessee. No. 4, Mollusks. Proceedings of the Academy of Natural Sciences of Philadelphia 48:487–506.

Poff, N.L., M.M. Brinson, and J.W. Day, Jr. 2002. Aquatic ecosystems and Global climate change: Potential Impacts on Inland Freshwater and Coastal Wetlands Ecosystems in the United States. Pew Center on Global Climate Change. 56 pp.

Poulton, B.C., P.T. Kroboth, A.E. George, D.C. Chapman, J. Bailey, S.E. McMurray, and J.S. Faiman. 2019. First examination of diet items consumed by wild-caught Black Carp (*Mylopharyngodon piceus)* in the U.S. American Midland Naturalist 182:89–108.

Price, J.E., C.E. Zipper, J.W. Jones, and C.T. Franck. 2014. Water and Sediment Quality in the Clinch River, Virginia and Tennessee, USA, over Nearly Five Decades. Journal of the American Water Resources Association 50(4):837–858.

Rahm, E.J. 2008. Spatial distribution and microhabitat of adult and juvenile mussels (Bivalvia: Unionidae) within a bed. Unpublished Master's Thesis, Tennessee Technological University. Cookeville, Tennessee. 52 pp.

Reed, M.P. 2014. Freshwater mussels (Bivavia: Margaritiferidae and Unionidae) of the Buffalo River drainage, Tennessee. University of Tennessee, unpublished Master's Thesis. 98 pp.

Ren, W., Y. Zhong, J. Meligrana, B. Anderson, W.E. Watt, J. Chen, H. Leung. 2003. Urbanization, land use, and water quality in Shanghai: 1947–1996. Environment International 29(5):649–659.

Ricciardi, A., R.J. Neves, and J.R. Rasmussen. 1998. Impending extinctions of North American freshwater mussels (Unionoida) following the zebra mussel (*Dreissena polymorpha*) invasion. Journal of Animal Ecology 67:613–619.

Roe, K.J. 2002. Conservation assessment for the Purple Lilliput (*Toxolasma lividus)* Rafinesque, 1831. USDA Forest Service, Eastern Region. 11 pp.

Sams, J.I., and K.M. Beer. 2000. Effects of coal-mine drainage on stream water quality in the Allegheny and Monongahela river basins – sulfate transport and trends. Water-Resources Investigations Report 99-4208. U.S. Geological Survey, National Water-Quality Assessment Program, Lemoyne, Pennsylvania. 17 pp.

Scheller, J.L. 1997. The effects of dieoffs of Asian Clams (*Corbidula fluminea*) on Native Freshwater Mussels (Unionidae). M.S. thesis. Virginia Polytechnic Institute and State University. 100 pp.

Schloesser, D.W., T.F. Nalepa, and G.L. Mackie. 1996. Zebra Mussel Infestation of Unionid Bivalves (Unionidae) in North America. American Zoologist 36:300–310.

Schloesser, D.W., W.P. Kovalak, G.D. Longton, K.L. Ohnesorg, and R.D. Smithee. 1998. Impact of zebra and quagga mussels (Dreissena spp.) on freshwater unionids (Bivalvia: Unionidae) in the Detroit River of the Great Lakes. The American Midland Naturalist 140:299-313.

Schloesser, D.W., J.L. Metcalfe-Smith, W.P. Kovalak, G.D. Longton, and R.D. Smithee. 2006. Extirpation of freshwater mussels (Bivalvia: Unionidae) following the invasion of Dreissenid mussels in an interconnecting river of the laurentian Great Lakes. The American Midland Naturalist 155(2): 307-320.

Schmerfeld, J. 2006. Reversing a textbook tragedy. Endangered Species Bulletin 31(1):12–13.

Schuster, G.A. 1988. The distribution of unionids (Mollusca: Unionidae) in Kentucky. Kentucky Department of Fish and Wildlife Resources, Frankfort. 1,099 pp.

Seaber, P.R., F.P. Kapinos, G.L. Knapp. 1987. Hydrologic Unit Map, U.S. Geological Survey Water-Supply Paper 2294. 63 pp.

[Service] U.S. Fish and Wildlife Service. 2009. Species assessment and listing priority assignment form – *Quadrula cylindrica cylindrica*. 65 pp.

[Service] U.S. Fish and Wildlife Service. 2011. Endangered and Threatened Wildlife and Plants; Partial 90-Day Finding on a Petition to List 404 Species in the Southeastern United States as Endangered or Threatened With Critical Habitat. 76 FR 59836–59862.

[Service] U.S. Fish and Wildlife Service. 2015. Programmatic safe harbor agreement and candidate conservation agreement with assurances for the Arkansas Fatmucket, Pink Mucket, Spectaclecase, Rabbitsfoot, Harperella and Twenty other Aquatic Species of Greatest Conservation Need in the upper Saline, Caddo, and Ouachita River (Headwaters) Watersheds, Arkansas. Arkansas Game & Fish Commission, The Nature Conservancy's Arkansas Field Office, Natural Resources Conservation Service, and The U.S. Fish and Wildlife Service. 91 pp.

[Service] U.S. Fish and Wildlife Service. 2016. U. S. Fish and Wildlife Service Species Status Assessment Framework: an integrated analytical framework for conservation. Version 3.4, dated August 2016.

[Service] U.S. Fish and Wildlife Service. 2017. Species status assessment report for the Atlantic Pigtoe (*Fusconaia masoni*). Version 1.2. March 2017. Atlanta, Georgia.

[Service] U.S. Fish and Wildlife Service. 2018. Species biological report for the Yellowcheek Darter (*Etheostoma moorei*). Conway, Arkansas.

[Service] U.S. Fish and Wildlife Service. 2018. Longsolid Mussel (Fusconaia subrotunda) Species Status Assessment. Version 1 Draft Report, November 2018.

[Service] U.S. Fish and Wildlife Service. 2019a. Unpublished data prepared and analyzed for management units and Purple Lilliput populations, Asheville, North Carolina.

[Service] U.S. Fish and Wildlife Service. 2019b. Unpublished data prepared and analyzed for management units and Round Hickorynut populations, Asheville, North Carolina.

Shafii, M. 2009. Total Maximum Daily Load (TMDL) for pH, Mulberry River, Arkansas. Arkansas Department of Environmental Quality. 21 pp.

Sickel, J.B. 1982. A survey of the freshwater mussel of the lower Cumberland River from Barkley Dam tailwater downstream to the Ohio River. Report to the U.S. Army Corps of Engineers, Nashville District. 24 pp.

Sickel, J.B., and C.C. Chandler. 1996. Unionid fauna of the lower Cumberland River from Barkley Dam to the Ohio River, Kentucky (Mollusca: Bivalvia: Unionidae). Transactions of the Kentucky Academy of Science 57(1):33–46.

Smith, D.R., R.F. Villella and D.P. Lemarie. 2003. Application of adaptive cluster sampling to low-density populations of freshwater mussels. Environmental and Ecological Statistics 10:7-15.

Smith, T.A., and E.S. Meyer. 2010. Freshwater mussel (Bivalvia: Unionidae) distributions of the Habitat Relationships in the navigational pools of the Allegheny River, Pennsylvania. Northeastern Naturalist 17(4):541–564.

Sparks, B.L., and D.L. Strayer. 1998. Effects of low dissolved oxygen on juvenile *Elliptio complanata* (Bivalvia: Unionidae). Journal of the North American Benthological Society 17(1):129–134.

Spooner, D. and C.C. Vaughn. 2008. A trait-based approach to species' roles in stream ecosystems: climate change, community structure, and material cycling. Oecologia 158:307–317.

Strayer, D.L. 1979. Some recent collections of mussels from southeastern Michigan. Malacological Review 12:93–95.

Strayer, D.L. 1980. The freshwater mussels (Bivalvia: Unionidae) of the Clinton River, Michigan, with comments on man's impact on the fauna, 1870-1978. The Nautilus 94(4):142–149.

Strayer, D.L. 1999. Use of flow refuges by unionid mussels in rivers. Journal of the North American Benthological Society 18(4):468–476.

Strayer, D.L. 2008. Freshwater mussel ecology: a multifactor approach to distribution and abundance. Vol. 1. University of California Press. 216 pp.

Strayer, D.L., J.A. Downing, W.R. Haag, T.L. King, J.B. Layzer, T.J. Newton, and S.J. Nichols. 2004. Changing perspectives on pearly mussels, North America's most imperiled animals. BioScience 54(5):429–439.

Strayer, D.L., and H.M. Malcom. 2012. Causes of recruitment failure in freshwater mussel populations in southeastern New York. Ecological Applications 22:1,780–1,790.

Stodola, A.P., S.A. Bales, and D.K. Shasteen. 2013. Freshwater mussels of the Vermilion and Little Vermilion rivers in the Wabash River in Illinois. Illinois Natural History Survey Technical Report 2013 (27). 31 pp.

Stodola, A.P., S.A. Douglass, and D.K. Shasteen. 2014. Historical and current distributions of freshwater mussels in Illinois. Illinois Natural History Survey Technical Report 2014 (37). 83 pp.

Taylor, S.E., R. Rummer, K.H. Yoo, R.A. Welch, and J.D. Thompson. 1999. What we know and don't know about water quality at stream crossings. Journal of Forestry 97(8):12–17.

[TDEC] Tennessee Department of Environment and Conservation. 2014. 2014 305(b) report: the status of water quality in Tennessee. Division of Water Pollution Control, Nashville, Tennessee. 114 pp.

