Species Status Assessment Report for Sheepnose (*Plethobasus cyphyus*)

Photo credit: Kristen Lundh, USFWS

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EXECUTIVE SUMMARY

Sheepnose (*Plethobasus cyphyus*) is a medium-sized species, elongate quadrate to ovate in shape, that is thick-shelled and reaches nearly 5.5 inches in length. The life span of sheepnose is estimated to be approximately 30 years. The only documented natural host fish species is the mimic shiner (*Notropis volucellus*); however, sheepnose has been described as a cyprinid host specialist, with a total of more than 30 suitable host fish species identified through laboratory trials. Although natural infestation of sauger (*Sander canadensis*) has been observed, metamorphosis has not been documented. Sheepnose is generally found in medium to large streams, typically within shallow shoal habitats with moderate to swift currents over mixtures of coarse sand, gravel, and clay; however, individuals have occasionally been found in water depths exceeding six meters in larger rivers.

Currently, sheepnose occurs in all 14 states of its historical range, but the species' distribution has decreased over time. We describe and analyze the distribution of sheepnose in terms of watersheds occupied, delineated by the U.S. Geological Survey (USGS) based on surface hydrological features. These hydrological areas are identified as hydrological units at various geographic scales (referred to as HUC). We used the HUC2 scale to delineate our representation units for sheepnose: Upper Mississippi River, Ohio River, Tennessee River, and Lower Mississippi River. The species' range currently includes portions of all four representation units, but is now considered extirpated, as defined in this assessment, from the historically occupied Lower Missouri River basin.

We used the HUC8 at the subbasin scale to define a population of sheepnose and conduct our current condition analysis. We categorized a population's status as extant or extirpated to assess the health, number, and distribution of populations through time. We analyzed current condition for extant populations (total of 37 populations). Overall, the amount and level of detail of survey efforts varied significantly between populations across the range. We assessed demographic population condition as high, moderate, low, or functionally extirpated based on demographic criteria. We assigned an estimate of the probability of persistence over 50 years (approximately 2 generations of sheepnose) for each population condition category based on the population's ability to withstand demographic stochastic events. For our current condition analysis, we also evaluated the five primary risk factors affecting sheepnose (water quality/contaminants, hydrological regime, landscape, connectivity, and invasive species). We assigned these risk factors to three categories of high, moderate, and low risk and assigned a probability of persistence over 50 years for each of the risk categories.

Of the roughly estimated 126 known populations of sheepnose, 37 are currently considered extant and approximately 89 populations (71%) are presumed extirpated. The extant populations are spread across the representation units unevenly, and a high percentage (81%) of populations are currently at high risk based on our risk factor analysis. Seven extant populations of sheepnose have not been detected within the last decade, indicating these populations may be more susceptible to extirpation from catastrophic events.

The Upper Mississippi River basin has 13 populations; of these, 12 are currently at high risk. The Ohio River basin has 15 extant populations; of these, 11 are at high risk. The Tennessee River basin has eight populations; of these, six are at high risk. The Lower Mississippi River basin has one population that is extant and at high risk. With a single population that is at high risk, the Lower Mississippi River basin representation unit is at risk of extirpation. The Upper Mississippi River basin currently has one population at moderate risk; however, evidence of recruitment has not been documented within the last 20 years, indicating the unit is at risk of extirpation with the remaining 12 populations being at high risk. The Ohio River and Tennessee River representation units have four and two populations, respectively, that are currently experiencing moderate risk. None of the basins contain populations experiencing low risk.

Lastly, we analyzed future condition by projecting each population's demographic condition into the future based on its current demographic condition as a baseline and the risk factor level projected for the future. Because there is substantial uncertainty regarding the magnitude, duration, and location of the risk factors, we forecasted future viability for sheepnose under two future scenarios that capture the range of plausible future conditions: (1) negative influences increase in magnitude/intensity 50 years into the future; and (2) current influences remain constant and/or improve 50 years into the future. We evaluated both scenarios where future threats determined the biological status of mussel populations and their habitats.

CHAPTER 1. INTRODUCTION

1.1 Background

This report summarizes the results of a species status assessment (SSA) conducted for sheepnose (*Plethobasus cyphyus*). Importantly, the SSA report is not a decisional document; rather, it provides a summary of our analysis of the best available information as it relates to the species' biological condition. In the case of sheepnose, it has been prepared to inform decisions about recovery plan development and critical habitat designation. Decisionmakers will consider the information in this document (or referenced in this document), in combination with all relevant laws, regulations, and policies regarding those decisions. The public will be provided appropriate opportunities for input on the results of any decision.

1.2 SSA Framework and Analytical Approach

To conduct this assessment, we followed the U.S. Fish and Wildlife Service's (Service) SSA framework (USFWS 2016, entire), which is designed to be a gathering and scientific review of the best available information about a species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. For this SSA, we define viability as the ability of sheepnose to maintain populations in the wild over a biologically meaningful timeframe.

Using the SSA framework, we consider what sheepnose needs to maintain viability by characterizing the status of the species in terms of the conservation biology principles of resiliency, redundancy, and representation, referred to hereafter as the 3Rs (Shaffer and Stein 2000, pp. 308–311).

Resiliency is "the ability of a species to withstand stochastic disturbance; resiliency is positively related to population size and growth rate and may be influenced by connectivity among populations" (Smith *et al.* 2018, p. 304). 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.

Redundancy is an indication of "the ability of a species to withstand catastrophic events by spreading risk among multiple populations or across a large area" (Smith *et al.* 2018, p. 304), thereby reducing the likelihood that all populations are exposed simultaneously and possess similar vulnerabilities to catastrophes. Redundancy can be measured by the number, distribution, and connectivity of resilient populations across a species' range.

Representation is an indication of "the ability of a species to adapt to changing environmental conditions over time as characterized by the breadth of genetic and environmental diversity within and among populations" (Smith *et al.* 2018, p. 304). Representation reflects the evolutionary or adaptive capacity of the species and its ability to persist or adapt in the face of changes in the environment. In the absence of species-specific genetic and ecological diversity information, we can evaluate representation based on the extent and variability of habitat characteristics across the geographical range.

A species with a high degree of resiliency, representation, and redundancy is better able to adapt to novel changes and to tolerate environmental stochasticity and catastrophes. In general, species viability will increase with increases in resiliency, redundancy, and representation (Smith *et al.* 2018, p. 306).

Our analytical approach for assessing the species' viability involved three iterative stages. In Stage 1, we described the species' needs and ecological requirements for survival and reproduction at the individual, population, and species levels. In Stage 2, we determined the species' current demographic and risk condition in terms of the 3Rs, using the ecological requirements of the species identified in Stage 1 and the past and ongoing factors influencing viability that have led to the species' current demographic and risk condition. In Stage 3, we projected the future condition of the species using the baseline conditions established in Stage 2 and the predictions for future risk and beneficial factors.

CHAPTER 2. SPECIES LIFE HISTORY AND RESOURCE NEEDS

This chapter reviews biological and ecological information about sheepnose, including taxonomy, genetics, morphology, and known life history traits that are important to viability now and into the future within the species' historical and extant distribution. We have summarized that information in this chapter; for additional discussion, refer to Appendix A.

2.1 Taxonomy and Genetics

Taxonomy

Sheepnose is a member of the mussel family Unionidae, also known as the naiads or pearlymussels. The sheepnose 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 Service recognizes *Unio aesopus* and *U. compertus* as synonyms of *Plethobasus cyphyus*. Sheepnose is the accepted common name for *Plethobasus cyphyus* (Williams et al. 2017, p. 41). The Service also recognizes "bullhead" and "clear profit" as older common names for sheepnose.

Genetics

Within recent years, researchers have shifted focus to examine the ecological and genetic conditions of imperiled freshwater mussel species at the population level, including sheepnose. While limited genetic work is available, one study investigated sheepnose population dynamics, connectivity, and distribution of genetic diversity throughout the species' range and incomparison to its historical condition (Schwarz and Roe 2022, entire). Samples from within the Upper Mississippi and Ohio River Basins found low rates of genetic migration within each basin, but not between (Schwarz and Roe 2022, p. 1, 5-6). Further, within each basin, multiple genetically distinct populations and sub-populations were identified (Schwarz and Roe 2022, p. 7-8). Refer to Appendix A for futher discussion.

2.2 Species Description

Sheepnose is a medium-sized species, elongate quadrate to ovate in shape, that is thick-shelled and reaches nearly 5.5 inches in length. There is a row of large, broad tubercular swellings on the center of the shell extending from the beak to the ventral margin and the periostracum (external shell surface) is generally light yellow to dull yellowish brown in color.

2.3 Species Historical Distribution

This species is known from the Mississippi, Ohio, Cumberland, Tennessee, and Ohio River main stems, and scores of tributary streams rangewide. Sheepnose was historically known from 79 streams (including 1 canal) in 14 states. These include, by stream system (with tributaries), the following:

Upper Mississippi River system

Mississippi River mainstem and the following tributaries: Minnesota (Cottonwood River), St. Croix, Chippewa (Flambeau River), Wisconsin, Rock, Iowa (Cedar River), Des Moines, Illinois (Des Plaines, Kankakee, Fox, Mackinaw, Salt, Skunk, Spoon, Sangamon (Salt Creek) Rivers; Quiver Creek; Illinois and Michigan Canal), Meramec (Bourbeuse, Big Rivers), Kaskaskia, Upper Castor, Upper Whitewater Rivers; Saline Creek.

Lower Missouri River system

Little Sioux, Little Blue, and Gasconade (Osage Fork) Rivers.

Ohio River system

Ohio River mainstem and the following tributaries: Allegheny, Monongahela, Beaver, Muskingum (Tuscarawas, Walhonding (Mohican River), Otter Fork Licking Rivers), Kanawha, Scioto, Little Miami, Licking, Kentucky, Green (Barren River), Wabash (Mississinewa, Eel, Tippecanoe, Vermillion, Embarras, White (East, West Forks White River) Rivers) Rivers; Duck Creek.

Cumberland River system

Cumberland River mainstem and the following tributaries: Obey, Harpeth Rivers; Caney Fork.

Tennessee River system

Tennessee River mainstem and the following tributaries: Holston (North Fork Holston River), French Broad (Little Pigeon River), Little Tennessee, Clinch (North Fork Clinch, Powell Rivers), Hiwassee, Duck Rivers.

Lower Mississippi River system

Hatchie, Yazoo (Big Sunflower, Tallahatchie Rivers), Big Black Rivers.

Sheepnose historically occurred in Alabama, Illinois, Indiana, Iowa, Kentucky, Minnesota, Mississippi, Missouri, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and Wisconsin. Sheepnose was last reported from some streams decades ago. According to Parmalee and Bogan (1998, p. 177) and Neves (1991, p. 280-281), sheepnose has been extirpated throughout much of its former range or reduced to isolated populations. The only records known from some streams are archaeological specimens (77 FR No. 49, p. 14923).

2.4 Individual Needs

Sheepnose has been reported to have an approximate life span extending up to at least 30 years (Stansbury 1961, p. 16; Watters et al. 2009, p. 221; Hove et al. 2015, p. 2, 5, 15). Age of sexual maturity for sheepnose is unknown. However, based on estimated longevity, it is suggested it may take place after a few years. Hove et al. (2015, p. 5) documented gravid females ranging from five to 26 years of age (Hove et al. 2015, p. 5).

Typically, reproduction begins with males releasing sperm into the water column and nearby females taking in sperm through their incurrent aperture (Figure 2.1). The sperm fertilize eggs in the suprabranchial chamber (dorsal part of the gills) as ova are passed from the gonad to the marsupia (Haag 2012, pp. 37–42). The developing glochidia (or larvae) remain in the gill chamber until they mature and are ready for release (Haag 2012, pp. 37–42). Sheepnose is a short-term brooder, or tachytictic, gravid from mid-May to early August with variation in response to local water temperature and along a longitudinal gradient (Ortmann 1919, p. 66; Parmalee and Bogan 1998, p.177; Hove et al. 2015, p. 4). Evidence suggests sheepnose brood glochidia in their outer gills (Hove et al. 2015, p. 4) with gill colors varying from dreamsicle to white. Hove et al. (2015, p. 4) found that gills cream and white in color often contain mature glochidia. It is presumed that glochidia release occurs in late summer (July and August) (Ortmann 1911, p. 306; Williams et al. 2008, p. 498).

Sheepnose releases its glochidia in conglutinates that are narrow and lanceolate in outline, solid, and red or pink and discharged in unbroken form (Oesch 1995, p. 118-119). At times glochidia, ova, or conglutinate pieces may be contained within a clear-colored mucus mass (Hove et al. 2015, p. 5). Sheepnose glochidia range from 204-237 µm in length and 197-228 µm in height, without styliform hooks (Williams et al. 2008, p. 498, Hove et al. 2015, p. 9). The glochidia are semicircular with the ventral margin obliquely rounded and hinge line long. Each conglutinate holds several hundred glochidia, suggesting that total fecundity is in the tens of thousands. Hove et al. (2015, p. 5) found no correlation between fecundity and sheepnose mussel age or length.

A host-fish is required for transformation of glochidia into juvenile mussels and dispersal. This requirement can add many vulnerable components and disrupt or prevent successful reproduction or recruitment. Mimic shiner (*Notropis volucellus*) is the only documented natural host fish for sheepnose. However, laboratory transformations have occurred on additional species and natural infestation has been observed on sauger (*Sander canadensis*). To-date, more than 30 species have been identified as suitable host-fish for sheepnose through laboratory trials (Jones et al. 2019, p. 205; Surber 1913, p. 110; Watters et al. 2005, p. 11; Hove et al. 2015, pp. 6-8); refer to Section 2.4.4 for further discussion. Time to transformation through propagation ranges from approximately nine to 32 days (Wolf et al. 2012, p. 7) and may vary among host-species.

See Figure 2.1 for a representative diagram of the sheepnose life cycle and Table 2.1 for a summary of the species' needs during each of its life stages. For additional information, see Appendix A.

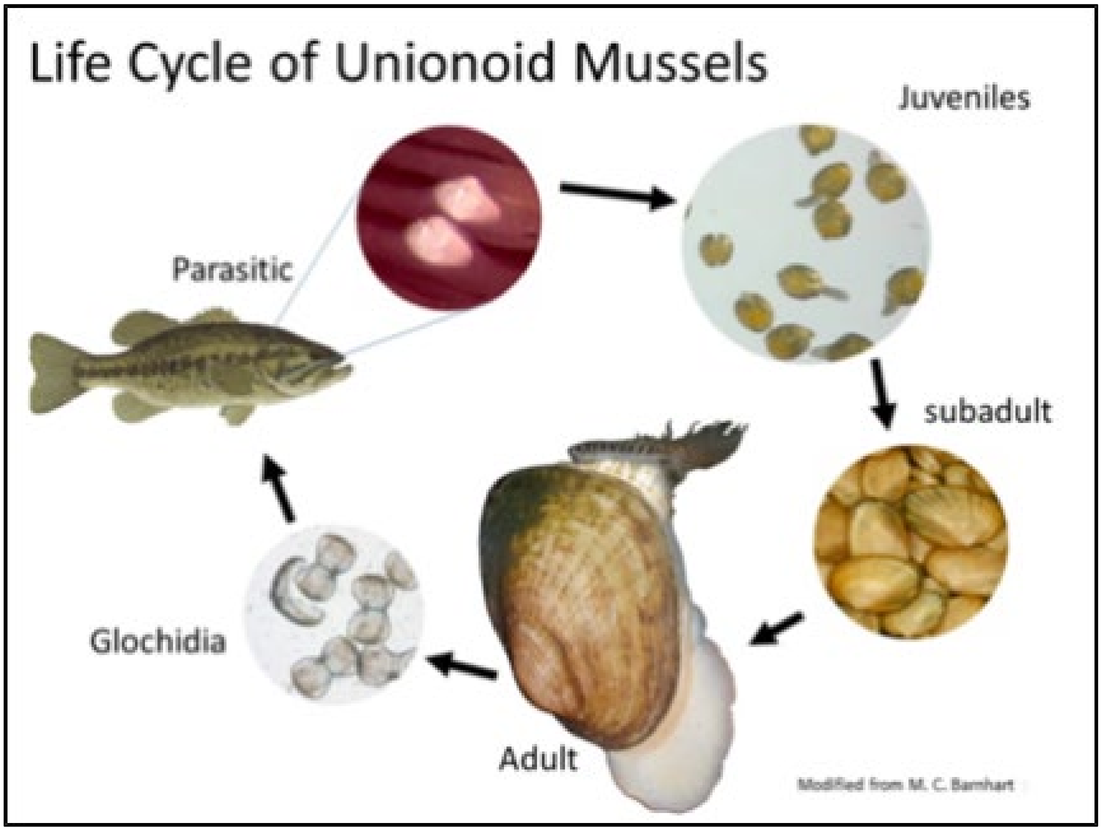


Figure 2.1. Representative life cycle of sheepnose (Credit: M.C. Barnhart).

Table 2.1. Individual needs for sheepnose.

Life Stage	Resources Needed to Complete Life Stage	Source
Fertilized eggs Spawning: Early Summer (May-June) Brooding: May - August	• Suitable water quality • Sexually mature males in proximity to sexually mature females • Suitable spawning water temperatures • Suitable flow conditions	Berg et al. 2008, entire, p. 397; Fuller 1974, p. 240-241; Haag 2012, pp. 38–39; Ortman 1919, p. 66
Glochidia Release and Host Encystment: Mid to late summer (July-August)	• Suitable water quality (clear water for visual attraction of host) • Availability of host fish for attachment • Suitable water temperature • Suitable flow conditions to ensure glochidia encounter host	Strayer 2008, p. 65; Fuller 1974, p. 240-241; Guenther et al. 2009, p. 20; Haag 2012, pp. 41–42; Hove et al. 2015, p. 4, 6-8, 12-13; Wolf et al. 2012, p. 7
Juveniles Excystment from host fish (July-September) to approx. 4 years of age	• Suitable water quality: appropriate interstitial chemistry, low salinity, low ammonia, low copper and other contaminants, high dissolved oxygen • Suitable water temperature • Suitable flow conditions • Host fish dispersal • Suitable substrate conditions (firm/stable; coarse sand, gravel, and cobble) for settlement • Food availability: smaller algae, detritus, bacteria, organic matter, pedal feeding for first several months	Augspurger et al. 2003, p. 2,574; Cummings and Mayer 1992, p. 50; Dimock and Wright 1993, p. 188-190; Fuller 1974, p. 220-221, 238-246; Sparks and Strayer 1998, p. 132; Augspurger et al. 2007, p. 2,025; Strayer and Malcom 2012, p. 1,787–1,788; Ortman 1919, p. 68; Watters et al. 2009, p. 221, Yeager et al. 1994, p. 221
Adults ≥ approx. 5 years of age	• Suitable water quality and temperature • Suitable flow conditions • Suitable substrate conditions: firm/stable, coarse sand and gravel, cobble and may include mud • Food availability: algae, detritus, bacteria, dissolved organic matter, microscopic animals	Yeager et al. 1994, p. 221; Nichols and Garling 2000, p.881; Chen et al. 2001, p. 213-214; Cummings and Mayer 1992, p. 50; Fuller 1974, p. 221, 240-246; Parmalee and Bogan 1998, p. 177; Ortmann 1919, p. 68; Spooner and Vaughn 2008, p. 308; Watters et al. 2009, p. 221

2.4.1 Food Availability

Adult freshwater mussels, including sheepnose, feed by filtering suspended particles including phytoplankton, zooplankton, rotifers, protozoans, detritus, and dissolved organic matter from the water column or sediments (Table 2.1, Figure 2.2; Strayer et al. 2004, pp. 430–431). Juvenile mussels collect food items from sediments and the water column (Vaughn et al. 2008, pp. 409–411). A very small amount of carbon is transferred from the fish to the cells that glochidia have clamped down on in the gills (M. Bradley, personal communication, 2021). Availability of nutrients is critical to the survival of mussels at the individual level. In general, the availability of nutrients is not considered a limiting factor except in cases where localized risk factors (for example, elevated water temperature, increased particle number, high flow causing aperture closure) are present that change the behavior of mussels' filtering capacity or an invasive species is present in such abundance that competition for resources becomes an issue (for example, competition with zebra mussels for food) (Strayer 1999, entire).

2.4.2 Suitable Water Quality and Temperature

Appropriate water quality is critical to the survival, reproduction, and persistence of all life stages of freshwater mussels. Point and non-point source contaminants result in water quality and habitat degradation. Contaminants alter the chemical, physical, and biological characteristics of a stream resulting in lethal and sub-lethal effects to mussels and their hosts. Although specific data for these parameters with respect to sheepnose are not available, mussels in general are similar in terms of sensitivity to certain thresholds depending on the life stage exposed. Mussels in general need water temperatures below about 86 degrees Fahrenheit (˚F) (30 degrees Celsius (˚C)), dissolved oxygen concentrations greater than 5 milligrams per liter (mg/L) (Pandolfo 2010, entire), and water quality concentrations below acute toxicity levels to mussels for contaminants including, but not limited to, total ammonia nitrogen, copper, chloride, and sulfate (see Appendix B for additional details).

2.4.3 Habitat Conditions (Suitable Substrate and Appropriate Flow Conditions)

Sheepnose is generally found in medium to large stream systems, typically within shallow shoal habitats with moderate to swift currents over mixtures of coarse sand, gravel, and clay (Oesch 1995, p. 121; Ortman 1919, p. 68; Jones et al. 2019, p. 205; Cummings and Mayer 1992, p. 50; Parmalee and Bogan 1998, p. 177). Evidence suggests individuals may occur in aquatic areas ranging from riffles of a few inches in depth to runs that exceed six meters in larger rivers (Ortman 1919, p. 68; Parmalee and Bogan 1998, p. 77; Williams et al. 2008, p. 498).

Normal fluctuations in velocity are expected; however, extreme changes can prove to be detrimental. Significant and prolonged increases in velocity typically associated with flood conditions have the potential to dislodge and scour mussels and move the bed destroying sheepnose and host-fish habitat. High shear stress and areas of scour may cause instability of rock structures creating unsuitable shelter habitat for sheepnose. Furthermore, abnormally high velocities have the potential to cause glochidia mortality due to wash out and displacement of juveniles and adults. Alternately, extreme low flow associated with drought or water withdrawal can impact reproduction, feeding, respiration, and in some cases result in dewatering, exposure, and desiccation of the species. Seasonal low flow is expected in some systems and can be tolerated by sheepnose, though periodic drying or intermittent flow in lotic and lentic habitats generally cannot support mussel assemblages. Appropriate flow is critical to delivering oxygen and nutrients for respiration and filtration, essential for reproduction to allow glochidia to move to their host and encyst, as well as removing silt and other fine sediments from the substrate preventing mussel suffocation.

2.4.4 Host Availability

Research from the Genoa National Fish Hatchery, the University of Minnesota, and Ohio State University show sheepnose are able to successfully undergo transformation on five fish species including: fathead minnow (*Pimephales promelas*), creek chub (*Semotilus atrromaculatus*), central stoneroller (*Campostoma anomalum*), brook stickleback (*Culaea inconstans*), and golden shiner (*Notemigonus crysoleucas*) (Watters et al. 2005, pp. 11–12; M. Bradley, USFWS, pers. comm. 2022). Recent research conducted by Hove et al. (2015, entire) found sheepnose to likely be a cyprinid host specialist (Hove et al. 2015, p. 12). Specifically, Hove et al. (2015, p. 6-8), Wolf et al. (2012, p. 7), and Guenther et al. (2009, p. 20), collectively identified more than 30 species as suitable host fish within the laboratory setting. Of the species identified, Hove et al. (2015) discovered 11 species had higher production of sheepnose juveniles (Table 2.2). Additionally, authors (2015, p. 6) state several juvenile mussel releases from cyprinid hosts increased when held at warmer temperatures (i.e., 22 – 25 ºC). Finally, it is important to note the fish species identified to have successfully transformed sheepnose glochidia were done within laboratory trials; due to differing habitat preferences, sheepnose interactions with many of the species identified may be infrequent or non-existent in the natural environment. To-date documentation of natural infestations has been limited to sauger (*Sander canadensis*) and mimic shiner (*Notropis volucellus*); of these, only mimic shiner has been observed to successfully facilitate transformation of sheepnose juveniles in the laboratory (Surber 1913, p. 110; Wilson 1914, pp. 338-340; Hove et al. 2015, p. 12).

Table 2.2. Species identified as suitable host fish (Hove et al. 2015, p 6-8; Wolf et al. 2012, p 7; Guenther et al. 2009, p. 20).

Host-Fish	
Common Name	**Scientific Name**
Sauger^n	*Sander canadensis*
Central stoneroller^	*Campostoma anomalum*
Largescale stoneroller	*Campostoma oligolepis*
Southern redbelly dace	*Chrosomus erythrogaster*
Whitetail shiner^	*Cyprinella galactura*
Red shiner	*Cyprinella lutrensis*
Spotfin shiner ^	*Cyprinella spiloptera*
Blacktail shiner^	*Cyprinella venusta*
Steelcolor shiner	*Cyprinella whipplei*
Brassy minnow	*Hybognathus hankinsoni*
Mississippi silvery minnow	*Hybognathus nuchalis*
Common shiner^	*Luxilus cornutus*
Bleeding shiner	*Luxilus zonatus*
Silver chub^	*Macrhybopsis storeriana*

Table 2.2 (continued). Species identified as suitable host fish (Hove et al. 2015, p 6-8; Wolf et al. 2012, p 7; Guenther et al. 2009, p. 20).

Host-Fish	
Common Name	**Scientific Name**
Allegheny pearl dace	*Margariscus margarita*
Hornyhead chub	*Nocomis biguttatus*
Golden shiner^	*Notemigonus crysoleucas*
Emerald shiner	*Notropis atherinoides*
River shiner	*Notropis blennius*
Spottail shiner	*Notropis hudsonius*
Ozark minnow^	*Notropis nubilus*
Topeka shiner^	*Notropis topeka*
Mimic shiner^n	*Notropis volucellus*
Suckermouth minnow	*Phenacobius mirabilis*
Bluntnose minnow	*Pimephales notatus*
Fathead minnow	*Pimephales promelas*
Bullhead minnow	*Pimephales vigilax*
Eastern blacknose dace	*Rhinichthys atratulus*
Longnose dace^	*Rhinichthys cataractae*
Creek chub^	*Semotilus atromaculatus*
Striped shiner	*Luxilus chrysocephalus*
Banded killifish*	*Fundulus diaphanous*
Blackspotted topminnow*	*Fundulus olivaceus*
Mosquitofish*	*Gambusia affinis*
Brook stickleback*	*Culaea inconstans*
Common molly*	*Poecilia sphenops*
Black crappie*	*Pomoxis nigromaculatus*

* = non-cyprinid hosts (Hove et al. 2015).

^ = high sheepnose juvenile production observed (Hove et al. 2015)

^{n} = natural infestation observed

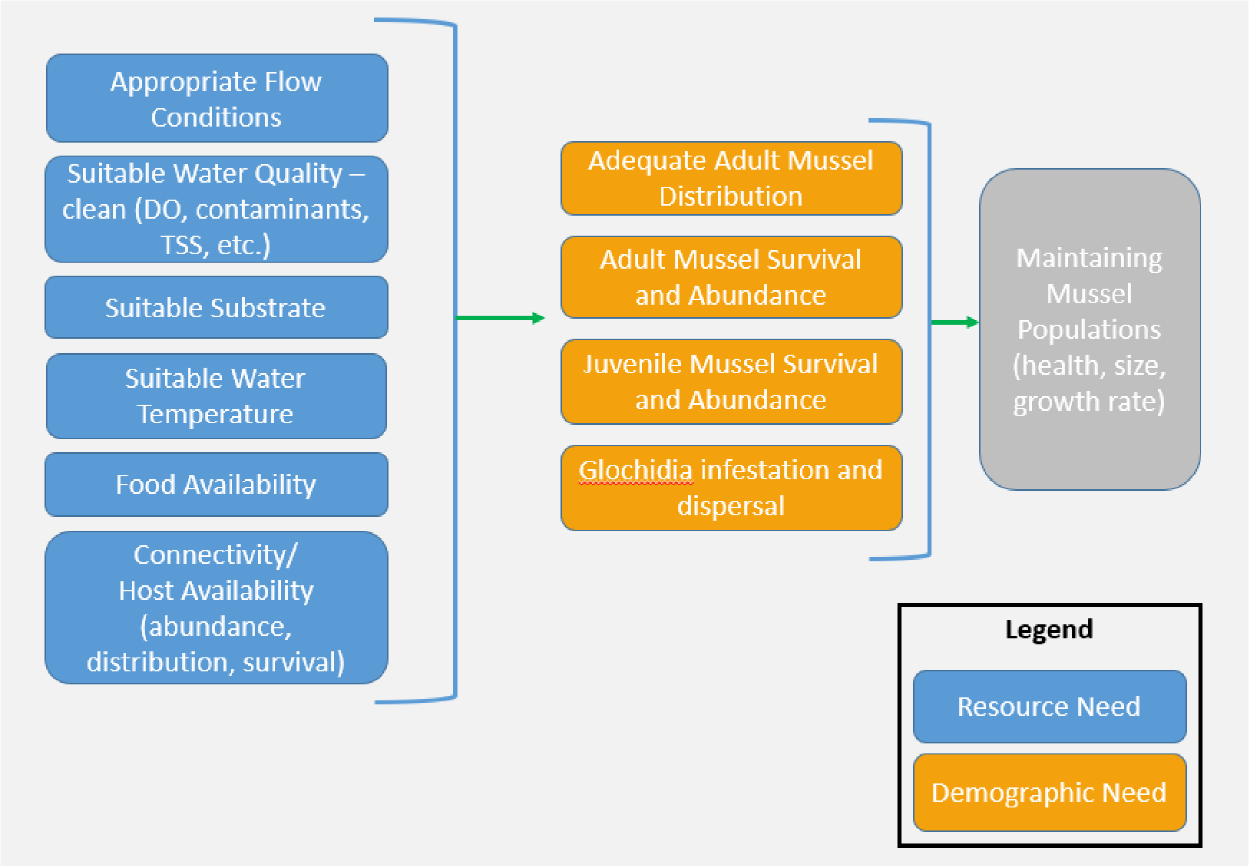


Figure 2.2. Conceptual model of the resource needs to support demographic needs to maintain sheepnose populations.

2.5 Population and Species Needs

We defined populations by the watersheds through which occurrence streams flow, using the U.S. Geological Service (USGS) Hydrologic Unit Code (HUC) system. We used HUC8 watersheds as a representation for an area's potential capability for dispersal and interaction of individuals. Watershed boundaries and natural and artificial barriers may constrain ecological processes, such as genetic exchange and ultimately adaptive capacity for aquatic species (Funk et al. 2019, entire). For the purposes of this assessment, populations were defined within the bounds of HUC8 watersheds.