Tiemann, J.S., K.S. Cummings, and C.A. Mayer. 2007. Updates to the distributional checklist and status of Illinois freshwater mussels (Mollusca: Unionidae). Transactions of the Illinois State Academy of Science. 100(1):107-123.

Tiemann, J.S., K.S. Cummings, and C.A. Phillips. 2011. Mollusks of the Shawnee National Forest, Illinois. Illinois Natural History Survey Technical Report 2011(5). 44 pp.

Terando, A.J., J. Costanza, C. Belyea, R.R. Dunn, A. McKerrow, J.A. Collazo. 2014. The southern megalopolis: Using the past to predict the future of urban sprawl in the southeast United States. PLOS ONE 9(7):1–8.

Trombulak, S.C. and C.A. Frissell. 2000. Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities. Conservation Biology 14(1):18–33.

Tyrrell, M., and D.J. Hornbach. 1998. Selective predation by muskrats on freshwater mussels in two Minnesota rivers. Journal of the North American Benthological Society 17(3):301–310.

[USGS] U.S. Geological Survey. 2018. Effects of Urbanization on Stream Ecosystems. *http://water.usgs.gov/nawqa/urban/* (Accessed: October 1, 2018).

[USGS] U.S. Geological Survey. 2018. *https://water.usgs.gov/GIS/huc.html*. (Accessed: October 1, 2018).

[USGCRP] U.S. Global Climate Change Research Program. 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC. 470 pp.

Valenti, T.W., D.S. Cherry, R.J. Neves, and J. Schmerfeld. 2005. Acute and chronic toxicity of mercury to early life stages of the rainbow mussel, *Villosa iris* (Bivalvia: Unionidae). Environmental Toxicology and Chemistry 24(5):1,242–1,246.

Van Hassel, J.H. 2007. Case Study: Discrimination of Factors Affecting Unionid Mussel Distribution in the Clinch River, Virginia, USA. Pp. 311-333. *in:* J.L. Farris and J.H. Van Hassel, eds. Freshwater Bivalve Ecotoxicology. CRC Press, Boca Raton, Florida.

Van Hees, E.H.P., E.I.B. Chopin, T.M. Sebastian, G.D. Washington, L.M. Germer, P. Domanski, D. Martz, L. Schweitzer. 2010. Distribution, sources, and behavior of trace elements in the Clinton River watershed Michigan. Journal of Great Lakes Research 36(4):606–617.

Vaughn, C.C. 2003. The mussel fauna of the Glover River, Oklahoma. Proceedings of the Oklahoma Academy of Science 83:1–6.

Vaughn, C.C. 2012. Life history traits and abundance can predict local colonization and extinction rates of freshwater mussels. Freshwater Biology 57(5):982–992.

Vaughn, C.C., and C.M. Taylor. 1999. Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. Conservation Biology 13:912–920.

Vaughn, C.C., and D.E. Spooner. 2004. Status of the mussel fauna of the Poteau River and implications for mussel harvest. The American Midland Naturalist 152(2):336–346.

Vaughn, C.C., S.J. Nichols, and D. Spooner. 2008. Community and foodweb ecology of freshwater mussels. Journal of the North American Benthological Society 27(2):409-423.

Vidic, R.D., S.L. Brantley, J.M. Vandenbossche, D. Yoxtheimer, and J.D. Abad. 2013. Impact of shale gas development on regional water quality. Science 340(1235009):1–9.

Wang, N., C.G. Ingersoll, I.E. Greer, D.K. Hardesty, C.D. Ivey, J.L. Kunz, W.G. Brumbaugh, F.J. Dwyer, A.D. Roberts, T. Augspurger, C.M. Kane, R.J. Neves, and M.C. Barnhart. 2007. Chronic toxicity of copper and ammonia to juvenile freshwater mussels (Unionidae). Environmental Toxicology and Chemistry 26(10):2,048–2,056.

Warrington, B.M., W.M. Aust, S.M. Barrett, W.M. Ford, C.A. Dolloff, E.B. Schilling, T.B. Wigley, and M.C. Bolding. 2017. Forestry best management practices relationships with aquatic and riparian fauna: A review. Forests 8(331):1–16.

Watters, G.T. 1988. A survey of the freshwater mussels of the St. Joseph River system, with emphasis on the federally endangered white cat's paw pearly mussel. Indiana Department of Natural Resources, West Lafayette. 127 pp.

Watters, G.T. 1998. Freshwater mussel survey of the St. Joseph River drainage, exclusive of Fish Creek. Final report to the Indiana chapter of The Nature Conservancy. 91 pp.

Watters, G.T. 2000. Freshwater mollusks and water quality: effects of hydrologic and instream habitat alterations. Pp. 261–274 *in*: P.D. Johnson and R.S. Butler, eds. Freshwater Mollusk Symposium Proceedings—Part II: musseling in on…biodiversity. Proceedings of the 1st symposium of the Freshwater Mollusk Conservation Society, March 1999, Chattanooga, Tennessee. Ohio Biological Survey, Columbus.

Watters, G.T., M.A. Hoggarth, and D.H. Stansbery. 2009. The Freshwater Mussels of Ohio. The Ohio State University Press, Columbus, Ohio. 421 pp.

Watters, G.T., and C.J.M. Flaute. 2010. Dams, zebras, and settlements: The historical loss of freshwater mussels in the Ohio River mainstem. American Malacological Bulletin 28:1–12.

Webster, J.R., S.W. Golladay, E.F. Benfield, J.L. Meyer, W.T. Swank, and J.B. Wallace. 1992. Catchment disturbance and stream response: An overview of stream research at Coweeta Hydrologic Laboratory. *In*: River conservation and management, P.J. Boon, P. Calow and G.E. Petts, eds. 231–253. Chichester, England: John Wiley and Sons Ltd.

Wenger, S. 1999. A Review of the Scientific Literature on Riparian Buffer Width, Extent, and Vegetation. University of Georgia, Institute of Ecology, Athens, Georgia. 59 pp.

Wentz, N.J., N.D. Henderson, and A.D. Christian. 2011. Assessment and characterization of physical habitat, water quality, and biotic assemblages of the Tyronza River, Arkansas. Journal of the Arkansas Academy of Science 65(21):143–Wa152.

Wheeler, A.P., P.L. Angermeier, and A.E. Rosenberger. 2005. Impacts of new highways and subsequent landscape urbanization on stream habitat and biota. Reviews in Fishery Science 13:141–164.

Wilson, C.B., and H.W. Clark. 1914. The mussels of the Cumberland River and its tributaries. Report to the U.S. Commission of Fisheries for 1912, Special Papers. 63 pp.

Wilson, C.O. 2015. Land use/land cover water quality nexus: quantifying anthropogenic influences on surface water quality. Environmental Monitoring and Assessment 187(7):424.

Williams, J.D., M.L. Warren, Jr., K.S. Cummings, J.L. Harris, and R.J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18(9):6–22.

Williams, J.D., A.E. Bogan, and J.T. Garner. 2008. Freshwater mussels of Alabama and the Mobile Basin of Georgia, Mississippi, and Tennessee. University of Alabama Press, Tuscaloosa.

Williams, J.D., A.E. Bogan, R.S. Butler, K.S. Cummings, J.T. Garner, J.L. Harris, N.A. Johnson, and G.T. Watters. 2017. A revised list of the freshwater mussels (Mollusca: Bivalvia: Unionida) of the United States and Canada. Freshwater Mollusk Biology and Conservation 20:33–58.

Wolf, S., B. Hartl, C. Carroll, M.C. Neel, and D.N. Greenwald. 2015. Beyond PVA: Why recovery under the Endangered Species Act is more than population viability. BioScience 65(2):200–207.

Woodside, M.D., Hoos, A.B., Kingsbury, J.A., Powell, J.R., Knight, R.R., Garrett, J.W., Mitchell, III, Reavis L., and Robinson, J.A. 2004. Water quality in the Lower Tennessee River basin, Tennessee, Alabama, Kentucky, Mississippi, and Georgia, 1999–2001: Reston, Virginia, U.S. Geological Survey Circular 1233. 38 pp.

Yeager, M.M., D.S. Cherry, and R.J. Neves. 1994. Feeding and burrowing behaviors of juvenile rainbow mussels, *Villosa iris* (Bivalvia: Unionidae). Journal of the North American Benthological Society 13(2):217–222.

Zipper, C.E., B. Beaty, G.C. Johnson, J.W. Jones, J.L. Krstolic, B.J.K. Ostby, W.J. Wolfe, and P. Donovan. 2014. Freshwater mussel population status and habitat quality in the Clinch River, Virginia and Tennessee, USA: A featured collection. Journal of the American Water Resources Association 50(4):807–819.

APPENDIX A—CURRENT EXTANT PURPLE LILLIPUT POPULATIONS AND MANAGEMENT UNITS.

**Includes magnitude and immediacy of potential threats negatively influencing the viability of purple Lilliput currently extant populations.*

GREAT LAKES BASIN = 3 populations and 3 MUs
OHIO RIVER BASIN = 31 populations and 11 MUs
CUMBERLAND RIVER BASIN = 10 populations and 7 MUs
TENNESSEE RIVER BASIN = 32 populations and 10 MUs
LOWER MISSISSIPPI RIVER BASIN = 21 populations and 11 MUs
ARKANSAS-WHITE-RED BASIN = 49 populations and 23 MUs
TOTAL POPULATIONS = 146; TOTAL MUs = 65

Managment Unit	Record State	Contiguous Population (occupied river/stream)	Year of Last Live or Fresh Dead Observation	Threat (low, moderate, high)	Threats Summary	Threats Reference
Great Lakes						
St. Joseph River	MI	Lake Wilson	2005	Low	Water quality degradation and agricultural impacts	The overall destruction of habitat, increased turbidity and draining of historic spawning sites had considerable impacts on the aquatic community of the Maumee. (Grabarkiewicz and Crail 2006 p. 4).
Blanchard	OH	Blanchard River	1995 Live; Relic collected by Hoggarth 2012 (p. 7).	Moderate	Habitat and water quality degradation	Hoggarth 2012, p. 4 states that siltation and fine sediments are dominant throughout the northern half of the river, Hoggarth *et al.* 2000, p. 23 stated that bedrock substrates were predominant at 4 of 11 sites in the upper river sections. EnviroScience 2016, p. 8, state that localized scour with litte available habitat limited mussel occurrence at a silt collector construction site. Lack of suitable mussel habitat is likely limiting the Purple Lilliput distribution and dispersal in the Blanchard River.

Clinton	MI	Clinton River	2004	High	Human population growth (an increase from 300,000 in 1930s to 1.6 mil in 2005), resulting in suburban sprawl and industrialization, and leading to heavy metal contamination and pollution. Water quality degradation through urban and storm water runoff as well as habitat alteration through geomorphic instability (soil erosion, scour, bank erosion, and flooding) (Morowski et al 2009, p. 9). The presence of zebra mussels in the watershed has led to changes in mussel population dynamics.	The Clinton River watershed has a range of trace element concentrations in its surficial sediments which reached levels similar to that found in known contaminated and larger watersheds characterized by heavy industrialization, urbanization and contamination. Agricultural land use was also characterized by elevated As and Mn as a result of irrigation, herbicide, pesticide and fertilizer treatments. (Van Hees *et al*. 2010, p. 618). Despite the appearance of two species of exotic bivalves since the 1978 study, only the invasive zebra mussel is likely to have had an impact. Like many semi-urban watersheds, the Clinton River has suffered from increases in % imperviousness that have led to increased storm water runoff, geomorphologic instability (bottom scouring and stream bank erosion), and increased non-point source contaminant concentrations. Regulation of lake level control structures in drought months has contributed to hydrodynamic instability. Unionids of the Clinton River therefore face two primary threats: watershed urbanization and exotic species invasion (Morowski *et al.* 2009, p. 1). There have been clear negative effects of zebra mussels on unionids in the Clinton system but those effects are primarily observed in lakes.
Ohio						
Upper Green	KY	Russell Creek	2001	Low	Similar to others in in MU	The aquatic fauna of the upper Green River drainage is affected by impoundments, intensive agriculture, and oil drilling (Haag and Cicerello 2016, p. 17).
	KY	Green River	2013	Moderate	Impoundment - habitat loss	Although there are multiple dams on the Green River mainstem, there is a large amount of riverine habitat available in numerous reaches. The KY CWCS lists the following as threats to the species: Aquatic habitat

Upper Green, cont.						degradation, loss of fish hosts, point and non-point source pollution, siltation and increased turbidity. Cochran and Layzer 1993, p. 64, determined that mussels in the middle Green and Lower Barren Rivers selected habitats that were less impacted by commercial harvest activities, although harvest was lighter in the Barren than the Green.
Vermillion	IL, IN	Jordan Creek	2014	Moderate	Human development, mining	Stodola 2013, p. 8, cites municipal wastewater effluent, channelization, impoundments and mining operations in the Vermilion River drainage of the Wabash Basin.
	IL	Middle Fork North Fork Vermilion River	2014			
	IL, IN	North Fork Vermilion river	2014			
	IL	Middle Fork Vermilion River	2002			
Low Ohio Bay	IL	Big Grand Pierre Creek	2010	Low	Human development, agriculture	The area has been relatively free of domestic and industrial pollutants but has been degraded by certain agricultural practices Tiemann *et al.* 2011, p. 2. Drought conditions
Middle Wabash - Little Vermillion	IN	Little Pine Creek	1995; Myers-Kinzie et al. 2001	Moderate	Agricultural impacts	Myers-Kinzie *et al.* 2001, p. 148 cite ditching to facilitate agricultural drainage as a primary threat, as well as isolation from other populations.
	IN	Big Pine Creek	2013	Moderate	Similar to others in in MU	No recent information
	IN	North Fork Coal Creek	2007	Moderate		No recent information
Tippecanoe	IN	Kuhn Lake	2016	Moderate	Similar to others in in MU	These lakes lie in a highly agricultural region in the upper Tippecanoe River watershed. Kuhn Lake was invaded by the zebra mussel in 1995, with 10 % of suitable lakes invaded in Indiana (Johnson *et al.* 2006, p. 484). Allen 1921, p. 229 cites a variety of factors influencing the mussel populations in Lakes in IN at the time - muskrats, wave action, and limited substrates suitable for mussel settlement and growth, as well as past dredging activities
	IN	Sechrist Lake	2014	Moderate		
Tippecanoe	IN	Lake Maxinkuckee & outlet	1999	Moderate		

	IN	Grassy Creek	2010	Moderate	Similar to others in in MU	No recent information
Tippecanoe	IN	Tippecanoe	2012	Moderate	Agriculture, Impoundment, nonnative species	Water withdrawal for irrigation, drought in 2012 (Fisher 2018, pers. comm.). Mussel threats in the Tippecanoe River were noted by Cummings and Berlocher (1990) and Ecological Specialists, Inc. (1993). They include evidence of nutrient enrichment manifest in abundance of filamentous algae in some reaches. Turbidity increases in downstream areas indicated that streambank and other sources of erosion were more prevalent than they were upstream. Unrestricted cattle access in some riparian areas is a sedimentation and nutrification concern. The extent of suitable habitat in the lower river has been compromised by two major reservoirs, Shafer and Freeman. Mussel populations in general below the impoundments were highly localized in deeper pools and comprised primarily of species indicative of slow water and soft substrate habitats generally associated with impoundments. This indicated to them that riffle habitats may be impacted by tailwater conditions, such as temporary exposure during low flow releases. The zebra mussel is known from the watershed for over 20 years but don't appear to directly impact mussels (Fisher 2018, pers. comm.).
		Big Monon Ditch	2016	Moderate	Similar to others in in MU	No recent information
Muscatatuck	IN	Vernon Fork Muscatatuck River	1992	Moderate	Similar to others in in MU	No recent information
		Graham Creek	2005	Moderate		
		Big Creek	2007	Moderate		
Upper East Fork White	IN	Clifty Creek	1994	Moderate	Water quality degradation due to agricultural impacts, and habitat loss through anthropogenic activities such as high impact recreation causing stream bank erosion and livestock access.	Predominantly agricultural (92 percent), land use for the Clifty Creek Watershed is characterized by corn and soy croplands with occasional grain, produce, greenhouse, and pastoral operations. Livestock operations vary throughout the watershed, ranging from small, concentrated hobby farms to large-scale feeding operations (IDEM 2008, p. 10). IDEM cites unstable stream banks and illegal dumping of appliances and tires, as well as sedimentation issues associated with overland runoff of exposed soil and stream bank erosion due to livestock access and ATV usage (IDEM 2008, pp. 67–68). Exceedingly high levels of phosphorous persist upstream and downstream of Columbus, IN.

Flatrock-Haw	IN	Flatrock River	2012	Moderate	Water quality degradation and agricultural impacts	The Flatrock River in Rush and Shelby counties are listed as 303d with fish consumption advisories for PCBs and Mercury (IDEM 2001a, p. 4). These designations indicate that water quality degradation and metal contamination are issues in the watershed. The Flatrock watershed is predominately in agricultural lands (IDEM 2001a, Figure 2-3).
Driftwood	IN	Brandywine Creek	1991	Moderate	Water quality degradation and agricultural impacts	Brandywine Creek, the Little Blue River, and Sugar Creek in Hancock, Shelby and Johnson counties are listed as 303d with fish consumption advisories for PCBs and Mercury (IDEM 2001b, p. 4). These designations indicate that water quality degradation and metal contamination are issues in the watershed. The Driftwood watershed is predominately in agricultural lands (IDEM 2001b, Figure 2-3).
		Little Blue River	1993	Moderate		
		Sugar Creek (Hancock, Shelby Co.)	1990	Moderate		
Eel (Wabash River trib.)	IN	Cedar Lake	1999	Moderate	Water quality degradation and agricultural impacts	These lakes lie in a highly agricultural region in the upper Eel River watershed.
		Round Lake	2014	Moderate		
		Shriner Lake	2014	Moderate		
Eel (Wabash River trib.)	IN	Eel River	2007	Moderate	Impoundment; Habitat and water quality degradation	A dam at the mouth of the Eel River precludes movement from the Wabash River into the Eel. Gammon and Gammon (1993 pp. 78–79, mention stream channelization activities causing erosion and scoured banks, as well as lack of riparian vegetation, and non-point source pollution leading to measured high turbidity readings, and high levels of suspended sediment
		Paw Paw Creek	2001	Moderate	Similar to others in in MU	No recent information
Cumberland						
South Fork Cumberland	KY	Little South Fork Cumberland River	2013	High	Mining impacts	Ahlstedt *et al.* (2014, p. 7): All previous studies referenced in this report implicate the impacts that resource extraction have had on the LSF mussel fauna. Clearly, the findings of our survey have determined that river conditions are not currently suitable for mussel population restoration activities to be initiated.
Rockcastle	KY	Horse Lick Creek	2003	High	Mining impacts	Enigmatic decline (Haag 2019, p. 7; Resource Extraction (Oil Drilling), (Haag and Cicerello 2016, p. 15). Houp and Smathers 1995 cite surface mining in the headwaters and excessive sedimentation as affecting the mussel fauna in the Rockcastle drainage.