In previous assessments, populations were considered at the stream level. However, sheepnose are estimated to occupy limited reaches within streams, with occupied areas often confined by tributary confluences, impoundments, and/or areas of unsuitable habitat. Although a limited number of these interactions persist at the HUC8 scale, this approach provided additional resolution and allowed us to assess sheepnose occurrences within a more ecologically appropriate context in regard to primary influences on viability (See Chapter 3 and Appendix B). However, it is important to note, defining populations at the HUC8 watershed scale is not indicative of the level of genetic flow between populations. Refer to Section 2.1, Section 2.5.2, and Appendix A for further discussion regarding population genetics and representation.

2.5.1 Population Connectivity

At a broader scale, suitable sheepnose habitat constitutes stream reaches where the host species is present and there is connectivity between localized populations to allow for both host and mussel dispersal. Connectivity is characterized by suitable water quality and lack of barriers to dispersal and host fish movement (for example, perched culverts, hydropower dams, water control structures). Having multiple occupied sites within a high degree of habitat connectivity can provide a source of resiliency and redundancy that can benefit the viability of the species. However, impoundments and other barriers to host species dispersal, such as river reaches with unsuitable water quality (for example, high concentrations of pollutants or temperature), effectively isolate populations from one another, making repopulation of extirpated locations from nearby populations unlikely without human intervention (in other words, active restocking). Refer to Appendix B for further discussion.

2.5.2 Representation

Maintaining species representation in the form of genetic and ecological diversity is important in safeguarding the ability of the populations to adapt to future environmental changes. Although information regarding the genetic diversity of sheepnose populations is limited, one study suggests that low levels of genetic migration may be occurring within basins (roughly HUC2 scale), but not between, with each basin being comprised of multiple genetically distinct populations and sub-populations (Schwarz and Roe 2022, p. 5-6, 8); refer to Section 2.1 and Appendix A for further discussion. Therefore, in the absence of range-wide species-specific genetic information, we can evaluate representation based on the extent and variability of environmental conditions within the species' geographic range. We considered geographic range as a surrogate for geographic variation and proxy for potential local adaptation and adaptive capacity because genetic information is not available. Therefore, representation was considered at the HUC2 watershed scale. We delineated four representation units for sheepnose: Upper Mississippi River, Ohio River, Tennessee River, and Lower Mississippi River basins.

2.5.3 Redundancy

Sheepnose needs multiple resilient populations distributed throughout its range to reduce the risk of a catastrophic natural or anthropogenic-induced event negatively affecting a large portion of the species' range at any given point in time. Species well distributed across their historical range are less susceptible to extinction and more likely to remain viable compared to species confined to a small portion of their historical range (Carroll et al. 2010, entire; Redford et al. 2011, entire).

CHAPTER 3. PRIMARY INFLUENCES ON VIABILITY

Sheepnose populations are susceptible to several natural and anthropogenic stressors occurring within their watersheds. These stressors can influence one or more of the individual and population needs discussed in Chapter 2. Stressors can vary by degree of impact across the range of the species. The habitat risk factors represent these stressors. Habitat risk factors influence the demographics of a population, such as survival, reproduction, and recruitment. Populations with healthy demographics can offset some effects of these stressors. We identified contaminants, hydrological regime, landscape alteration, lack of connectivity, and invasive species as the primary risk factors influencing the resources upon which sheepnose relies, either directly or indirectly (Figure 2.2). We considered host availability as a potential threat, but did not identify host vulnerability as a primary risk at this time due to the current condition and distribution of natural host fish populations. We also considered direct threats to the mussel, including the influence of mussel disease and the effect of catastrophic events. An overview of risk factors influencing past, current, and future population condition is available in Appendix B.

CHAPTER 4. CURRENT CONDITION

4.1 Species Current Distribution

We describe and analyze the distribution in terms of watersheds occupied. Watersheds are delineated by the U.S. Geological Survey (USGS) based on surface hydrological features. These hydrological areas are identified by hydrological units at various scales. The different scales are assigned Hydrologic Unit Codes (HUCs). The hydrological units start with a 2-digit code at the regional level, expanding from there to a finer scale. We used the HUC2 at the regional scale (representation unit) and the HUC8 at the subbasin (population) scale (https://nas.er.usgs.gov/hucs.aspx). Conducting our current condition analysis at the HUC8 scale allowed us to assess occurrences at an ecologically relevant scale for which we have data on the primary stressors affecting populations.

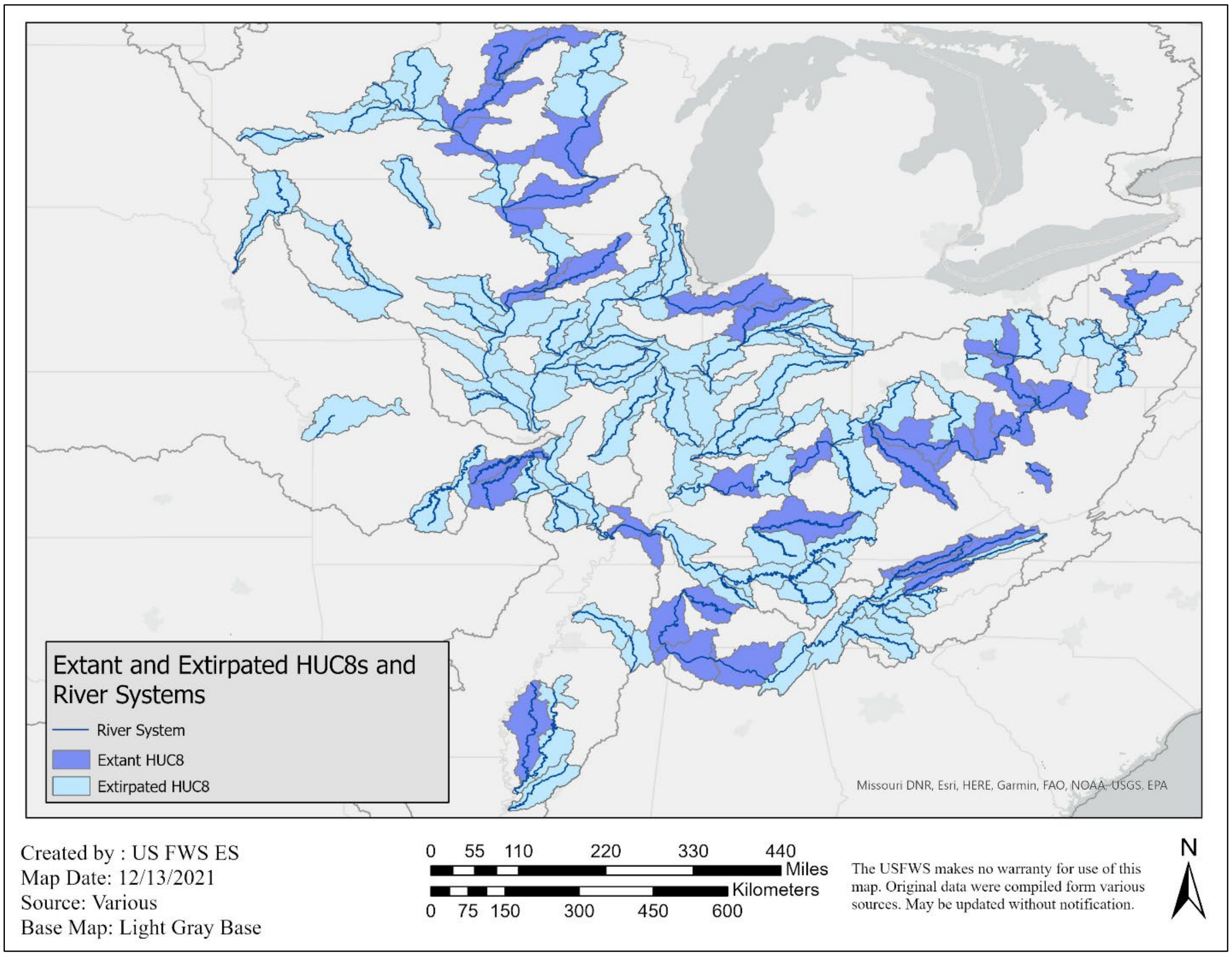
For the purposes of this assessment, we considered populations of sheepnose to be extant if we identified information indicating that live or fresh-dead specimens have been observed or collected within the last two decades (2000-2020). Although this report was published in 2022, we did not consider collections beyond 2020 as part of this assessment. We recognize the number of mussel surveys, locations of surveys, level of effort expended, and survey methodology, among other factors, may greatly influence the detection of sheepnose populations and numbers of individuals. However, given the increase in sheepnose collection reporting and surveys conducted to inform presence of the species since its listing as a federally endangered species in 2012, we determined 20 years was an appropriate timeframe to assess population status. Further, the Final Listing Rule (77 FR 14914) used a similar timeframe of approximately 20-years to identify extant populations of sheepnose through the collection of live or fresh dead shells (p. 14917). All populations (defined at the stream scale) that were identified as extirpated at the time of listing continued to be considered extirpated through this assessment, providing additional support to this methodology.

We developed categories that define a population's status as extant or extirpated to assess the health, number, and distribution of populations through time (Table 4.1). Because sheepnose is a thick-shelled species, weathered dead shells are expected to persist in a system for an extended period of time. Therefore, we did not classify the collection of weathered dead shells in any year as an indicator of extant populations. Instead, we carried forward and analyzed current condition for only the extant populations (total of 37 populations, Figure 4.1, Table 4.2).

We made every effort to accurately depict the historic range of the sheepnose mussel through identification of HUC8s where live or fresh dead specimens have been detected prior to 2000 or where weathered dead shells have been collected in any year (Figure 4.1). However, as a result of instances of location uncertainties and incomplete data records, the identified extirpated HUC8s should be considered a conservative estimation of sheepnose's historic range and not relied on as conclusive.

Table 4.1. Definitions of status assigned to sheepnose populations.

Status	Definition
Extant (E)	Observation(s) from 2000 – 2020 of live or fresh dead specimens
Extirpated (X)	Observation(s) from pre-2000 of live or fresh dead specimens or detection of weathered dead specimens in any year



Created by : US FWS ES
Map Date: 12/13/2021
Source: Various
Base Map: Light Gray Base

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Figure 4.1. Rangewide extant and extirpated sheepnose populations (HUC8).

Table 4.2. Summary of population status (HUC 8 watersheds) by representation unit (HUC 2 river basins) for sheepnose.

Status	Extant (E) HUC8s	Extirpated/ Presumed Extirpated (X) HUC8s	Extant (E) Streams	Extirpated/ Presumed Extirpated (X) Streams
Upper Mississippi River Basin	13	36	8	22, including 1 canal
Ohio River Basin	15	36	8	21
Tennessee River Basin	8	8	5	6
Lower Mississippi River Basin	1	5	1	4
Lower Missouri River Basin	0	4	0	4
Species Range Total	37	89 (conservative estimate)	22	57, including 1 canal

4.2 Population Resiliency

4.2.1 Demographic Factors Methodology

We utilized available demographic data to qualitatively evaluate population health in regard to the ability to withstand demographic stochastic events. We assessed demographic population condition (HUC8 watersheds) as high, moderate, low, or functionally extirpated based on the demographic criteria (Table 4.3). Although a specific threshold for population viability has not been identified for sheepnose, we use the term "functionally extirpated (Fx)" for the purposes of this assessment to identify where available data suggest the presence of a highly fragmented population comprised of a small number of non-reproducing individuals (Table 4.3). Available data included a variety of survey types, methodologies, and levels of effort expended across the species' range, with collections ranging from incidental to large-scale relocation surveys. We recognize these differences may greatly influence the detection of sheepnose individuals within a population, and therefore, skew the assigned demographic conditions. Additionally, in limited instances, the available data for a population did not align with individual demographic metric definitions, as presented in Table 4.3. Where possible, we accounted and adjusted for these variations, as described in Appendix C, Appendix E, and Table E.1, and verified the resulting demographic scores with local State and/or federal resource managers familiar with the respective populations, as available.

We defined a total of four demographic categories to assess the demographic condition of each population. These four categories, Cumulative Population Size, Reproduction and Recruitment, Population Distribution, and Year of Last Observation, are described in detail, below and Appendix C. Additive scoring was used across the four categories to generate an overall demographic score for each population. Definitions associated with high, moderate, low, or functionally extirpated conditions are provided for each of the four condition categories within Table 4.3. Populations were assigned three points for each category meeting the "high" condition definition, two points for "moderate" condition, one point for "low" condition, and zero points for a demographic condition of "functionally extirpated." Points across the four demographic condition categories were summed for each population with an additive score of 0-3 representing an overall demographic condition of "functionally extirpated," a score of 4-7 representing an overall "low" condition, a score of 8-10 representing an overall "moderate" condition, and a score of 11-12 representing an overall "high" condition (Refer to Table C.1 in Appendix C). For further information on methods used to evaluate metrics within each of these demographic factors and the scoring system, refer to Appendix C.

Additionally, we assigned an estimate of the probability of persistence over 50 years (approximately two generations for sheepnose) for each population condition category based on best professional judgement of a population's ability to withstand demographic stochastic events. These opinions were provided by the Core SSA Team (including species experts, a malacologist, SSA, and recovery experts).

Table 4.3. Condition category descriptions for sheepnose demographic factors.

Condition Category	Demographic Factors				Estimation of Probability of Persistence over 50 years
	Cumulative Population Size	Reproduction and Recruitment	Population Distribution	Year of Last Observation	
High (3 points)	Cumulative high number (101+) of individuals observed since 2000 across all surveys and incidental findings	Juveniles (live or FD) collected or evidence of recruitment (gravid females) observed within each of the last two decades (2000-2010, 2010-2020), with at least one juvenile collected within the last 5 years (2015-2020)	Occurs at multiple sites, roughly evenly distributed over 30+ river miles	Most recently identified within last 5 years (2015-2020)	>90%
Moderate (2 points)	Cumulative moderate number (21-100) of individuals observed since 2000 across all surveys and incidental findings	No juveniles (live or FD) collected within the last 5 years (2015-2020), but collected within preceding 5 years (2010-2015) AND additional juveniles or evidence of recruitment (gravid females) observed within the preceding decade (2000-2010)	Occurs at multiple sites, roughly evenly distributed over 10-30 river miles	Most recently identified within last 10 years (2010-2015)	60-90%
Low (1 point)	Cumulative low number (5-20) of individuals observed since 2000 across all surveys and incidental findings	Zero juveniles collected within the past 10 years (2010-2020) BUT evidence of recruitment (gravid females or juveniles) observed within the preceding 10 years (2000-2010)	Occupies a single or limited number of sites, distributed over 1-10 river miles	Most recently identified within last 15 years (2005-2010)	30-60%
Functionally Extirpated (0 points)	Survey efforts conducted over past 20 years have resulted in the collection of <5 live or fresh dead individuals OR limited survey efforts have been conducted within the last 20 years with the population size unknown	No juvenile individuals or gravid females identified within past 20 years (2000-2020)	<1 river mile OR Unknown	Most recently identified within last 20 years (2000-2005)	<30%

4.2.2 Risk Factors Methodology

We grouped the risk factors into five primary categories (water quality/contaminants, landscape, hydrological regime, connectivity, and invasive species) to assess the current condition of each population. Water quality/contaminants include four primary contaminants (ammonia, chloride, nitrate, and copper) and six secondary contaminants (lead, potassium, sulfate, zinc, aluminum, and cadmium). To evaluate the effects of various land use activities, we assessed a suite of landscape metrics derived from the 2016 National Landcover Dataset (Jin et al. 2019, entire). Specific metrics include percent imperviousness mean within the population; percent vegetative cover remaining within a 108-meter riparian buffer; and percent urban, percent agriculture, and canopy cover within a 108-meter riparian buffer. We used U.S. Drought Monitoring Data to assess drought risk for the hydrological regime and the number of dams and density of unpaved roads to evaluate connectivity. The invasive species assessment included twelve species known to impact native freshwater mussels: zebra mussel, Asian clam, five species of invasive carps (silver, bighead, black, grass, common), rusty crayfish, spiny waterflea, brown trout, quagga mussel, and hydrilla.