Obey	TN	Wolf River	2005-2006	Moderate	Lack of suitable substrates	Availability of suitable habitat appears to be a major factor limiting mussel abundance and distribution in the Wolf River; substrates in the upper reaches of the river are dominated by bedrock (Moles *et al.* 2007, p. 81).
Upper Cumberland - Lake Cumberland	KY	Buck Creek	2003	High	Resource Extraction (Oil Drilling) (Haag and Cicerello 2016, p. 15).	Enigmatic decline (Haag 2019, p. 7; Haag and Cicerello (2016, p. 14): The middle Cumberland River drainage has been completely transformed by Wolf Creek Dam. Sickel and Chandler 1996 p. 45 cite Impoundment (both Barkley Dam and Lock and Dam 52 on the Ohio) and pollution as primary impacts to the mussel fauna in the Cumberland River, and impoundment as the primary cause for changes in mussel species composition.
Lower Cumberland-Old Hickory Lake	TN	Peyton Creek	2015	Moderate	water quality degradation, lack of suitable habitat	These streams lie on the Cumberland Plateau which are characterized by poorly buffered soils and dominated by bedrock substrates. Although mining activities are present in the watershed, these basins are not in an intensively mined area. Hitt *et al.* (2016, p. 55) cite high levels of stream conductivity as influencing imperiled fish abundance in upper Cumberland River drainage tributaries.
		Goose Creek	2015	Moderate		
		Little Goose Creek	2015	Moderate		
Upper Cumberland-Cordell Hull Reservoir	TN	Flynn Creek	2015	Moderate	water quality degradation, lack of suitable habitat	These streams lie on the Cumberland Plateau which are characterized by poorly buffered soils and dominated by bedrock substrates. Although mining activities are present in the watershed, these basins are not in an intensively mined area. Hitt *et al.* (2016, p. 55) cite high levels of stream conductivity as influencing imperiled fish abundance in upper Cumberland River drainage tributaries.
Caney	TN	Hickman Creek	2015	Moderate	water quality degradation, lack of suitable habitat	These streams lie on the Cumberland Plateau which are characterized by poorly buffered soils and dominated by bedrock substrates. Although mining activities are present in the watershed, these basins are not in an intensively mined area. Hitt *et al.* (2016, p. 55) cite high levels of stream conductivity as influencing imperiled fish abundance in upper Cumberland River drainage tributaries.
		Smith Fork	2015	Moderate		
Tennessee						
Pickwick Lake	AL	Cypress Creek	2015	Moderate	Agricultural impacts, human development	Johnston *et al.* (2013, p. 3,254) cite fish passage barriers such as culverts, habitat degradation due to agricultural impacts, and the loss of aquatic habitats to the construction of farm ponds.
Pickwick Lake	AL	Shoal Creek	2003	Moderate		
		Town Creek (Colbert/ Lawrence Co.)	1996	Moderate	Water quality degradation due to agricultural impacts and human	Similar to others in in MU

					development (ammonia)	
		Big Nance Creek	2015	Low	Water quality degradation due to agricultural impacts and human development (ammonia)	Big Nance Creek, a part of the Tennessee River basin, is located in Lawrence County near Courtland, Alabama. It has been on the State of Alabama's §303(d) use impairment list since 1992 for organic enrichment & low dissolved oxygen (O.E./D.O.), and ammonia as nitrogen (NH3-N), as well as siltation (ADEM 2002, p. 4).
		Tennessee River (Wilson Dam tailwaters/ Pickwick Reservoir)	2016	High	Impoundment, dredging/navigation impacts	Isom (1969, p. 410) reported the species from the Sevenmile Island Area Muscle Shoals, Wilson Dam tailwater (TRM 247-253). The 53 RM reach of the Tennessee River in northwestern Alabama collectively referred to as Muscle Shoals historically harbored 69 species of mussels, making it the most diverse mussel fauna ever known from a single river reach (Garner and McGregor 2001). The construction of three dams (i.e., Wilson in 1925, Wheeler in 1930, Pickwick Landing in 1940) inundated most of the historical mussel habitat, leaving approximately 13 RMs of riverine habitat. The largest remnant habitat remaining is the Wilson Dam tailwaters, a several mile reach adjacent to, and downstream from, Florence, Alabama (Garner and McGregor 2001).
Buffalo	TN	Buffalo River	2011; 2013	Moderate	Agricultural impacts	Reed 2014, p. 13 cites increases in human population and associated municipal effluent as the primary source of degradation in Buffalo River tributaries. Additional increased herbicide and pesticide use and changes to hydrology were also cited as contributors to mussel decline in the river.
Bear	AL	Bear Creek	2012	Moderate	Agricultural impacts, human development	Isom and Yokley (1968, p. 192) report loss of shoal habitat at Old Burleson which is where Ortmann collected in 1920s. McGregor and Garner (2004, p. 61) cite impoundment, channelization, wastewater discharge, and sedimentation from strip mining, agriculture, and silviculture.

Upper Clinch-Tennessee, Virginia	TN	Clinch River	1990s	Moderate	Ahlstedt et al. (2016, p. 8) Clinch & Powell Rivers, 1870-2003: logging resulting in increased sedimentation, deep & surface coal mining; discharges of industrial & mine wastes, mine blowouts, black water release events & fly-ash spills from mining activities, soil erosion from agricultural activities, construction of impoundments, overharvest, sulfuric acid spills, 100-yr floods & prolonged drought. Point and nonpoint source contaminants from coal mine activities.	Contaminant Spills have been particularly detrimental and are an ongoing threat to this population. Ahlstedt *et al.* (2017, p. 224), state that the mussel fauna of the Clinch River downstream of the Appalachia Power Company's Steam Plant at Carbo, Virginia, was severely affected by a fly ash spill in 1967 and a sulfuric acid spill in 1970. Jones *et al.* (2001, p. 20), reference a 1,400 gallon spill of rubber accelerator into the upper Clinch River just above Cedar Bluff, Virginia (CRM 323) in August 1998, which killed at least 7,000 mussels of 16 species (Jones *et al.* 2001, p. 22). High concentration levels of the toxic metals zinc and copper in sediments present below a coal processing plant resulted in reduced survival of juvenile mussels in the Clinch River, Virginia (Ahlstedt and Tuberville 1997, p. 75). Mussel die-offs of unknown origin have been and continue to be a threat, mussel die-offs and were documented in the Clinch (1986-1988) and recently (2016) in the Clinch River, VA. Black-water release events associated with mining activity were documented in the drainage in 2002-2003 (Ahlstedt *et al.* 2016, p. 9). The Clinch River in Virginia and Tennessee has chronic threats including concentrated agricultural and mining activities and transportation corridors, as well as acute threats such as wastewater treatment effluents and chemical spills (Zipper *et al.* 2014, p. 810). From Diamond *et al.* (2002, p. 1,153): Point and nonpoint source contaminants from coal mine activities, agricultural uses, and urban areas are also likely to be limiting aquatic fauna distribution. Non–point-source inputs of agricultural pesticides, particularly in the more fertile bottomlands and valleys, also are a potential source of toxic stress on native fish and mussels in this watershed. The Clinch River in Virginia and Tennessee has significant chronic threats including concentrated agricultural and mining activities and transportation corridors, as well as acute threats such as wastewater treatment effluents and chemical spills (Zipper *et al.* 2014, p. 810).
Emory	TN	Clear Creek	2014; Dinkins and Faust 2015	Low	This population has potentially been affected by an oil spill, but occurs on National Park Service lands, and is somewhat protected through the	An oil well fire and spill occurred in Clear Creek in 2005 (Dinkins and Faust 2015).

					Obed Wild and Scenic River.	
Lower Tennessee	KY	East Fork Clarks River	2005	Moderate	Agriculture, water quality and habitat degradation, impoundment	The construction of dams on the Tennessee (Kentucky Lake) and Ohio (L & D 52, 53 and future Olmstead), isolate populations and prohibit fish movement (Haag and Cicerello 2016, p. 11). The Clarks River, which has been channelized, drains to the lower Tennessee River below Kentucky Dam in an area that receives substantial commercial navigation traffic, and has a mussel fauna which contains large populations of lentic species that have adapted to impoundment.
Guntersville Lake	AL	Town Creek (Marshall Co.)	2010	Moderate	Agriculture, water quality and habitat degradation, impoundment	Woodside *et al.* (2004, p. 1) cite sediment from cultivated fields, storm-water runoff from pasture lands, livestock wastes and agricultural fertilizers resulting in high E. coli levels, high phosphorus levels from limestone deposits, pesticides, and DDT and PCBs detected in fish tissues as threats to the surface waters of the lower TN river system.
		Tennessee River (Nickajack Dam tailwaters/Guntersville reservoir)	2015	Moderate	Habitat fragmentation, population isolation, hydrologic alteration	Hundreds of miles of large river habitat on the Tennessee main stem has been lost under nine reservoirs. Operation of Nickajack dam directly impacts this population. Habitat fragmentation
Wheeler Lake	AL	Second Creek (Lauderdale Co.)	2010	Low	Agriculture, human development	Woodside *et al.* (2004, p. 1) cite sediment from cultivated fields, storm-water runoff from pasture lands, livestock wastes and agricultural fertilizers resulting in high E. coli levels, high phosphorus levels from limestone deposits, pesticides, and DDT and PCBs detected in fish tissues as threats to the surface waters of the lower TN river system.
		First Creek (Lauderdale Co.)	2004	Low	Agriculture, human development	
		Goldfield Branch (embayment)	2008	Low	Agriculture, human development	
		Spring Creek (Lawrence Co.)	1983	Low	Agriculture, human development	
		Fox Creek	2000	Low	Agriculture, human development	