Risks associated with each of the five factors were assigned as either high, moderate, or low risk (Table 4.4). Similar to our demographic criteria, we assigned a probability of persistence over 50 years for each risk category to create a common understanding of what we mean when we categorize a population as being at high, moderate, or low risk (Table 4.4). To assess overall current condition for the risk factors we developed a rule set as follows: if any one of the risk factors is high = overall population condition is high risk; if none of the risk factors are high an additive approach was used, with scores of 5–7 indicating low risk, 8–10 indicating moderate risk, and 11–15 indicating high risk. These break points were based on three or more risk factors being categorized as moderate. In order to be considered an overall low risk, the majority of risk factors have to be categorized as low. For further information on the methods used to evaluate metrics within each of these risk factors and the scoring system, see Appendix D.

Table 4.4. Summary of risk category descriptions for the five risk factors evaluated for the current condition of each population. A detailed description of the risk factor categories is in Appendix D.

Risk Category	Water Quality/Contaminants[1]	Landscape[2]	Hydrological Regime[3]	Connectivity[4]	Invasive Species[5]	Estimation of probability of persistence over 50 years
High (3 points)	Concentration of primary and/or secondary contaminants exceeds acute toxicity levels in >2% of samples	Landscape condition severely altered by anthropogenic factors	Hydrological regime highly altered by anthropogenic factors	Habitat severely fragmented by dams and road crossing density	Present in abundance	<60%
Moderate (2 points)	Concentration of primary and/or secondary contaminants exceeds acute toxicity levels in <2% of samples	Landscape condition moderately altered by anthropogenic factors	Hydrological regime slightly altered by anthropogenic factors	Some habitat fragmentation due to dams and road crossing density	Present in moderation	60–90%
Low (1 point)	Concentration of primary and/or secondary contaminants at levels below acute toxicity to mussels	Landscape condition slightly altered or unaltered due to anthropogenic factors	Hydrological regime characteristic of natural conditions, unaltered by anthropogenic factors	Few, if any, known habitat fragmentation issues	Absent	>90%

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[1] See Tables D.1 and D.2 for details
[2] See Table D.3 for details
[3] See Table D.4 for details
[4] See Table D.5 for details
[5] See Table D.8 for details

4.2.3. Current Condition

Sheepnose is currently known to occupy portions of 37 HUC8s, though it was historically found in an estimated 126 HUC8s (Figure 4.1, Table 4.2). Although sheepnose populations have decreased over time, the species continues to be found in all 14 States of its historic range. We evaluated demographic (Table 4.3) and risk (Table 4.4) factors for the 37 populations we consider extant and from where available data documented the collection of live or fresh dead specimens within the last 20 years (2000-2020). Additional detailed information for each population is presented in Appendix E.

Upper Mississippi River Basin Representation Unit

Demographic condition – The Upper Mississippi River basin spans portions of Minnesota, Wisconsin, Iowa, Illinois, and Missouri (Figure 4.2). There are 13 extant populations that are currently known within the basin (Bourbeuse, Upper Chippewa, Lower Chippewa, Flambeau, Kankakee, Meramec, Buffalo-Whitewater, La Crosse-Pine, Grant-Little Maquoketa, Copperas-Duck, Lower Rock, Castle Rock, and Lower Wisconsin) (Table 4.2). An additional 36 populations (estimate) are presumed extirpated. Of the extant populations, three are currently considered to be in high condition, two in moderate condition, five in low condition and three are considered functionally extirpated (Figure 4.2, Figure 4.3, Table 4.7, Table E.1, Table E.3).

Risk Factors – Twelve (92 percent) of the 13 sheepnose mussel populations within the Upper Mississippi River basin are currently in an overall high risk condition (Figure 4.2, Table 4.7, Table E.2). The remaining population, the Upper Chippewa, is currently considered to be at moderate risk. Half of the high risk populations are experiencing high risk from multiple sources. Of the populations at high risk, 85 percent are experiencing high risk associated with invasive species. Additional sources of high risk within the Upper Mississippi River basin include water quality (n=7), connectivity (n=2), and landscape (n=1) conditions. Catastrophic risks associated with coal mines are considered to be low for the Upper Mississippi River basin; however, all of the populations within the basin are currently at high risk due to oil and natural gas activities and infrastructure within the basin (Table E.3, Table G.10).

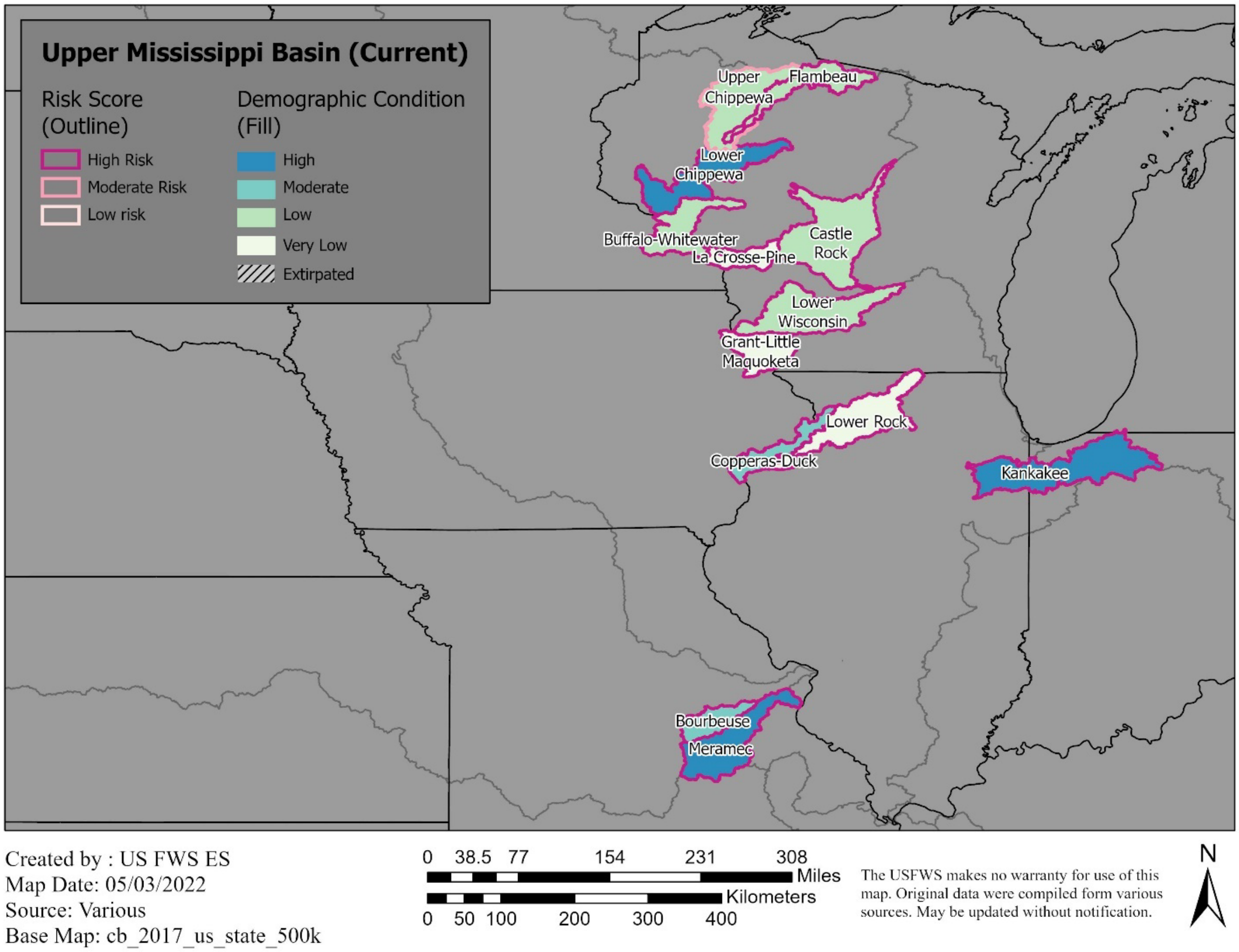

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Figure 4.2. Extant populations within the Upper Mississippi River basin for sheepnose.

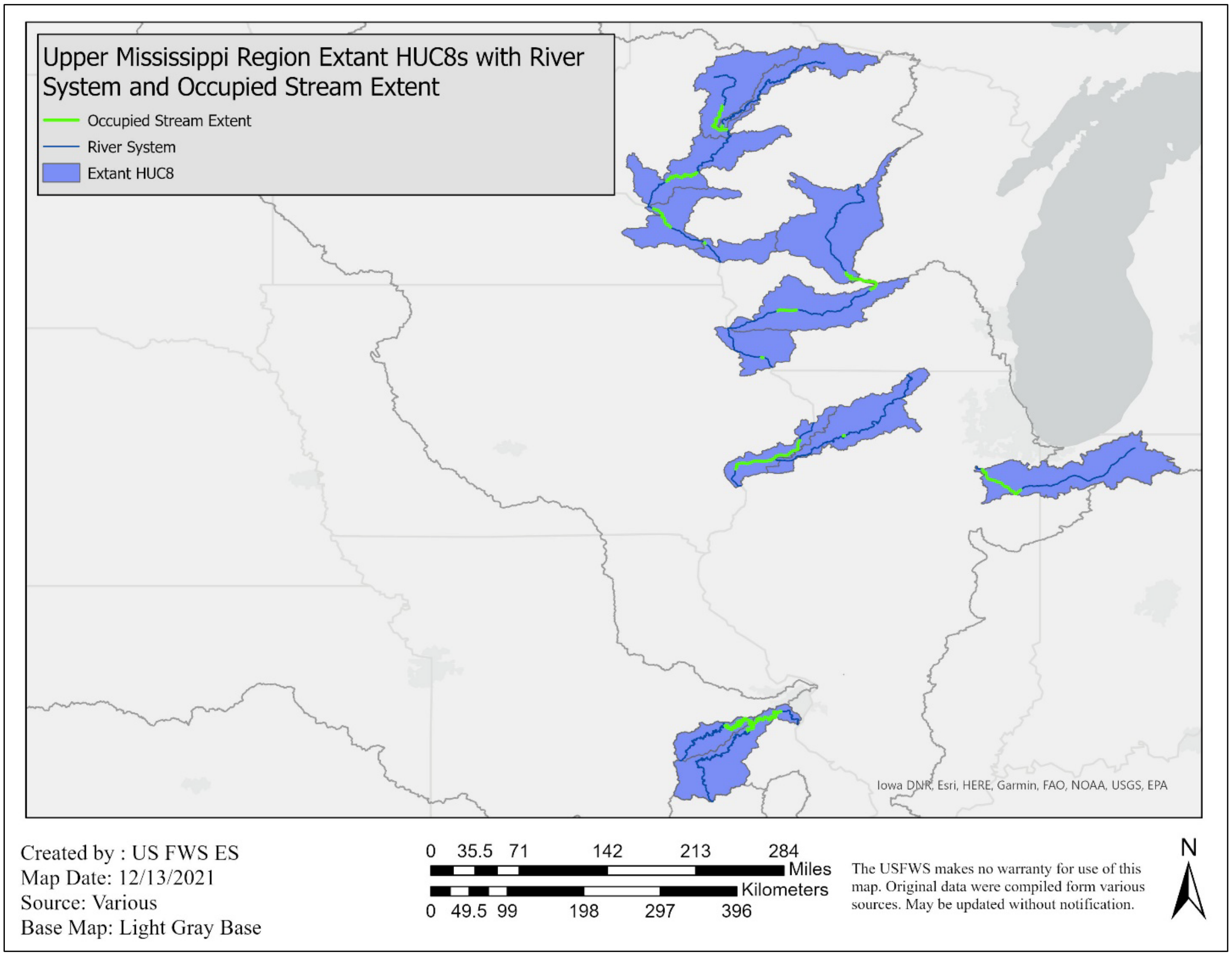

Figure 4.3. Estimated occupied stream extent of extant populations within the Upper Mississippi River basin for sheepnose.

Ohio River Basin Representation Unit

Demographic condition – The Ohio River basin spans portions of Illinois, Indiana, Ohio, Kentucky, Tennessee, Virginia, West Virginia, Pennsylvania, North Carolina, and New York (Figure 4.4). There are 15 extant populations that are currently known within the basin (Allegheny-Tionesta, Upper Green, Upper Kanawha, Licking, Muskingum, Lower Ohio, Lower Ohio-Little Pigeon, Silver-Little Kentucky, Ohio Brush-Whiteoak, Little Scioto-Tygarts, Raccoon-Symmes, Upper Ohio-Shade, Little Muskingum-Middle Island, Tippecanoe, and Walhonding). An additional 36 populations (estimate) are presumed extirpated. Two of the populations are currently considered to be in high condition, five in moderate condition, seven in low demographic condition, and one is considered functionally extirpated (Figure 4.4, Figure 4.5, Table 4.7, Table E.1).

Risk factors – The majority of the fifteen Ohio River basin populations are currently experiencing high overall risk levels (73%), with the remaining four populations experiencing a moderate level of overall risk (27 percent) (Figure 4.4, Table 4.7, Table E.2). All of the 11 high risk populations are at high risk due to water quality impairment. An additional source of high risk includes invasive species impacts. All 15 of the Ohio River basin populations are considered to be at high risk for catastrophic events associated with oil and natural gas and approximately 40 percent are at high risk for coal mine impacts (Table E.3, Table G.10).

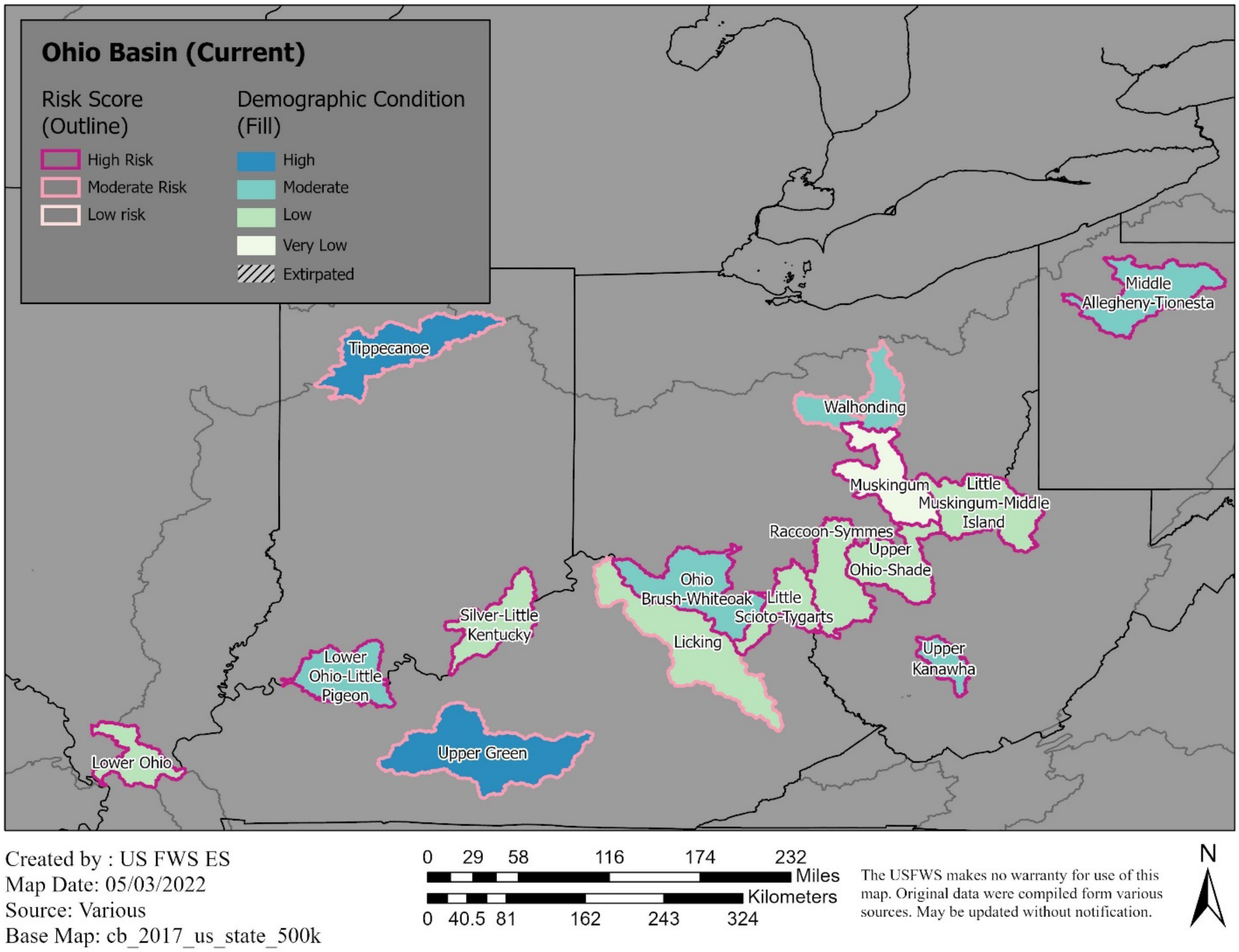

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Figure 4.4. Extant populations within the Ohio River basin for sheepnose.

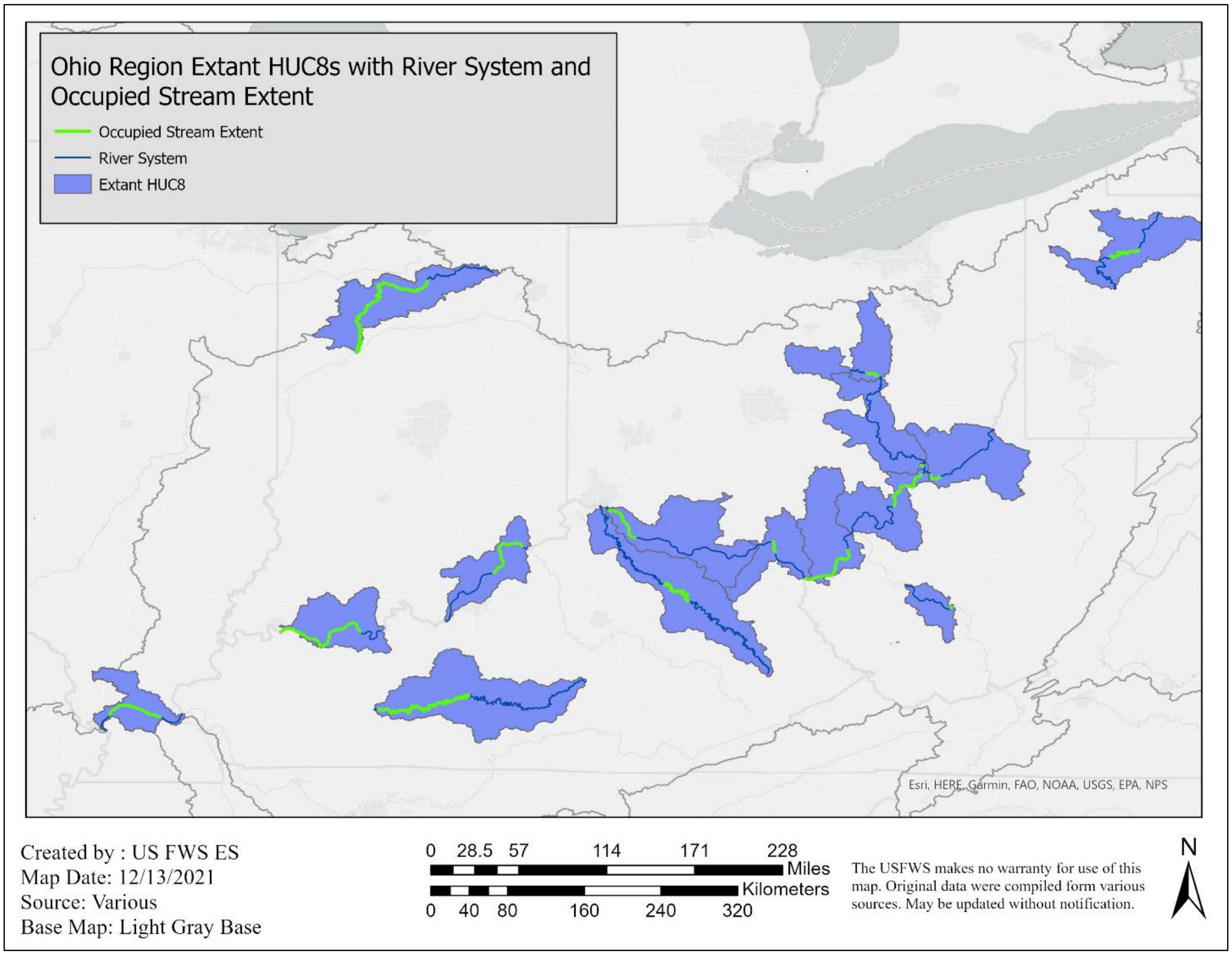

Figure 4.5. Occupied stream extent of extant populations within the Ohio River basin for sheepnose.

<u>Tennessee River Basin Representation Unit</u>

Demographic condition – The Tennessee River basin spans portions of Kentucky, Tennessee, Mississippi, Alabama, Georgia, North Carolina, and Virginia (Figure 4.6). There are eight extant populations that currently known within the basin (Upper Clinch, Tennessee, Virginia; Lower Duck; Holston; Powell; Lower Tennessee; Lower Tennessee-Beech; Pickwick Lake; and Wheeler Lake). An additional eight populations (estimate) are presumed extirpated (Table 4.2, Figure 4.1). One of the extant populations is currently considered to be in high condition, two in moderate condition, three in low condition and two are considered functionally extirpated (Figure 4.6, Figure 4.7, Table 4.7).

Risk factors – Approximately 75 percent of the Tennessee River basin populations are experiencing overall high levels of risk, with the remaining two populations (Pickwick Lake, Wheeler Lake, 25 percent) experiencing overall moderate risk conditions (Figure 4.6, Table 4.7, Table E.2). High risk conditions are fairly evenly distributed across water quality impairment, invasive species impacts, and reduced connectivity (Table E.2). All eight of the populations within the Tennessee River basin are considered to be at high risk of a catastrophic event for activities associated with oil and natural gas and 25 percent are considered at high risk for catastrophic events associated with coal mining impacts (Table E.3, Table G.10).

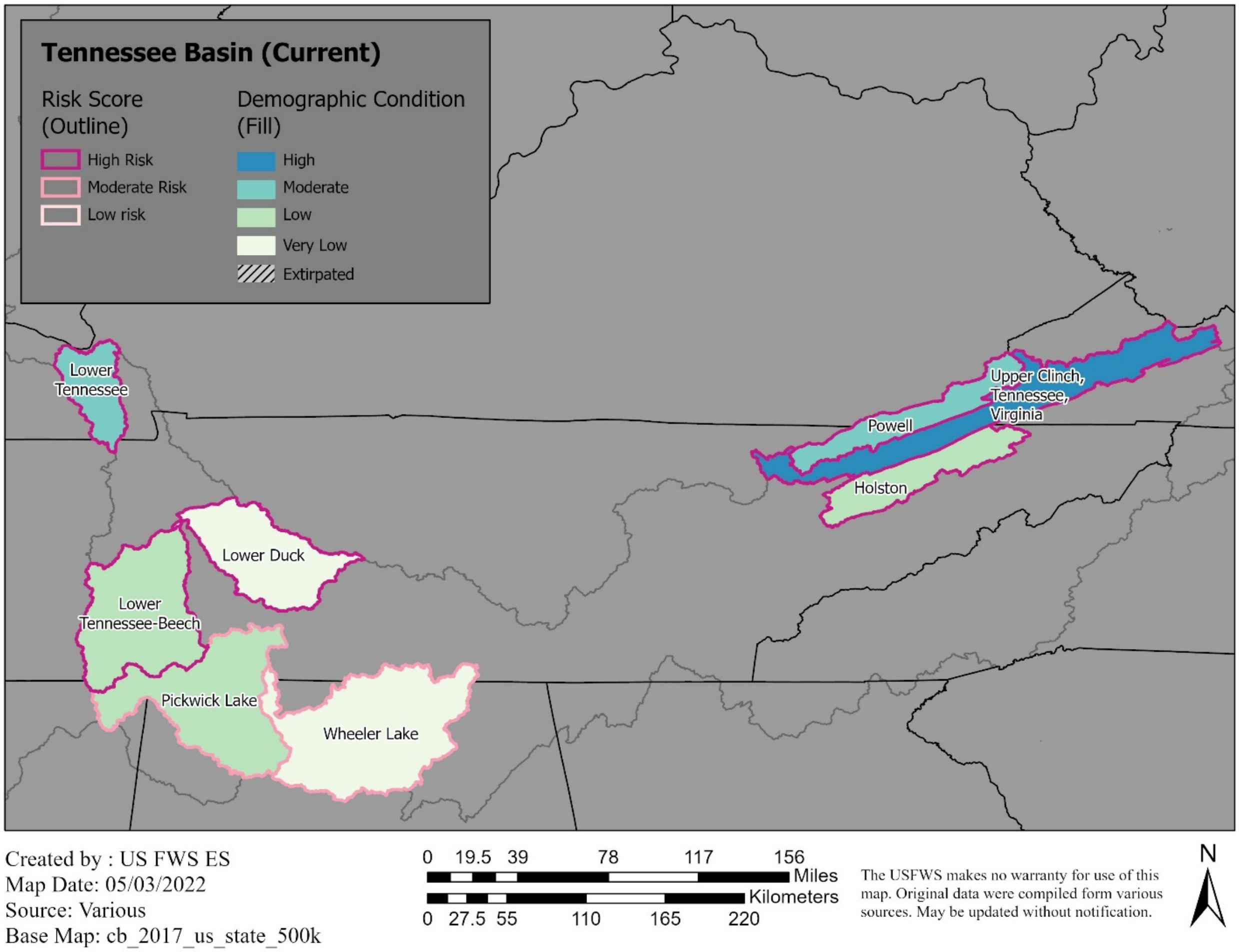

Figure 4.6. Extant populations within the Tennessee River basin for sheepnose.

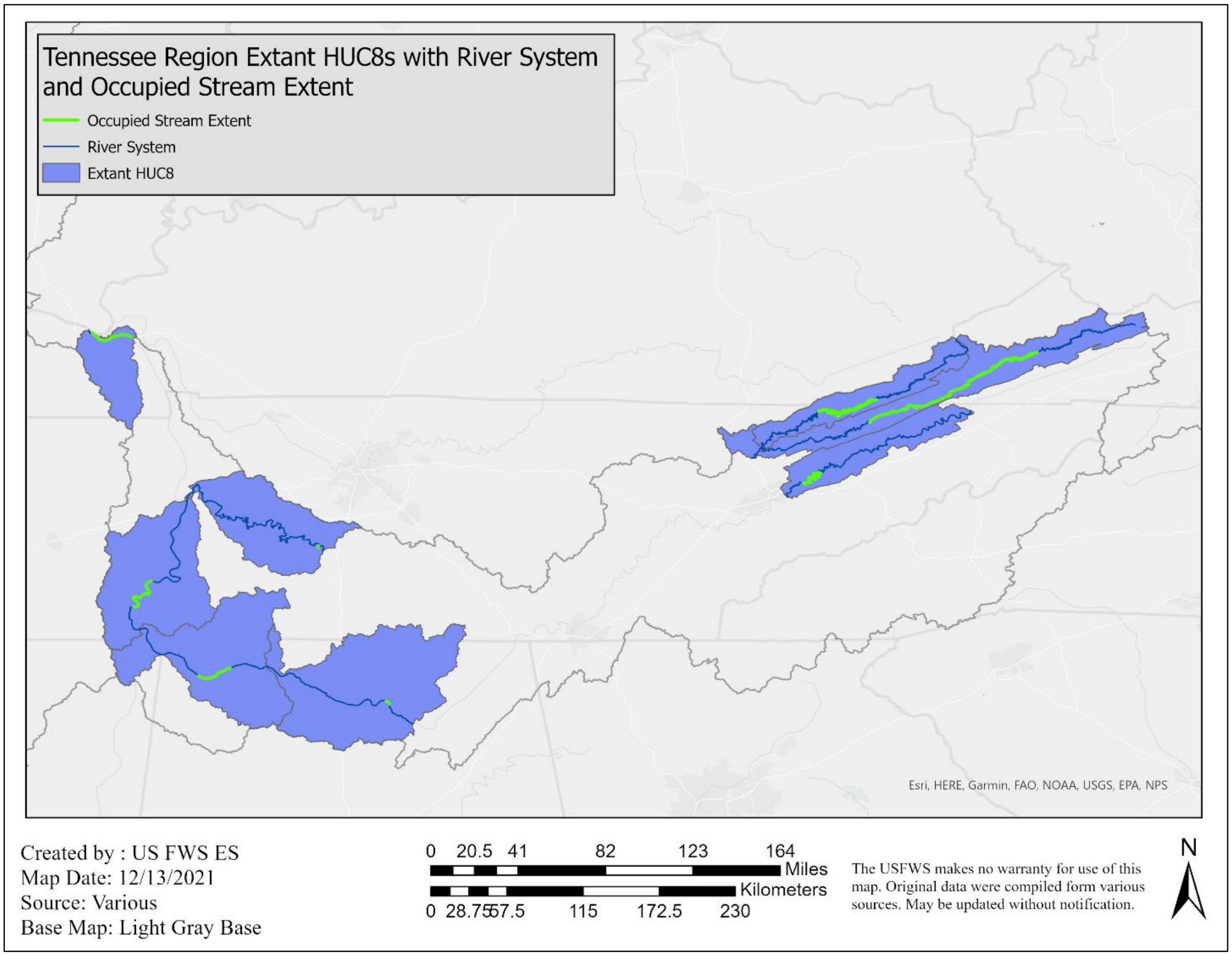

Figure 4.7. Occupied stream extent of extant populations within the Tennessee River basin for sheepnose.

Lower Mississippi River Basin Representation Unit

Demographic condition – The Lower Mississippi River basin spans portions of Missouri, Kentucky, Tennessee, Mississippi, Arkansas, and Louisiana (Figure 4.8). There is one extant population currently known within the basin (Big Sunflower) (Figure 4.8, Figure 4.9). An additional five populations (estimate) are presumed extirpated (Table 4.2). The Big Sunflower population is currently considered to be in low condition (Figure 4.8, Table 4.7, Table E.1), with less than five individuals collected within the last 20 years. Although one juvenile specimen was collected in 2003, sheepnose has not been detected within the Big Sunflower since 2005.

Risk factors – The Big Sunflower population is currently experiencing overall high risk conditions due to water quality impairment (Figure 4.8, Table 4.7, Table E.2). Catastrophic risk associated with the presence of coal mines is considered to be low; however, the population is at high risk for oil and natural gas related activities (Table E.3, Table G.10).