Wheeler Lake	AL	Round Island Creek	2010	Moderate	Agriculture, human development	Rapid urban and industrial growth around Huntsville, including the portion of Limestone and Madison counties that encompasses Limestone, Piney, and Round Island creek drainages, threatens the environmental quality of the Round Island, Limestone, and Piney Creek watersheds (Haggerty and Garner 2008, p. 730). Limestone Creek, Piney, and Round Island Creeks lie in an area of intense agriculture, making species susceptible to pesticide and fertilizer pollution, excessive irrigation, and sedimentation (Mirarchi *et al.* 2004, p. 118).
		Limestone Creek	1998	Moderate	Similar to others in in MU	Rapid urban and industrial growth around Huntsville, including the portion of Limestone and Madison counties that encompasses Limestone, Piney, and Round Island creek drainages, threatens the environmental quality of the Round Island, Limestone, and Piney Creek watersheds (Haggerty and Garner 2008, p. 730). Limestone Creek, Piney, and Round Island Creeks lie in an area of intense agriculture, making species susceptible to pesticide and fertilizer pollution, excessive irrigation, and sedimentation (Mirarchi *et al.* 2004, p. 118).
		Piney Creek	2007	Moderate		
		Flint River	2008	Low	Agriculture, water quality and habitat degradation	The physical condition of the streams in the Flint River system is very similar to that of streams in the Paint Rock system, yet they are even more susceptible to the effects of encroaching urbanization from the city of Huntsville and its suburbs and burgeoning industry (McGregor and Shelton 1995, p. 18).
		Hurricane Creek (1) (Flint trib., Madison Co.)	1995	Low		The physical condition of the streams in the Flint River system is very similar to that of streams in the Paint Rock system, yet they are even more susceptible to the effects of encroaching urbanization from the city of Huntsville and its suburbs and burgeoning industry (McGregor and Shelton 1995, p. 18).
		Lick Fork	2003	Low		Continuing threats to the watershed include siltation and erosion from poor farming practices along with commercial and residential development (Godwin 2002).
		Larkin Fork	2013	Low		Continuing threats to the watershed include siltation and erosion from poor farming practices along with commercial and residential development (Godwin 2002).
		Estill Fork	2013	Low		Continuing threats to the watershed include siltation and erosion from poor farming practices along with commercial and residential development (Godwin 2002).
Wheeler Lake	AL	Hurricane Creek (2); yes, different creek)	2011	Low	Agriculture, water quality	Continuing threats to the watershed include siltation and erosion from poor farming practices along with commercial and residential development (Godwin 2002).

		(Paint Rock trib, Jackson Co.)			and habitat degradation	
		Little Paint Creek	1995; 1996	Low	Agriculture, water quality and habitat degradation	Continuing threats to the watershed include siltation and erosion from poor farming practices along with commercial and residential development (Godwin 2002).
		Paint Rock River	2013	Low		The Paint Rock River drainage was severely affected in past decades by small impoundments, stream channelization, erosion, and agricultural runoff. A major detrimental impact on habitat occurred with the channelization and removal of snags and riverbank timber in the upper drainage and the lower reaches of Larkin and Estill forks and Hurricane Creek by the US Army Corps of Engineers during the 1960s (Ahlstedt 1995-1996). This direct headwater habitat manipulation was probably a large contributor to freshwater mussel loss in the drainage. Wheeler Dam was completed by the Tennessee Valley Authority (TVA) in 1936, resulting in loss of most of the mussel fauna and riverine habitat in the lower 21 km of PRR (Ahlstedt 1995-1996).
		Tennessee River (Guntersville Dam tailwaters/ Wheeler reservoir)	2008	High	Impoundment, habitat degradation from flow releases	The continued operation of Guntersville Dam and Browns Ferry Nuclear Plant.
Upper Elk	TN	Elk River	1995	Moderate	Cold water discharges, agricultural impacts to habitat and water quality	The Elk River in Tennessee, which has significant agricultural activity throughout the watershed, supports a recruiting population (Hoos *et al.* 2000). Additionally, construction and operation of Tims Ford Dam has impacted the fauna considerably above Harms Mill dam. Although the operations have changed, the lack of mussel recruitment above Harms Mill indicates that translocation or propagation for population restoration is likely needed.
Upper Duck		Big Rock Creek	1995; 2017	Moderate	Agriculture human development	Increased human development pressure, agricultural impacts. Urban development is increasing rapidly throughout the Duck River drainage, resulting in the large-scale removal of riparian vegetation, (conversion of pasture to row-crop) and increased human development (expansion of metro-Nashville).
		Duck River	1995; 2015	Moderate		
Arkansas-White-Red						

Spring	MO	Coon Creek	2014 (WD)	Low	Agriculture, sedimentation	Jacobson and Primm 1994 (applies to all streams in the Arkansas-White-Red Drainage)
		Shoal Creek	2018	Moderate	Heavy metal contamination, agriculture	ESI 2018, Angelo et al. 2007, Jacobson and Primm 1994
Elk		Indian Creek	1995	Low	agriculture & human development	Grand Lake O' the Cherokees; sedimentation and gravel loading; Elk River Watershed Inventory and Assessment MDC (Rick Horton)
James	MO	James River	2009	Moderate	Watershed is mostly agriculture, dam (Lake Springfield) in upper watershed.	James River Watershed Inventory and Assessment MDC (Kiner, L. and C. Vitello). Water qual. issues (*E. coli*) Urbanization, wastewater effluent, Chlordane, compounds and semi-volatile organic compounds have been detected, sedimentation & gravel loading occur. McMurray, S.E. and J.S. Faiman. 2018. Changes in the distribution and status of the freshwater mussel (Bivalvia: Unionida) fauna of the James River basin, Missouri. The Southwestern Naturalist 63:102-111. Table Rock Dam on the White River inundates the lower river.
		Flat Creek	2009	Low	Watershed is mostly agriculture, sedimentation and gravel loading occur.	James River Watershed Inventory and Assessment MDC (Kiner, L. and C. Vitello). Water quality issues (*E. coli*), low head dam (McDonald Mill Dam). McMurray, S.E. and J.S. Faiman. 2018. Changes in the distribution and status of the freshwater mussel (Bivalvia: Unionida) fauna of the James River basin, Missouri. The Southwestern Naturalist 63:102-111
		Finley Creek	2009	Low	Watershed is mostly agriculture, sedimentation and gravel loading occur	James River Watershed Inventory and Assessment MDC (Kiner, L. and C. Vitello), McMurray, S.E. and J.S. Faiman. 2018. Changes in the distribution and status of the freshwater mussel (Bivalvia: Unionida) fauna of the James River basin, Missouri. The Southwestern Naturalist 63:102-111.
Eleven Point	MO	Eleven Point River	2018	Low	Agriculture, water quality and habitat degradation	MDC. 2000. Eleven Point River Watershed Inventory and Assessment. 44 mi are National & Wild Scenic River, some lacking riparian corridor in upper river, but middle river has good riparian corridor (p. 2). High fecal coliform, nutrient loading & sediment. & gravel deposition are most severe threats to water quality (p. 2).

Bull Shoals		Swan Creek	2006	Low	Water quality degradation from increased human population	MDC. White River Watershed Inventory and Assessment. Lower river inundated by Bull Shoals Lake.
		Bull Creek	2004	Low	Water quality from increased human population	MDC. White River Watershed Inventory and Assessment. Lower river inundated by Bull Shoals Lake.
North Fork White		Bryant Creek	2013	Low	Sedimentation, gravel loading, and minor erosion;	North Fork River Watershed Inventory and Assessment MDC (Miller and Wilkerson), McMurray and Faiman 2019. Freshwater mussels of the North Fork River and Bryant Creek, Missouri.
North Fork White	MO	North Fork White River	2012	Low	Sedimentation, gravel loading; Dawt Mill Dam constructed in 1893 but was removed in 2017	North Fork River Watershed Inventory and Assessment MDC (Miller and Wilkerson). McMurray and Faiman 2019. Freshwater mussels of the North Fork River and Bryant Creek, Missouri.
Lower Black		West Fork Fourche Creek	2002	Moderate	No specific data to stream. The lower Black river has been channelized.	Jacobson and Primm (1994), MDC (2003). Current River Watershed Inventory and Assessment. Gravel loading and sedimentation is a common issue throughout most of the Ozarks, headcutting could be a problem.
Upper Black		Black River		Moderate	Human development, numerous public and private wastewater treatment plants	Huston and Barnhart 2004 (pp. 155-156). Sediment pollution and contamination from lead mine tailings dams in watershed, gravel mining, erosion, Lake Wappapello.
Current		Jacks Fork River	2007	Moderate	Resource extraction, human development, agriculture.	MDC 2001. Jacks Fork watershed inventory and assessment (pp. 81-87). Municipal waste water discharges, and the presence of livestock in riparian zones for extended periods, erosion and sedimentation. Gravel dredging, indiscriminate land clearing, high levels of recreational river use,