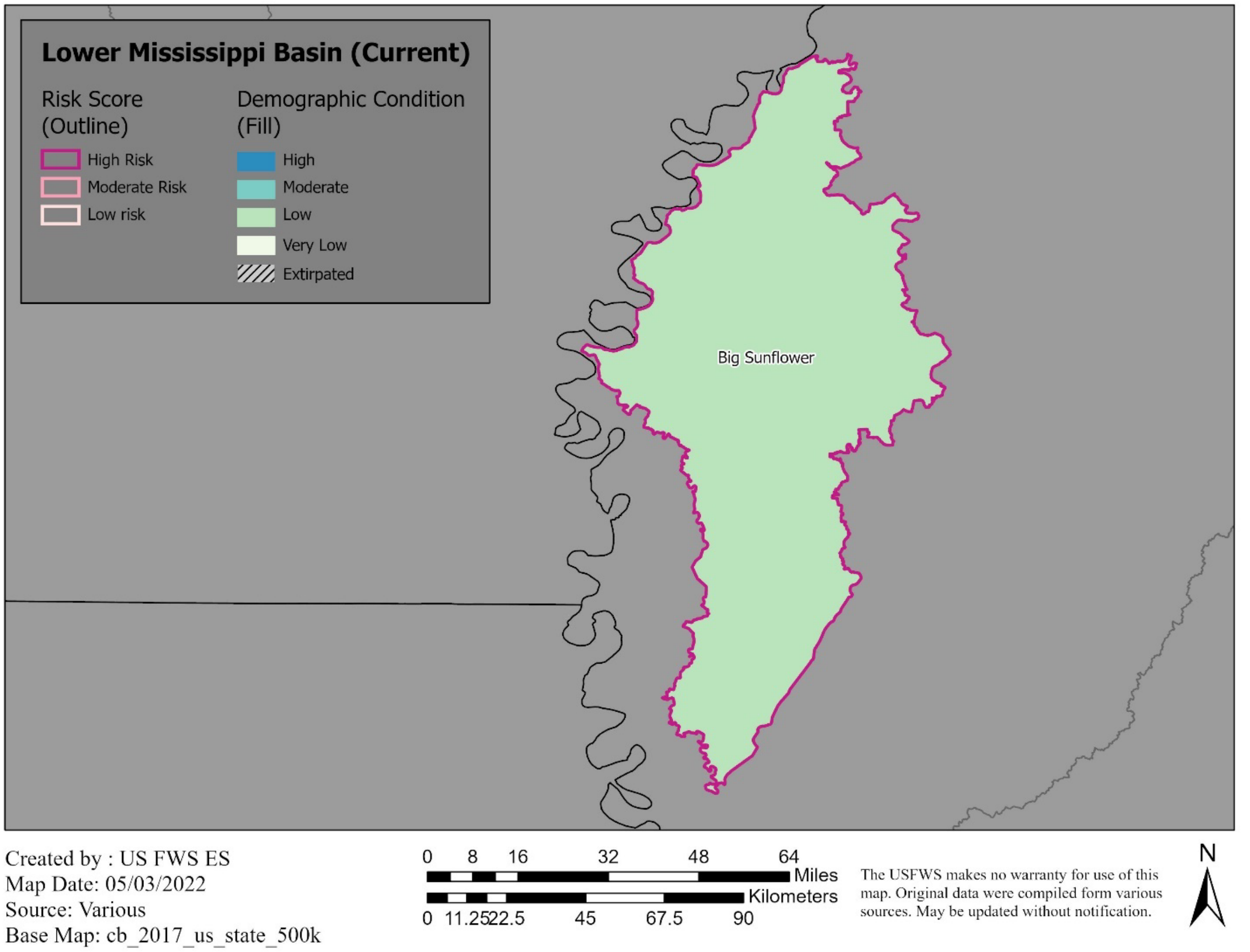

Figure 4.8. Extant populations within the Lower Mississippi River basin for sheepnose.

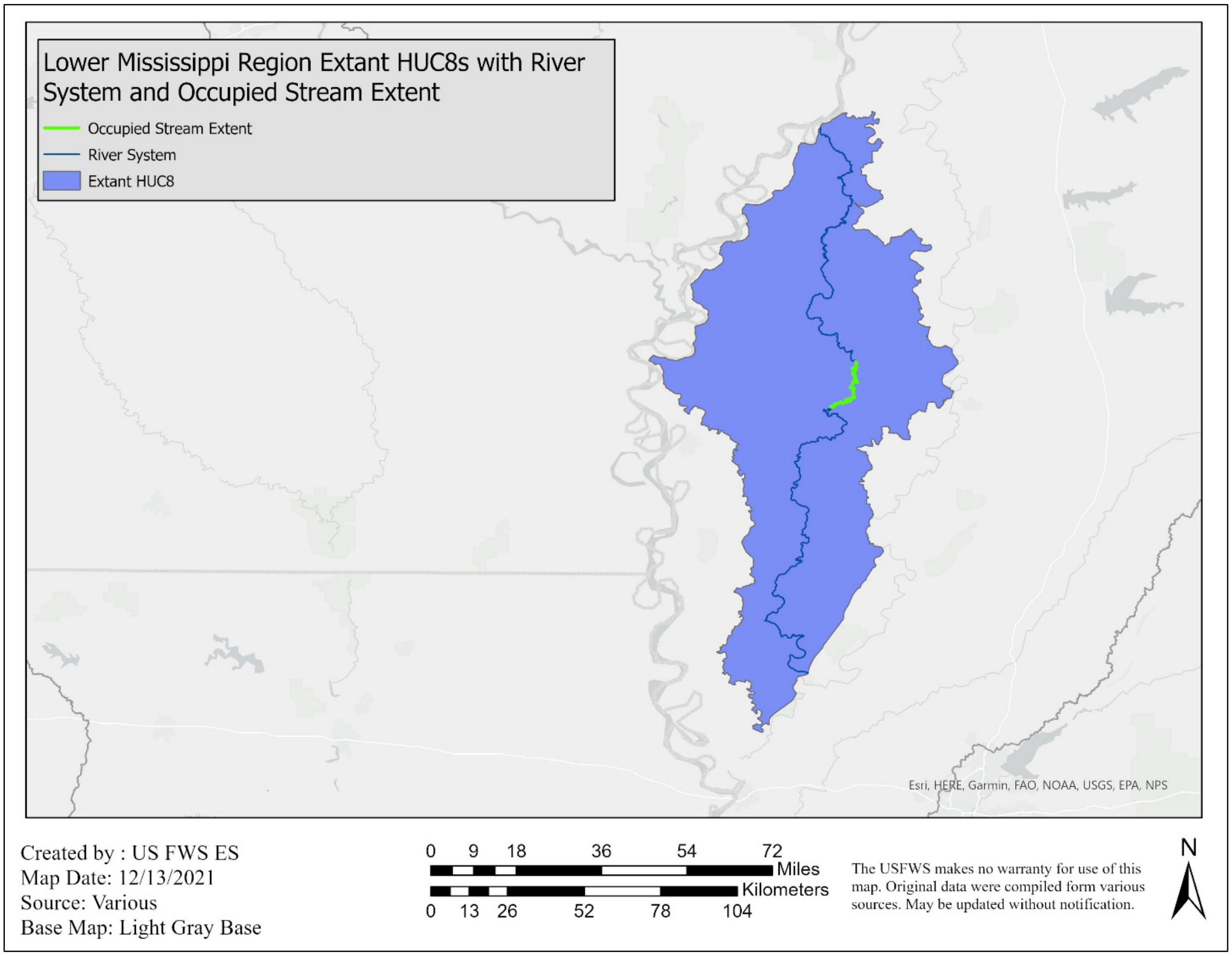

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Figure 4.9. Occupied stream extent of extant populations within the Lower Mississippi River basin for sheepnose.

4.2.4 Population Resiliency Summary

Demographic condition – Of the 37 extant and presumed extant populations, six (16%) are considered to be in high condition, nine in moderate condition (24%), 16 in low condition (43%), and six are considered functionally extirpated (16%) (Figure 4.10, Table 4.5, Table E.1, Table E.3).

Risk factors - Approximately 81% of the 37 extant sheepnose populations are currently experiencing high risk, meaning there is a less than 60% chance of population persistence over 50 years (Figure 4.10, Table 4.6, Table E.2, Table E.3). Seven (19%) of the of the 37 extant populations experience moderate risk (1 functionally extirpated, 3 low, 1 moderate, and 2 high demographic population condition; Table 4.7), meaning there is a 60–90% probability of population persistence over 50 years (Table 4.3, Table 4.4).

Overall, sheepnose mussel populations have decreased by roughly 71% from historical numbers rangewide (estimate). The number of populations are estimated to have declined by more than or equal to 50 percent of the historic range throughout each the Ohio River, Upper Mississippi River, Lower Mississippi River, and Tennessee River basins (Figure 4.1, Table 4.2). Aside from the now extirpated Lower Missouri River Basin, the Lower Mississippi River basin has experienced the greatest propotional decline (estimated 83%), with only one population persisting (Figure 4.1, Table 4.2). Although within the species' historic range, sheepnose has not been observed within the Lower Missouri River basin in the last two decades (last observed in 1999, Figure 4.1, Table 4.2).

Table 4.5. Summary of demographic condition for sheepnose populations across the range.

Demographic Condition	**Number of Populations**
High	6
Moderate	9
Low	16
Functionally Extirpated	6
Total	37

Table 4.6. Summary of risk factor condition for sheepnose populations across the range.

Risk Factor Condition	**Number of Populations**
High Risk	30
Moderate Risk	7
Low Risk	0
Total	37

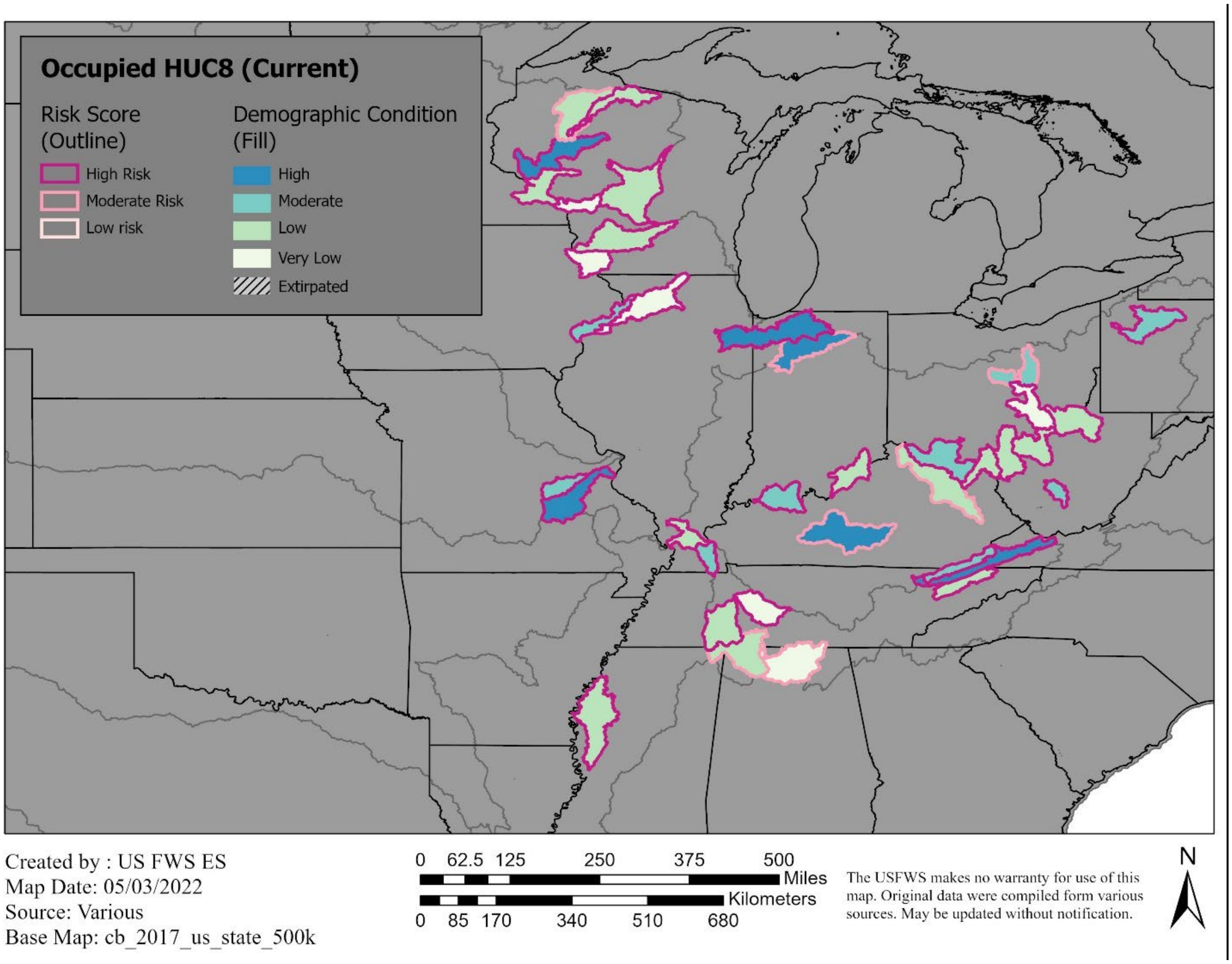


Figure 4.10. Map of sheepnose population status, risk factor condition, and demographic condition range wide.

4.3 Species Representation

We used HUC2 river basins to delineate four representative units currently occupied by extant sheepnose populations: Upper Mississippi River, Lower Mississippi River, Ohio River, and Tennessee River (refer to section 2.5.2, Figure 4.1, Figure 4.10). The Upper Mississippi River and Lower Mississippi River basins have 13 and 1 extant populations, respectively, all of which are currently experiencing high risk conditions, with the exception of the Upper Chippwa population within the Upper Mississippi River basin (Table 4.7). The Ohio River basin has 15 populations, of these, 11 are at high risk (Table 4.7). The Tennessee River basin has eight populations; of these, six are at high risk (Table 4.7). Across the species' range, only 19 percent of the populations are not experiencing high risk conditions. All seven of these populations are currently experiencing moderate risk (Table 4.7, Table E.3). These seven popualtions are limited in distribution to three representative units.

4.4 Species Redundancy

Of the 126 (estimate) historic populations of sheepnose rangewide, 37 are currently known to be extant. Extant populations are distributed throughout a total of 22 streams, often occurring in highly fragmented reaches, and are spread across the representation units unevenly (Figure 4.3, Figure 4.5, Figure 4.7, Figure 4.9, Figure 4.10, Table 4.2). The Upper Mississippi River basin contains 13 populations; the Lower Mississippi basin contains 1 population; the Ohio basin contains 15 populations; and the Tennessee basin contains 8 populations (Figure 4.10, Table 4.2). The total number of presumed extirpated populations by basin are conservatively estimated to be: Upper Mississippi River (n=36), Lower Mississippi River (n=5), Ohio River (n=36), and Tennessee River (n=8) (Figure 4.1, Table 4.2). Given the extant range encompasses 37 populations and all basins except one have more than one population, the species currently retains redundancy for withstanding and surviving potential catastrophic events. However, it is important to note that a high percentage (81%) of populations are currently at high risk. Further, approximately 22 percent of the populations are at high risk from both oil and natural gas activities as well as coal activities. Overall, the species has decreased redundancy across its range compared to its historical range due to the extirpated status of 89 populations (71%, conservative estimate).

Table 4.7. Summary of sheepnose mussel current demographic condition and risk category (L = Low, M = Moderate, H = High) for the major river basin representation units.