		Big Barren Creek	2013	Moderate	Resource extraction, gravel mining, channelization, agriculture sedimentation	MDC 2003. Current River Watershed Inventory and Assessment (pp. 95-101); Geomorphic characteristics and sediment transport in natural and channelized reaches of Big Barren Creek, Southeast Missouri
Current	MO	Current River	2002	Moderate	Human development, resource extraction	MDC 2003. Current River Watershed Inventory and Assessment (pp. 95-101). Improper gravel mining techniques, bank erosion, gravel loading, and sedimentation, large volume of "floaters" (canoes, tubs, etc), horse trails with river crossings, mill dam.
		Little Black River	2006	Moderate	water quality degragation, agricultural operations	Bruenderman *et al.* 2001. Survey for the Curtis Pearly Mussel, *Epioblasma florentina curtisi* (Utterback 1914) and Other Mussel Species in Little Black River, Missouri (pp. 12-13). Unregulated timber harvest in past, low DO and high bacteria levels have occurred in the past.
		North Prong Little Black River	1998	Moderate	Similar to others in MU	Not documented for the stream, but has similar threats to Little Black River
Spring	AR	South Fork Spring River	2005	Moderate	Geomorphic instability, agriculture	2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica*. Very unstable stream channel, thought to be the result of low water road crossings with culverts (which act as lowhead dams), blowing out areas downstream from accelerated flow rates through the culverts. Cattle having easy access to stream banks have exacerbated sedimentation in the stream and contribute nitrogenous wastes
Spring	AR	Spring River	2004	Moderate	Human Development; agriculture	Developmental activities primarily associated with retirement villages, recreation, sedimentation, and agricultural runoff (p. 30) 2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica*
Frog-Mulberry		Frog Bayou	2007	Moderate	Similar to others in in MU	No recent information
		Mulberry River	1994	Moderate	Water quality degradation;	Shafii, M. 2009. Total Maximum Daily Load (TMDL) For pH Mulberry River, Arkansas.

					303(d) list for pH impairment	
Beaver Reservoir		Upper White River	2013	Moderate	Resource extraction, water quality degradation	Threats in the White River include gravel mining, sedimentation, and pollutants (p. 29) 2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica*
Beaver Reservoir	AR	War Eagle Creek	2013	Moderate	Agriculture, resource extraction, habitat and water quality degradation	Runoff from poultry production, other agricultural runoff, and sedimentation from eroding stream banks and unpaved roads in the watershed. Gravel mining is prevalent in the watershed further exacerbating sedimentation and instream channel alteration. Unrestricted cattle access and lack of riparian buffers has led to numerous stream banks destabilizing, thus increasing channel instability (p. 29) 2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica*
Illinois	AR	Illinois River	1994	Moderate	Agriculture, human development	Non-point source organic runoff from poultry farming & municipal wastewaters in the watershed, & most prevalent in AR, less strict enforcement than OK. Headwaters of the Illinois drain Benton County, AR. With 308 broiler chicken farms, the county is ranked 3rd among the nation's producers. Phosphorus levels are 10x higher in the IL at the AR border than OK regulations permit. Sedimentation. Two large reservoirs are on the river, Lake Frances (state border & dividing the extant rabbitsfoot pop., is partially drained, but its spillway continues to act as a barrier to fish migration). Tenkiller Ferry Dam impounds or has tailwater influence on lower river, affecting nearly 1/3 of the entire main stem. (pp. 31-32). 2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica*
Dardanelle Reservoir	AR	Cadron Creek	2016	Moderate	Similar to others in in MU	No recent information
		East Fork Illinois Bayou	2000	Moderate		No recent information

	AR	Middle Fork Illinois Bayou	2000	Moderate	Similar to others in in MU	No recent information
		Illinois Bayou	2007	Moderate		No recent information
		Big Piney Creek	1999	Moderate	Water quality degradation and agriculture	Turbidity, total dissolved solids, chlorides and DO occasionally exceed Boston Mountain ecoregion water quality standard. Stream bank erosion, septic tanks, pastures and CAFO operations. Indication of nutrient enrichment and siltation at some sites (p. 21). Davidson *et al*. 2000. Location and Notes on Freshwater Mussels (Bivalvia: Unionacea) Inhabiting Big Piney Creek within the Ozark-St. Francis National Forest, Arkansas.
Strawberry	AR	Strawberry River	2013	Moderate	Agriculture, resource extraction	Cattle pastures, increased sedimentation, nutrient over enrichment from riparian conversion and incompatible agricultural practices, gravel mining (p. 69). Status assessment report for the snuffbox, *Epioblasma triquetra*, a freshwater mussel occurring in the Mississippi River and Great Lakes Basins
Buffalo		Buffalo River	2011	Moderate	Human development	Pollutants from developmental activities associated with resorts, excessive canoe traffic (p. 68). Status assessment report for the snuffbox, *Epioblasma triquetra*, a freshwater mussel occurring in the Mississippi River and Great Lakes Basins.
Little Red	AR	Archey Fork Little Red River	2019	Moderate	Resource extraction, agriculture	Gravel mining, unrestricted cattle access to stream, water withdrawal from ag and rec use, lack of adequate riparian buffers, county road construction and maintenance (p. 10). Service 2018. Species Biological Report: Yellowcheck Darter (*Etheostoma moorei*)
		South Fork Little Red River	2019	Moderate	Resource extraction, agriculture, water quality degradation	Gravel mining, unrestricted cattle access to stream, water withdrawal from agricultural use, lack of adequate riparian buffers, county road construction and maintenance (p. 10). Low water crossing causing scour at Gulf Mountain Road. Unrestricted cattle access, channelization, gravel mining and Clinton-West Wastewater Treatment Plant.(pp. 18-19)
		Turkey Creek	2010	Moderate	Agriculture, resource extraction	Gravel mining, unrestricted cattle access to stream, water withdrawal from ag and rec use, lack of adequate riparian buffers, county road construction and maintenance (p. 10). USFWS. 2018. Species Biological Report: Yellowcheck Darter (*Etheostoma moorei*)

		Beech Fork Little Red River	2004	Moderate	Agriculture, resource extraction	Gravel mining, unrestricted cattle access to stream, water withdrawal from ag and rec use, lack of adequate riparian buffers, county road construction and maintenance (p. 10). Service 2018. Species Biological Report: Yellowcheck Darter (*Etheostoma moorei*)
Little Red		Middle Fork Little Red River	2019	Moderate	Agriculture, forest conversion,	2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica*. Davidson and Wine 2004. Threats Assessment for the Speckled Pocketbook *(Lampsilis streckeri)* and Yellowcheek Darter (*Etheostoma moorei)* in the Upper Little Red River Watershed, Arkansas. Davidson and Wine (2004, pp. 15-17) identified dozens of stress points, most of them erosion associated with poorly maintained buffers, sloughing banks, and low-water crossings. Numerous sites were also identified where there was unrestricted cattle access. Cattle in the stream probably accounted for the elevated fecal coliform levels, which typically are associated with increases in nutrients associated with cattle defecating in the stream. Lack of riparian buffers and signs of bank failure along the stream indicated that sedimentation may become an increasing problem (p. 30)
		Big Creek	2019	Moderate	Impoundment (fragmentation)	Service 2018. Species Biological Report: Yellowcheck Darter (*Etheostoma moorei*). Below Greers Ferry Dam, other populations in the basin are above reservoir.
Cadron	AR	Jones Creek	2008	Moderate	Similar to others in in MU	No recent information
		East Fork Cadron Creek	2018	Moderate		No recent information
		North Fork Cadron Creek	2018	Moderate		No recent information
Lake Conway-Point Remove		East Fork Point Remove Creek	2018	Moderate		No recent information
		West Fork Point Remove Creek	2018	Moderate		No recent information
Fourche La Fave		Black Fork Fourche LaFave River	2014	Moderate		No recent information
		South Fourche	2002	Moderate		No recent information

		LaFave River			Similar to others in in MU	
Poteau		Jones Creek	1994	Moderate		No recent information
Poteau		Ross Creek	1994	Moderate		No recent information
		Poteau River	2007	Moderate		No recent information
Mountain Fork		Mountain Fork Little River	2005	Moderate		No recent information
Lower Little Arkansas, Oklahoma		Saline River	2013	Moderate		No recent information
Lower Mississippi						
Upper Saline	AR	Middle Fork Saline River	2015	Moderate	Similar to others in in MU	No recent information
Upper Saline	AR	Little Alum Creek	2009	Moderate	Similar to others in in MU	No recent information
		Alum Fork Saline River	2015	Moderate		No recent information
		South Fork Saline River	2006	Moderate		No recent information
		North Fork Saline River	2015	Moderate		No recent information
Upper Saline		Saline River	2015	Moderate	Agriculture, resource extraction, water quality degradation	2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica.* The lowermost 12 RMs of the Saline are impounded by a lock & dam on the Ouachita River. Open pit bauxite mines. Once thought to be the sole source of bauxite in the world, the Hurricane Creek watershed was extensively mined for 100yrs until 1990. While reclamation is ongoing to restore mined areas, acid runoff still impacts water quality in Hurricane Creek (p. 34).
Little Missouri		Little Missouri River	2004	Moderate	Agriculture	2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica.* Riparian

						zones with cattle may result in nutrient loadings and localized streambank erosion (p. 33).
Lower Saline	AR	Saline River	2015	Moderate	Agriculture, resource extraction, water quality degradation	2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica*. The lowermost 12 RMs of the Saline are impounded by a lock & dam on the Ouachita River. Open pit bauxite mines. Once thought to be the sole source of bauxite in the world, the Hurricane Creek watershed was extensively mined for 100yrs until 1990. While reclamation is ongoing to restore mined areas, acid runoff still impacts water quality in Hurricane Creek (p. 34).
Big		East Fork Flat Creek	2008	Moderate	Similar to others in in MU	No recent information
Little River Ditches	MO	Castor River	2008	Moderate	Agriculture, channelization, habitat degradation; resource extraction	Corps Stream Stewardship Trustfund Compensation Planning Framework - Upper St. Francish/Castor Rivers Geographic Service Areas. Livestock over grazing & unregulated access to stream, bank erosion, riparian corridor removing, gravel mining, watershed urbanization (p. 3), now flows into a diversion channel created in 1913.
Little River Ditches	AR	Ditch 28	2009	Low	Similar to others in in MU	Nonspecific - It is a manmade canal like other Little River ditches, channelize & potentially could be dredged; located within Big Creek NWR and WMA. Purpose is to supply water to Big Lake.
Upper St. Francis	MO	St. Francis River	2002	Moderate	Water quality and habitat degradation	Huston and Barnhart (2004 pp. 86-88). Sedimentation, water quality and wastewater discharge, heavy metals, fragmented by Lake Wappapello
Lower St. Francis	AR	Tyronza River	2007	Moderate	Channelization, habitat degradation	Channelized and ditched late 1800s, habitat quality determined to be suboptimal (p. 146). Wentz *et al*. 2011. Assessment and Characterization of Physical Habitat, Water Quality, and Biotic Assemblages of the Tyronza River, Arkansas
		National Ditch	2003	Moderate	Channelization, habitat degradation	Man-made drainage ditch, channelized, headcut erosion
Lower St. Francis	MO	Varney River	2011	Moderate	Channelization, habitat degradation	Headcutting in the mainstem St. Francis, tributaries, and lateral ditches has caused lower stream bed elevations, wider and shallower stream channels, and steeper banks, which are experiencing severe sloughing and erosion in many locations (p. 1). Poor riparian corridor (p. 3), manmade drainage ditch for draining swampy areas constructed late 1800s to early

						1900s. MDC. 2001. St. Francis River Watershed Inventory and Assessment.
Cache	AR	Cache River	2007	Moderate	Channelization, habitat degradation, agriculture practices	Upper river has been channelized and headcutting causing sedimentation in the basin (pp. 4-6), sedimentation, nitrogen from runoff (pp. 3-10), bank erosion, lead from sediment (pp. 3-12), agriculture practices. Corps. 2016. Cache River Watershed-Based Management Plan
Upper Ouachita	AR	Caddo River	2007	Moderate	Channelization, habitat degradation, fragmentation	Separated from Ouachita populations by De Gray Lake, upper river is relatively clear and unpolluted, but segments of the steam have been privately channelized causing some reduction in habitat and gravel piles (p. 477). Hambrick and Robison. 1979. Life History Aspects of the paleback darter, *Ehteostoma pallididorsum* (Pisces: Percidae) in the Caddo River System, Arkansas.
		Ouachita River	1998	Moderate	Channelization, habitat degradation, fragmentation, resource extraction	3 mainstem dams, highly degraded river segment, maintained as inland waterway by Corps, 2 lock and dams, Natural gas and oil development is prevalent in the system and these fuels are transported down the river by barge, barium sulfate mining activities, sedimentation, and agricultural activities (p. 33). 2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica*
Ouachita Headwaters		South Fork Ouachita River	2015	Moderate	Similar to others in in MU	No recent information
		Ouachita River	2018	Moderate	Channelization, habitat degradation, fragmentation, resource extraction	3 mainstem dams, highly degraded river segment, maintained as inland waterway by Corps, 2 lock and dams, Natural gas and oil development is prevalent in the system and these fuels are transported down the river by barge, barium sulfate mining activities, sedimentation, and agricultural activities (p. 33). 2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica* 2009. U.S. Fish & Wildlife Service Species Assessment and Listing Priority Assignment Form - *Quadrula cylindrica cylindrica*
Whitewater	MO	Crooked Creek	2014	Moderate	Agriculture, water quality degradation, human development	Highly erodible and cultivated cropland with soil losses, nitrogen, and phosphorus pollutants, 34 percent of the riparian corridors, primarily in cropland, pasture/grass, and urban areas, are unprotected or vulnerable (p. 16). NRCS.Whitewater Sub-Basin Rapid Watershed Assessment

APPENDIX B—EXTIRPATED PURPLE LILLIPUT POPULATIONS ACROSS THE HISTORICAL RANGE.

GREAT LAKES BASIN = 13 populations and 8 MUs
OHIO RIVER BASIN = 41 populations and 22 MUs
CUMBERLAND RIVER BASIN = 19 populations and 10 MUs
TENNESSEE RIVER BASIN = 39 populations and 18 MUs
LOWER MISSISSIPPI RIVER BASIN = 5 populations and 4 MUs
ARKANSAS-WHITE-RED BASIN = 10 populations and 8 MUs
TOTAL EXTIRPATED POPULATIONS = 119; TOTAL EXTIRPATED MUs = 67

Management Unit	Record State	Former Contiguous Population	Last Collected / Reported or Extirpated	Comments on collections in river/stream
Great Lakes				
Raisin	MI	River Raisin	1976	OSUM 53002
		Macon Creek	McRae et al 2004	Badra 2004; OSUM 53002, 12396
Cass River		Cass River	pre-1930 C. Davis (Badra 2004, p. 30).	The site was resurveyed in 1984 but the species was not found. No live individuals or empty shells were found in surveys performed by MNFI. T. lividus may have been extirpated from the watershed sometime in the last 70+ years (Badra 2004, p. 31).
Lake Erie		Lake Erie	van der Schalie 1975	Goodrich and van der Schalie 1932
Lower Maumee	OH	Swan Creek (Lucas Co.)	Watters 2009, p. 301, Not collected live or fresh dead since 1980	"Very rare if not extirpated" from Ohio (Watters *et al.* 2009)
St. Joseph River	IN, OH	St. Joseph River	1908 (Clark & Wilson 1912)	"Very rare if not extirpated" from Ohio (Watters *et al.* 2009)
	MI	East Fork West Branch St. Joseph River	1998 (Watters 1998)	Watters (1998, p. 40) collected 6 live at 1 of 6 sites, Watters (1988, p. 14) reported 12 live/2 fresh dead "common" at 1 of 5 sites
St. Joseph River	IN	St. Joseph Feeder Canal	1908 (Clark & Wilson 1912)	"few" L/FD @ 2 of 3 sites (E & F)

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	IN, OH	Fish Creek	1986	Clark (1977) 1 spec. @ 1 of 4 sites. "Very rare if not extirpated" from Ohio (Watters *et al*. 2009)
St. Joseph River	IN. OH	Eel Creek	1971	"Very rare if not extirpated" from Ohio (Watters *et al*. 2009)
Lower Maumee		Maumee River	1962	"Very rare if not extirpated" from Ohio (Watters *et al*. 2009)
Upper Maumee	IN	Maumee River	2012	1 collection; (Service 2019a, unpublished data)
St. Mary's	IN	Reservoir of Feeder Canal St. Joseph River	1908	1 collection; (Service 2019a, unpublished data)
Ohio				
Little Miami	OH	Little Miami River	1973	Hoggarth 1992; OSUM 42820
Middle Green	KY	Green River	1927	Clench and Van der Schalie 1944
Licking (also in Extant list) – suggest extirp.	KY	Licking River	1999	Haag & Cicerello 2016, p. 238
Salt		Salt River	pre 1990	Cicerello *et al*. 1991, p. 121; Haag and Cicerello 2016, p. 238
		Bullskin Creek	pre 1990	Cicerello *et al*. 1991, p. 121; Haag and Cicerello 2016, p. 238
Barren		Barren River	pre 1990	Cicerello *et al*. 1991, p. 121; Haag and Cicerello 2016, p. 238
		Drakes Creek	1927	Clench and Van der Schalie 1944, p. 225; Schuster 1988, p. 971; UMMZ 44626
		West Fork Drakes Creek	1927	Clench and Van der Schalie 1944, p. 225; Schuster 1988, p. 971; UMMZ 44649
		Bays Fork	1927	Clench and Van der Schalie 1944, p. 225; Schuster 1988, p. 971; UMMZ 44704
Tippecanoe	IN	Winona Lake	1902	Headlee 1906, p. 306
		Walnut Creek	1992	OSUM 62896

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		Trimble Creek	1992	OSUM 57184
		Mill Creek	1992	OSUM 58766, 58431
		Tippecanoe Lake	pre 1903	Daniels 1903
Tippecanoe	IN	Lost Lake	pre 1973	OSUM 68445; USNM 541905
		Bruce Lake	1900	USNM 420791
Wildcat	IN	Kilmore Creek	2014	5 collections, WD best condition. Clinton County (Service 2019a, unpublished data)
		Wildcat Creek	2010	1 SF collection in Tippecanoe County (Service 2019a, unpublished data)
		Middle Fork Wildcat Creek	2013	1 WD collection in Tippecanoe County (Service 2019a, unpublished data)
		South Fork Wildcat Creek	2004	2 SF collections. Tippecanoe and Clinton Counties (Service 2019a, unpublished data)
		North Fork Wildcat Creek	2018	14 collections, best condition WD. Howard and Carroll Counties (Service 2019a, unpublished data)
		Mud Creek	2004	1 WD collection in Howard County (Service 2019a, unpublished data)
Middle Wabash-Deer		Rock Creek	1975	OSUM 36913, 36849, 36847, 33699
		Wabash River	1988	Cummings *et al.* 1988
		North Fork Wildcat Creek	1899	USNM 420822
Upper Wabash	IN	Wabash River	1988	weathered dead and subfossil only reported from 3 sites Cummings *et al.* 1992, p. 24
Mississinewa		Mississinewa River	1993	ESI 1995
Salamonie		Salamonie River	1994	ESI 1995
Lower East Fork White		East Fork White River	1990	Daniels 1903