Demographic Condition	**High**			**Moderate**			**Low**			**Funtionally Extirpated**			**Total**
Risk Category	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	
Upper Mississippi River Basin	0	0	3	0	0	2	0	1	4	0	0	3	13
Ohio River Basin	0	2	0	0	1	4	0	1	6	0	0	1	15
Tennessee River Basin	0	0	1	0	0	2	0	1	2	0	1	1	8
Lower Mississippi River Basin	0	0	0	0	0	0	0	0	1	0	0	0	1
Total	0	2	4	0	1	8	0	3	13	0	1	5	37

CHAPTER 5. FUTURE CONDITION

5.1 Future Projections of Influences on Viability

5.1.1 Demographic Factors Methodology Overview

We created a ruleset using the SSA Core Team's best professional judgment to project each population's demographic condition into the future based on its current demographic condition as a baseline and the risk factor level projected for the future (Table 5.1). If a population is projected to be at high risk into the future, the demographic condition will decline two levels (in other words, high current demographic condition is projected to decline to a low demographic condition into the future). If a population is projected to be at moderate risk into the future, the demographic condition is projected to decline a single level. If low risk levels are projected into the future, the population will stay at the same demographic condition as identified in current condition. We recognize that a low risk level may provide the opportunity for successful reproduction and dispersal, which may improve the population's demographic condition. However, conservation efforts would likely have to be implemented (in addition to the low risk level) for populations in low or moderate demographic condition to generally improve demographically.

Table 5.1 Rule set for projected future demographic condition based on current demographic condition and projected future risk factor condition.

Current Demographic Condition	**Projected Future Risk Factor Condition**		
	High	**Moderate**	**Low**
High	Low	Moderate	High
Moderate	Functionally Extirpated	Low	Moderate
Low	Extirpated	Functionally Extirpated	Low
Functionally Extirpated	Extirpated	Extirpated	Functionally Extirpated

5.1.2 Risk Factors Methodology Overview

There is substantial uncertainty regarding the magnitude, duration, and location of effects related to water quality/contaminants, hydrological regime, habitat degradation (landscape), connectivity, and invasive species into the future. Because of this, we forecasted future viability for sheepnose under two future scenarios that represent the range of plausible environmental conditions and the projected consequences on the species' viability (Table 5.2, Appendix F). We projected out 50 years when information was available (2070; approximately two life spans). We restricted our evaluation to 50 years primarily due to uncertainties regarding future land cover projections and limitations projecting non-modeled, extrapolated future conditions for water quality. We evaluated both scenarios where future threats determined the biological status of mussel populations and their habitats.

In this chapter, we considered climate change under various likely scenarios. Climate change directly or indirectly exacerbates the most relevant stressors (for example, water quality, hydrological regime, landscape alterations) to freshwater mussels wherever they occur. We expect climate change effects to occur throughout the species' range; refer to Appendix B and Appendix F for further discussion.

Scenario 1 is the lower plausible-limit scenario reflecting the least favorable, but still plausible, future condition for the species; Scenario 2 is the upper plausible-limit scenario reflecting the most favorable, plausible future conditions for the species (see Table 5.2). Together, these two scenarios provide the upper and lower bounds of the plausible future condition of the species - - the actual future condition likely falls somewhere between these two scenarios.

Table 5.2. Description of the future scenarios relative to the five risk factors.

	Method/Data Source	Future Scenario 1	Future Scenario 2
Contaminants	USGS FORE-SCE land cover change model to project how land cover types associated with the contaminants of interest will change. The FORE-SCE model uses IPCC Special Report on Emissions Scenarios (SRES) to develop different scenarios for land cover change under various emissions scenarios. The IPCC SRES A2 and B1 scenarios are roughly analogous to the updated IPCC Representative Concentration Pathway scenarios 8.5 and 4.5, respectfully, and were chosen to bookend climate scenarios in accordance with internal SSA guidance (FWS 2021).	High carbon emissions (IPCC SRES A2). The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.	Medium-low carbon emissions (IPCC SRES B1) The B1 storyline and scenario family describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
Landscape	Used the USGS FORE-SCE land cover change model to project how land cover types of interest may change in the future. Projected changes in urban and forest land cover types were used as proxies	High carbon emissions (IPCC SRES A2) (See Contaminants for more details)	Medium-low carbon emissions (IPCC SRES B1) (See Contaminants for more details)

Table 5.2 (continued). Description of the future scenarios relative to the five risk factors.

Landscape (continued)	to project percent changes in imperviousness and vegetative/canopy cover, respectively.		
Hydrological Regime	USFS Cumulative Severe Drought Index projections which predict severe drought based on climate models representing warm/wet; hot/wet; hot/slightly dry; and hot/dry conditions.	Warm/wet scenario for drought severity	Hot/dry scenario for drought severity
Connectivity	Unpaved road crossings: U.S. Global Roads Inventory Project (GRIP) Shared Socioeconomic Pathway (SSP) scenarios. Assumed that future unpaved road length would increase commensurately with overall projected changes in road length in the GRIP model, which did not distinguish between road surface types.	Dams: No change Unpaved road crossings: High-end projection of road length in the U.S. (SSP5)	Dams: American Rivers dam removal database to predict where dams may be removed based on recent (last two decades) dam removals Unpaved road crossings: Low-end projection of road length in the U.S. (SSP3)
Invasive species	Optimized Hotspot Analysis	Increased risk from invasive species if there was an invasive species hotspot in an adjacent watershed. If currently an invasive species hotspot, no change.	No change (due to difficulty to eradicate established invasive species).

Table 5.3. Summary of risk factor metric projections for future scenarios. [1]primary contaminants [2]secondary contaminants. (FOREcasting Scenarios of Land Cover (FORE-SCE) IPCC Special Report on Emissions Scenarios (SRES); U.S. Global Roads Inventory Project (GRIP)).

Risk Factor Metrics	**Future Scenario 1**	**Future Scenario 2**
Contaminants (2070)		
Ammonia[1]	Percent change for agriculture and development in FORE-SCE land cover change model SRES A2	Percent change for agriculture and development in FORE-SCE land cover change model SRES B1
Chloride[1]	Percent change for agriculture and development in FORE-SCE land cover change model SRES A2	Percent change for agriculture and development in FORE-SCE land cover change model SRES B1
Copper[1]	Percent change for development in FORE-SCE land cover change model SRES A2	Percent change for development in FORE-SCE land cover change model SRES B1
Lead[2]	Percent change for development in FORE-SCE land cover change model SRES A2	Percent change for development in FORE-SCE land cover change model SRES B1
Landscape (2070)		
% impervious surface	Percent change as modeled for development in FORE-SCE land cover change model SRES A2	Percent change as modeled for development in FORE-SCE land cover change model SRES B1
% vegetative cover within riparian buffer	Percent change as modeled for vegetative cover in FORE-SCE land cover change model SRES A2	Percent change as modeled for vegetative cover in FORE-SCE land cover change model SRES B1
% agriculture	Percent change as modeled for agriculture in FORE-SCE land cover change model SRES A2	Percent change as modeled for agriculture in FORE-SCE land cover change model SRES B1
% urbanization	Percent change as modeled for development in FORE-SCE land cover change model SRES A2	Percent change as modeled for development in FORE-SCE land cover change model SRES B1
% Canopy Cover within riparian buffer	Percent change as modeled for vegetative cover in FORE-SCE land cover change model SRES A2	Percent change as modeled for vegetative cover in FORE-SCE land cover change model SRES B1

Table 5.3 (continued). Summary of risk factor metric projections for future scenarios. ¹primary contaminants ²secondary contaminants. (FOREcasting Scenarios of Land Cover (FORE-SCE) IPCC Special Report on Emissions Scenarios (SRES); U.S. Global Roads Inventory Project (GRIP)).

Risk Factor Metrics	Scenario 1	Scenario 2
Hydrological Regime (2040–2069)		
Drought	Warm Wet projections of the Cumulative Severe Drought Index (CDSI) developed by the U.S. Forest Service	Hot Dry projections of the Cumulative Severe Drought Index (CDSI) developed by the U.S. Forest Service
Connectivity (2040–2050)		
Number of Dams	No changes from current condition	Dam removal based on 2000–2020 trends
Unpaved road stream crossing density	Increase density by 27.3% (GRIP Scenario SSP5)	Increase density by 3.2% (GRIP Scenario SSP3)
Invasive Species		
Optimized Hotspot Analysis	Neighbor hotspot analysis	No changes from current condition
Catastrohpic Events		
Oil and Natural Gas	U.S. Energy Information Administration (EIA) Annual Energy Outlook 2021 - High oil and gas supply case, we assume production and consumption increase where infrastructure is present	U.S. Energy Information Administration (EIA) Annual Energy Outlook 2021 - Low oil and gas supply case, we assume production and consumption decrease
Coal	U.S. Energy Information Administration (EIA) Annual Energy Outlook 2021, Electricity generation from coal expected to decrease, we assume no change in risk	U.S. Energy Information Administration (EIA) Annual Energy Outlook 2021, Electricity generation from coal expected to decrease, we assume reduction in risk where activities are currently present

5.2 Population Resiliency Future Assessment

For most populations, the overall risk did not change from the current condition risk under Scenario 1 or Scenario 2 (Table 5.3, Table 5.4, Table G.1, Table G.2, Table G.4). The only changes occurred in the Walhonding where the overall risk is projected to increase from moderate to high under both scenarios, and the Upper Chippewa, Upper Green, and Tippecanoe populations where the overall risk is projected to increase from moderate to high under Scenario 1 only (Figure 5.1, Figure 5.2, Table G.4).

Based on the projected overall risk factor, 31 populations are projected to become extirpated or functionally extirpated under both scenarios (Figure 5.1, Figure 5.2; Table 5.3, Table 5.4, See Appendix G for more detail). Of the remaining eight populations, four are projected to be in low demographic condition into the future under both scenarios, meaning there is a 30-60% probability of persistence over 50 years (Table 5.3, Table 5.4, Table G.4), and two populations are projected to be in low condition under Scenario 1, but moderate condition under Scenario 2. The remaining extant populations are widely distributed throughout three of the four river basins, further reducing connectivity, and thereby, the potential for genetic exchange between them. According to Scenarios 1 and 2, sheepnose populations are expected to be less resilient into the future based on the current condition and future projected risks.

5.3 Species Representation Future Assessment

Ohio River Basin

Species representation is projected to be either lost or reduced in the future regardless of scenario. The Ohio River basin is expected to be in the best condition into the future of the four basins (HUC2), with two populations, the Upper Green and Tippecanoe, projected to be in low condition with a high level of risk under Scenario 1 and moderate demographic condition with a moderate level of risk under Scenario 2. The remainder of the Ohio River basin is expected to decline to extirpated or functionally extirpated condition under both scenarios, an 87% reduction of populations within the basin.

Upper Mississippi River Basin

The Lower Chippewa, Kankakee, and Meramec are the only extant, functional populations projected to persist in the Upper Mississippi River basin into the future under both scenarios. All three of these populations are projected to be at high risk and low demographic condition into the future under both scenarios. Overall, approximately 77 percent of the populations within the Upper Mississippi River basin are expected to be lost (extirpated or functionally extirpated) under both Scenarios 1 and 2.

Tennessee River Basin

The Upper Clinch, Tennessee, Virginia is the only extant, functional population projected to persist in the Tennessee River basin, an 88% loss. The Upper Clinch, Tennessee, Virginia population is projected to decline from a high to low demographic condition with a high level of risk under both future scenarios.

Lower Mississippi River Basin

The Big Sunflower is currently the only known sheepnose population within the Lower Mississippi River basin and is projected to become extirpated with a high level of risk under both scenarios. Given sheepnose has not been detected within the Big Sunflower population since 2005 and less than five individuals have been detected within the system throughout the last two decades, it is probable this population is already approaching functional extirpation. Should this population decline to extirpation, the species would lose the environmental and genetic variation associated with the Lower Mississippi River basin.

Summary

Rangewide, approximately 84% of the 37 extant sheepnose populations are expected to decline to functionally extirpated or extirpated demographic condition under both future scenarios. Although the populations that are projected to persist under Scenarios 1 and 2 are broadly distributed across three of the four representation basins, the resulting reduced connectivity and demographic conditions are likely to accelerate loss of genetic diversity, thereby eroding representation of sheepnose across the range of the species.

5.4 Species Redundancy Future Assessment

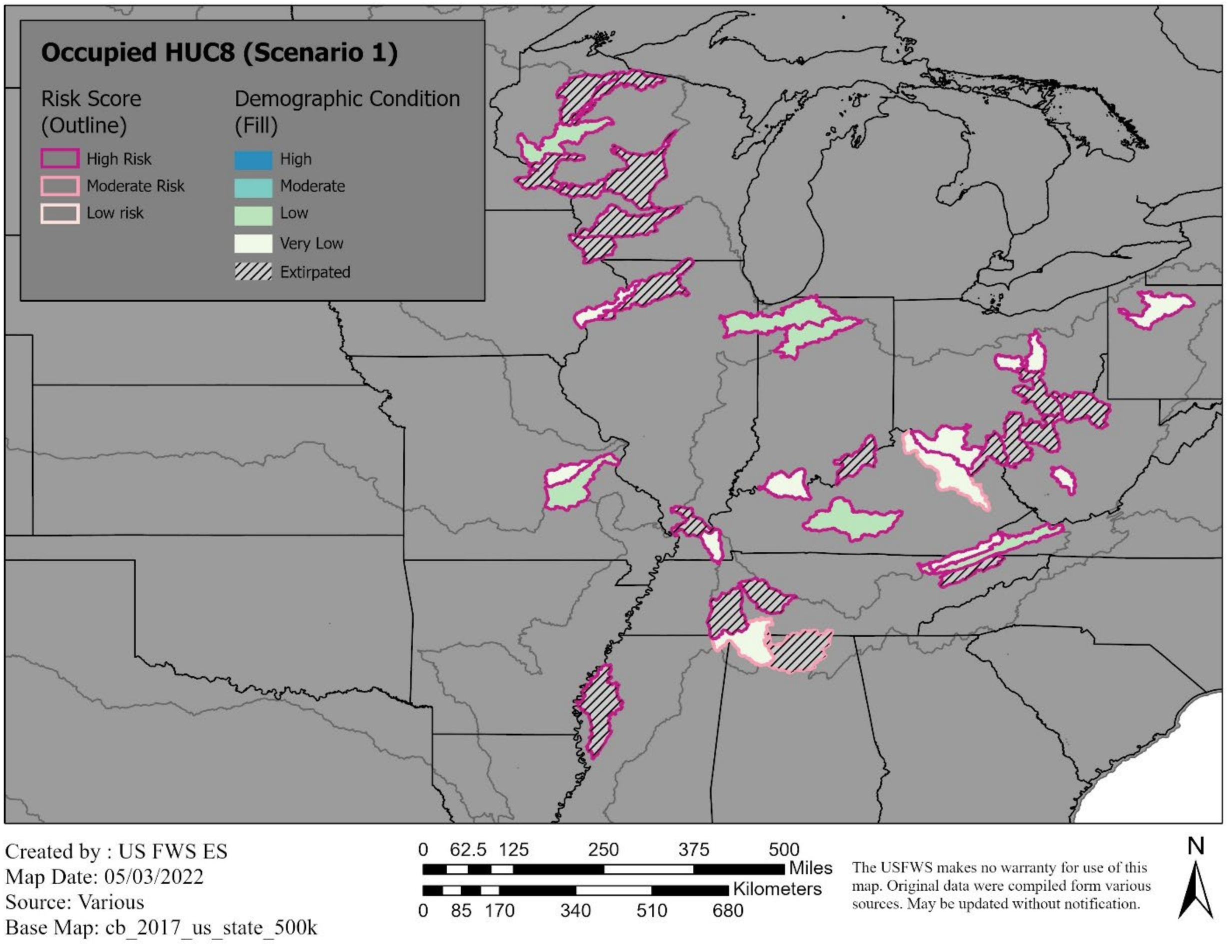
Sheepnose populations are spread across the representation units unevenly. The core area of the sheepnose mussel range remains the Ohio River, Tennessee River, and Upper Mississippi River basins. However, the number of Ohio River basin populations are projected to decrease from 15 to eight under both Scenarios 1 and 2, with six of the remaining populations projected to decline to functionally extirpated status. The Upper Mississippi River basin is projected to lose more than half of its sheepnose populations under both scenarios with two of its five remaining populations projected to become functionally extirpated under Scenario 1 and three of its six remaining populations projected to become functionally extirpated under Scenario 2. Similarly, the Tennessee River basin is projected to lose four of its eight populations, with three of the remaining populations projected to decline to functionally extirpated status under both scenarios. Across the three “core” basins, approximately 50 (Scenario 2) to 53 (Scenario 1) percent of the populations are expected to become extirpated, with an additional 31 (Scenario 1) to 33 (Scenario 2) percent projected to decline to functionally extirpated demographic condition. Functionally, only 17 percent of the populations are expected to persist under Secnarios 1 and 2. Of these, roughly two-thirds are projected to decline to low demographic condition with a high level of risk under both scenarios.