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Sugar		Sugar Creek (Boone Co.)	1991	Harmon 1992 (INDNR database records) (Service 2019a, unpublished data)
Lower White		White River	1996	Daniels 1903
Upper White		West Fork White River	1989	(Service 2019a, unpublished data)
Highland-Pigeon	IN	Wabash River	1800s	Lea collection (Service 2019a, unpublished data)
Driftwood	IN	Snail Creek	1992	Harmon 1992, p. 41
Embarras	IL	Embarras River	2000	No recent records of live or fresh dead, considered extirpated from the Embarras River mainstem in IL
Vermillion	IL	Salt Fork Vermillion River	2012	Van Cleave 1940
Vermillion		Vermillion River	2014	Tiemann *et al.* 2007; 1 valve reported in 2014 in IL by Stodola *et al.* (no longer in mainstem in Illinois). 1 subfossil valve reported in IN by Fisher in 2001 (Service, 2019, unpublished data)
		East Branch North Fork Vermilion River	1996	Cummings *et al.* 1998, p. 96
Little Wabash		Little Wabash River	2012	INHS 21196; Tiemann *et al.* 2007
Skillet		Dry Fork	2011	INHS 41769; 2.1 mi E Sims, Co. Rd. 1100E, Wayne Co.
Middle Wabash - Little Vermillion		Little Vermillion River	1994	INHS 17428; 2 valves at 1 site, 4 mi SE Georgetown
Blue - Sinking	IN	Blue River	1900	ANSP 47928

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Cumberland				
Lower Cumberland-Old Hickory Lake	TN	Little Peyton Creek	2015	Moles 2015; (Service 2019a, unpublished data)
Upper Cumberland-Cordell Hull Reservoir	TN	Defeated Creek	2015	Moles 2015; (Service 2019a, unpublished data)
Rockcastle	KY	Middle Fork Rockcastle River	1983	Schuster 1988, p. 971
		Rockcastle River	1978; 1983	Haag and Cicerello 2016, p. 239: appears extirpated
Upper Cumberland - Lake Cumberland	KY	Pittman Creek	1979	Haag and Cicerello 2016, p. 239: appears extirpated
		Cumberland River (Russell, Wayne, Pulaski, McCreary Co.)	1948	Schuster 1988, p. 972; Neel and Allen 1964; Wilson and Clark 1914
		Marrowbone Creek	2005 (relic)	Haag and Cicerello 2016, p. 239: appears extirpated
South Fork Cumberland		Kennedy Creek	2013 (relic)	Ahlstedt *et al.* 2014
Lower Cumberland - Sycamore	TN	Cumberland River (Davidson Co.)	pre-1900	OSUM 57267
Harpeth		Harpeth River	2002	Hubbs 2002; (Service 2019a, unpublished data)
Red	KY	Red River	1988; pre-1990	OSUM 56248, 21674
	TN		1967; 1988	OSUM 82139

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	KY	South Fork Red River	1967	OSUM 82211
		Whippoorwill Creek	pre-1990	Haag and Cicerello (2016, p. 238)
		West Fork Red River	1971	OSUM 26994
Caney	TN	Caney Fork River	pre-1993	Layzer *et al.* 1993, p. 67
Stones - These pops appear extirp. based on Moles *et al.* 2007	TN	West Fork Stones River	1998	3 collections in stream; Hubbs collections (Schmidt *et al.* 1989)
		Overall Creek	1966	OSUM 19909
Stones - These pops appear extirp. based on Moles et al. 2007		Middle Fork Stones River	1998 (Schmidt et al. 1989)	only 1 live collection in stream; Hubbs collections (Schmidt et al. 1989)
		East Fork Stones River	2002; Hubbs TWRA (1 relic)	only WD shells collected in 1996
Tennessee				
Powell	VA	South Fork Powell River	pre 1918	Ortmann 1918
	VA	Powell River	1899 (Lee Co., VA)	Ortmann 1918
	TN		1899 Union Co., TN	Ortmann 1918
Emory	TN	Emory River	1895	Pilsbry and Rhoads 1896
North Fork Holston	VA	North Fork Holston River	1971; 1996	Jones and Neves 2007
South Fork Holston	VA	South Fork Holston River	pre 1918	Ortmann 1918, p. 574 reports Washington and Scott Co. VA, SF Holston localities
	TN		Parmalee and Polhemus 2004	(Sullivan Co., TN); Service 2019a, unpublished data

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			Archaeological Material	
Holston	TN	Holston River	pre 1918	Ortmann 1918, p. 574 reports Hawkins Co. TN
Upper French Broad	NC	French Broad River	< 1838	Ortmann (1918, p. 574): It is rather sure that the specimens from "Warm Springs, NC", (Hot Springs) are actually *T. lividum*
Lower French Broad	TN	West Prong Little Pigeon River	1987	Parmalee 1988
		Little Pigeon River	1987	Parmalee 1988
Lower French Broad	TN	French Broad River	2004 Archaeological Material	UT McClung 8807
Watts Bar Lake		Tennessee River	pre 1870	Ortmann 1918, p. 574
		Little River	pre-1990	Parmalee and Bogan 1998, p. 231
		Pistol Creek	pre 1918	Ortmann 1918, p. 574
Middle Tennessee - Chickamauga	GA	Lookout Creek	1957	Athearn MFM Collection 7562
Lower Little Tennessee	TN	Tellico River	1983	Parmalee and Klippel 1984
Guntersville Lake		Crow Creek	1966	OSUM 21989; USNM 218135
		Battle Creek	1910	ANSP 100699
Upper Duck		North Fork Creek	1967; 2001, 2017 (relic)	Ahlstedt *et al.* 2004; Irwin and Alford 2018
		Wilson Creek	1983	OSUM 40904; 40895
		Weakly Creek	1967	OSUM 40906
		East Rock Creek	1990; 2001 (relic)	Ahlstedt *et al.* 2004; Ahlstedt *et al.* 2017, p. 109

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		Alexander Creek	2017 (relic)	Irwin and Alford 2018
		Flat Creek	1972	OSUM 33875
		Fall Creek	2017 (relic)	Irwin and Alford 2018
		Sugar Creek	1976	OSUM 40914
Wheeler Lake	AL	Indian Creek	1966	Isom (1968, p. 516), reported as common at 2 sites in 1964-1965, rare in 1966 - all from muskrat middens
Wheeler Lake	AL	Rocky Branch (Lawrence Co.)	1996	OSUM 57545
		Mud Creek Trib. (Limestone Co.)	1991	OSUM 59007
Wheeler Lake	AL	Unnamed trib. to Gum Springs Run (Morgan Co.)	1996	OSUM 59036
		Flint Creek (Morgan Co.)	1924	Ortmann 1925, p. 352
		Yellow Branch (Jackson Co.)	1996	OSUM 59891
Pickwick Lake	AL	Town Creek	1966	OSUM 59073 (Marshall Co.)
Lower Elk	TN	Elk River	1966	Isom *et al.* 1973, Elk River Mile 34
Bear	AL	Bear Creek	2012	Isom and Yokley 1968 (Ortmann 1925 citation)
Lower Duck	TN	Duck River	1964	Stansbery (OSUM records)
Upper Clinch, Tennessee	VA	Clinch River	1980	@ RM279.5
		Wallen Creek (mis-labeled as Waldens River)	~1900	USNM 150486
Arkansas-White-Red				

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Spring	AR	Janes Creek	1993	INHS 14165; 1 mi SW Ravenden Springs, Rt. 90 bridge, Randolph Co.
Lower Neosho	OK	Fourteen Mile Creek	1890	Isely 1925
Spring	MO	Spring River	1979	Has been collected in Coon Cr and Shoal Cr (tributaries), Service 2019a, unpublished data. Was not found during Spring River basin sampling efforts of Obermeyer 1998, Angelo 2007, ESI 2018
Elk	MO	Elk River	1979	1 live reported in 1979, 1 site (MDNR database; Buchanan collector); Service 2019a, unpublished data
		Big Sugar Creek	1979	2 weathered dead in 1979, 1 site (MDNR mussel database; Buchanan collector); Service 2019a, unpublished data
Eleven Point		Frederick Creek	1983	2 live collected in 1983, 1 site (MDNR mussel database; Buchanan collector); Service 2019a, unpublished data
Current River		Beaverdam Creek	1979	dead only reported in 1979, 1 site (MDNR database; Buchanan collector); Service 2019a, unpublished data
Current River	MO	South Prong Little Black River	1979	1 live reported in 1979, 1 site (MDNR database; Buchanan collector); Service 2019a, unpublished data
Upper White-Village	AR	Willow Slough	1983	4 live reported in 1983, 1 site (AGFC mussel database; Harris collector); Service 2019a, unpublished data
Lower Mississippi				
Cache	AR	Cache River Ditch	1978	Christian *et al.* 2005, p. 495; Bates 1978, 1 dead; 1 site (AGFC mussel database)
Lower White		White River	1978	Bates in 1978,1 dead; 1 site (AGFC mussel database); Service 2019a, unpublished data
Lower Ouachita-Smackover		Locust Bayou	1983	Robison in 1983, 2 live, 1 site (AGFC mussel database); Service 2019a, unpublished data
Lower St. Francis		Macks Bayou	1984	Harris in 1981, 50 live, 1 site (AGFC mussel database); Service 2019a, unpublished data

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		St. Francis River	1984	Bates in 1978,1984: 3 live, 1 site (AGFC mussel database); Service, 2019, unpublished data