The Lower Mississippi River basin is on the edge of the range (Figure 5.1, Figure 5.2). The single population (Big Sunflower) in the Lower Mississippi River basin is projected to continue to experience a high level of risk and become extirpated under both scenarios.

The expected declines in the number of resilient populations will likely make sheepnose more vulnerable to catastrophic events related to oil, natural gas, and coal. Although we project that production and consumption of oil, nautral gas, and coal would decrease under Scenario 2, infrastructure associated with these commodities is projected to remain in place regardless of production and transport levels. However, the populations that are projected to persist under Scenarios 1 and 2 are broadly distributed throughout the species' range, potentially maintaining some capacity to withstand catastrophic events through spreading risk across a large area.

Table 5.4. Summary of sheepnose population overall risk category by status and representation unit for Future Scenario 1. (E = Extant, Fx = Functionally Extirpated, X = Extirpated)

Risk Category	**High**		**Moderate**		**Low**			**Total Remaining Population Count**
Representation Unit	**E**	**Fx**	**E**	**Fx**	**E**	**Fx**	**X**	
Upper Mississippi River	3	2	0	0	0	0	8	**5**
Ohio River	2	5	0	1	0	0	7	**8**
Tennessee River	1	2	0	1	0	0	4	**4**
Lower Mississippi River	0	0	0	0	0	0	1	**0**
Species Range Total	**6**	**9**	**0**	**2**	**0**	**0**	**20**	**17**



Created by : US FWS ES
Map Date: 05/03/2022
Source: Various
Base Map: cb_2017_us_state_500k

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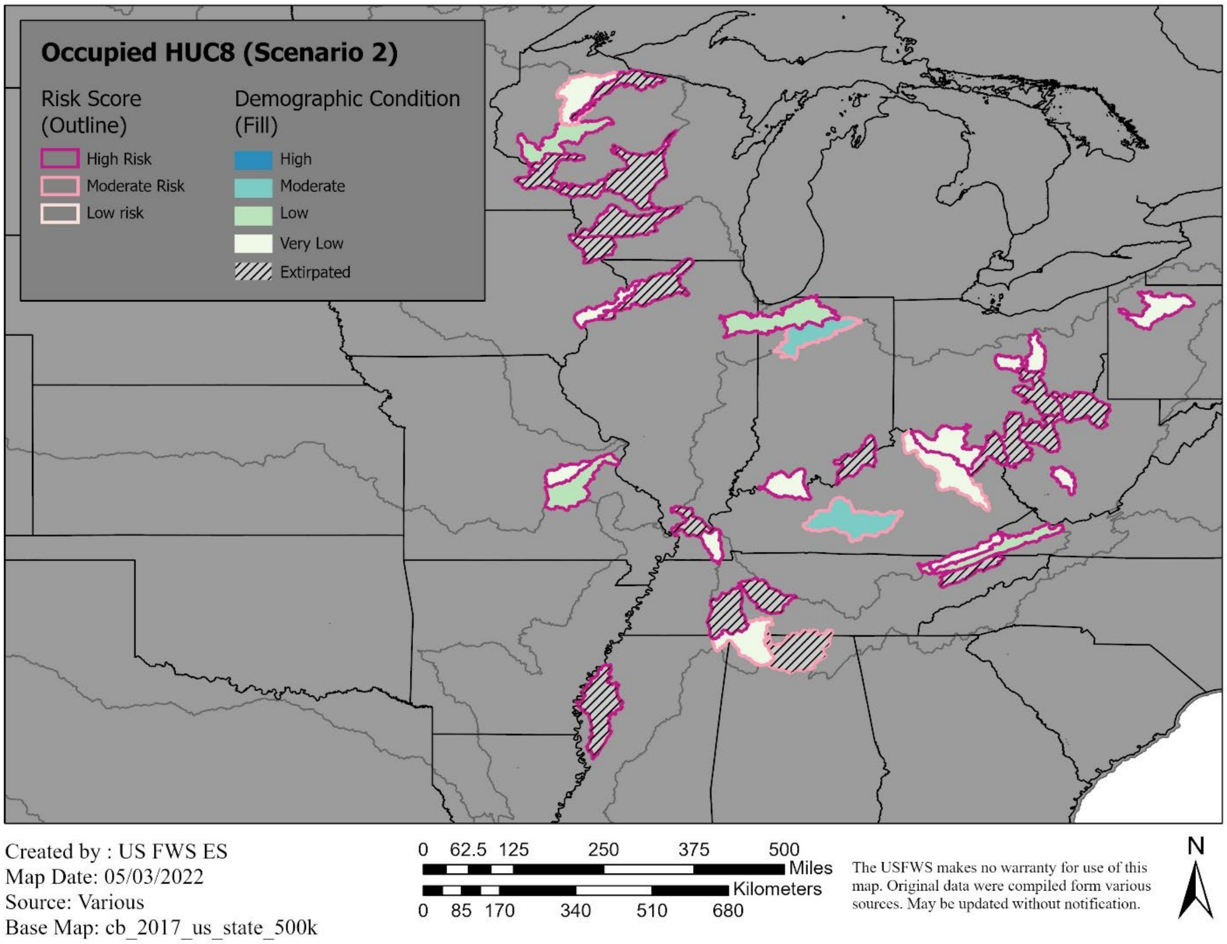
Figure 5.1. Sheepnose Future Scenario 1 projected status, risk factor condition, and demographic condition range wide for extant populations.

Table 5.5. Summary of sheepnose population overall risk category by status and representation unit for Future Scenario 2. (E = Extant, Fx = Functionally Extirpated, X = Extirpated)

Risk Category	**High**		**Moderate**		**Low**			**Total Remaining Population Count**
Representation Unit	**E**	**Fx**	**E**	**Fx**	**E**	**Fx**	**X**	
Upper Mississippi	3	2	0	1	0	0	7	**6**
Ohio	0	5	2	1	0	0	7	**8**
Tennessee	1	2	0	1	0	0	4	**4**
Lower Mississippi	0	0	0	0	0	0	1	**0**
Species Range Total	**4**	**9**	**2**	**3**	**0**	**0**	**19**	**18**



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Map Date: 05/03/2022
Source: Various
Base Map: cb_2017_us_state_500k

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Figure 5.2. Sheepnose Future Scenario 2 projected status, risk factor condition, and demographic condition range wide for extant populations.

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APPENDIX A. ECOLOGY BACKGROUND

A.1 Taxonomy

Sheepnose is a member of the mussel family Unionidae and originally was described as *Obliquaria cyphya* by Rafinesque, 1820. The species was found in the Falls of the Ohio (Parmalee and Bogan 1998, p. 175) on the Ohio River near Louisville, Kentucky, and adjacent Indiana (77 FR No. 49, p. 14914). Parmalee and Bogan (1998, p. 49) summarized the synonomy of sheepnose. Over the years, the specific epithet of this species has been variably spelled cyphya, scyphius, cyphius, cyphia, cyphyum, and ultimately as cyphyus. Sheepnose or its synonyms have been placed in the genera Unio, Pleurobema, Margarita, and Margaron. It was ultimately placed in the genus Plethobasus by Ortmann (1919, p. 65-66), where it remains today (Williams et al. 2017, p. 41). The Service recognizes *Unio aesopus* and *U. compertus* as synonyms of *Plethobasus cyphyus*. Sheepnose is the accepted common name for *Plethobasus cyphyus* (Williams et al. 2017, p. 41). The Service also recognizes “bullhead” and “clear profit” as older common names for sheepnose.

The currently accepted taxonomic ranking for sheepnose is described below.

Kingdom	Animalia
Subkingdom	Bilateria
Infrakingdom	Protostomia
Superphylum	Lophozoa
Phylum	Mollusca
Class	Bivalvia Linnaeus, 1758
Subclass	Palaeoheterodonta Newell, 1965
Order	Unionoida Stoliczka, 1871
Superfamily	Unionoidea Rafinesque, 1820
Family	Unionidae Rafinesque, 1820
Subfamily	Ambleminae Rafinesque, 1820
Tribe	Pleurobemini Hannibal, 1912
Genus	*Plethobasus* Simpson, 1900
Species	*Plethobasus cyphyus* Rafinesque, 1820

*Retrieved 5/17/2021 from the Integrated Taxonomic Information System on-line database, http://www.itis.gov

A.2 Genetics

Within recent years, researchers have shifted focus to examine the ecological and genetic conditions of imperiled freshwater mussel species at the population level, including sheepnose. While limited genetic work is available, one study has been conducted. In their 2022 (entire) article, Schwarz and Roe investigated sheepnose population dynamics, connectivity, and distribution of genetic diversity throughout the species’ range and in comparison to its historical condition. To address their objectives, the authors focused efforts on seven of the 25 streams where sheepnose is known to be extant. Specifically, this study was focused within two river basins, the Upper Mississippi River Basin and the Ohio River Basin (Schwarz and Roe 2022, p. 2-3).

The authors found there to be five genetically distinct populations within their sample area. These populations are the Chippewa and Wisconsin River cluster, the Meramec River, and the Mississippi River within the Upper Mississippi River Basin and the Tippecanoe and Tennesse River cluster and Allegheny River within the Ohio River Basin (Schwarz and Roe 2022, p. 8). Each of the identified populations were found to contain sub-populations with distinct genetic composition (Schwarz and Roe 2022, p. 8). Overall, the authors found low rates of genetic migration with each basin, but not between. Further, the authors found genetic migration to primarily occur in only one direction (Schwarz and Roe 2022, p. 7, 9). In the Upper Mississippi Basin, the tributaries were found to migrate toward the Mississippi River mainstem; however, within the Ohio River Basin, the Tippecanoe and Tennessee Rivers were found to counterintuitively migrate towards the Allegheny River. The authors note this observation may be a result of the lack of samples from the Ohio River mainstem included within the study. The study provided limited evidence of genetic bottlenecks, and in fact, most populations (aside from the Wisconsin River) displayed characteristics of population expansion (Schwarz and Roe 2022, p. 6).

The authors concluded that the populations investigated have been isolated for a long period of time, likely an artifact of landscape and climatic changes that occurred during the Pleistocene (Schwarz and Roe 2022, p. 8-9). Further, due to the long lifespan of sheepnose and population sizes, it is suspected that human alterations of the landscape (for example, dams, stream channelization, habitat fragmentation) have likely not yet resulted in genetic loss (Schwarz and Roe 2022, p. 7). However, the authors warn that anthropogenic changes resulting in continued and increasing habitat fragmentation and isolation may be compounding observed genetic isolation conditions that may result in future deterioration of genetic diversity (Schwarz and Roe, p. 10). As a result, Schwarz and Roe encourage a focus of future conservation efforts on increasing connectivity and conserving areas of suitable habitat conditions (Schwarz and Roe 2022, p. 10).

A.3 Species Description

The following description of sheepnose is generally summarized from Oesch (1995) and Parmalee and Bogan (1998). Sheepnose is a medium-sized mussel that reaches nearly 5.5 inches in length. The shape of the shell is elongate ovate, moderately inflated, and with the valves being thick and solid. The anterior end of the shell is rounded, but the posterior end is somewhat bluntly pointed to truncate. The dorsal margin of the shell is nearly straight, while the ventral margin is uniformly rounded or slightly convex. The posterior ridge is gently rounded, becoming flattened ventrally and somewhat biangular. There is a row of large, broad tubercular swellings on the center of the shell extending from the beak to the ventral margin. A broad, shallow sulcus lies between the posterior ridge and central row. Beaks are elevated, high, and placed near the anterior margin. Juvenile beak sculpture consists of a few concentric ridges at the tip of the beaks. The periostracum (external shell surface) is generally smooth, shiny, rayless, and light yellow to a dull yellowish brown. Concentric ridges resulting from rest periods are usually darker. Internally, the left valve has two heavy, erect, roughened, somewhat triangular and divergent pseudocardinal teeth. The right valve has a large, triangular, roughened pseudocardinal tooth. The lateral teeth are heavy, long, slightly curved, and serrated. The beak cavity is shallow to moderately deep. The color of the nacre (mother-of-pearl) is generally white, but may be pinkish to cream-colored, and iridescent posteriorly. There is no sexual dimorphism in the shells of this species. The shell of sheepnose is extremely hard (thus given the name clear profit by early commercial shellers, being too hard to cut into buttons [Wilson and Clark 1914]) and preserves well in archaeological material (Morrison 1942). The soft anatomy was described by Oesch (1995). Key characters useful for distinguishing sheepnose from other mussels is its shell color, the occurrence of central tubercles, and its outline.

Culture studies at Genoa National Fish Hatchery have informed that subadult sheepnose are very similar to juvenile threeridge (*Amblema plicata*) as they are both pale and quadrate with delicate posterior-leaning beaks elevated above the hinge line, and deep, posterior-leaning, moderate-to-widely spaced ridges for beak sculpture (M. Bradley, USFWS, pers. comm. 2022). They can be distinguished as the brown-to-olive periostracum or as growth of the posterior-dorsal margin remains aligned in Threeridge, or the sulcus and first distinguishable bumps or corrugations form on the disc, or the broadly rounded ventral edge begins to show concavity at the meeting with the posterior edge in sheepnose.

APPENDIX B. PRIMARY INFLUENCES ON VIABILITY

B.1 Contaminants

B.1.1 Metals, Nutrients, and Major Ions

Freshwater mussels are among the most sensitive freshwater species to metals, ammonia, and ion constituents including copper, sulfate, alachlor, nickel, chloride, sulfate, zinc, and potassium (Wang et al. 2017, pp. 786–796). Representative species from different families or tribes had similar sensitivities to copper, sulfate, alachlor, nickel, chloride, sulfate, zinc, and potassium, regardless of mode of toxic exposure (Wang et al. 2017, pp. 786–796).

Heavy metals can cause mortality and affect biological processes, for instance, disrupting enzyme efficiency, altering filtration rates, reducing growth, and changing behavior of freshwater mussels (Jacobson et al. 1997, pp. 2384–2392; Keller and Zam 1991, pp. 539–546; Naimo 1995, pp. 341–362; Valenti et al. 2005, pp. 1242–1246; Wang et al. 2007, pp. 2048–2056, pp. 2036–2047; Wang et al. 2010, pp. 2053–2063). Low but chronic heavy metal and other toxicant inputs may reduce mussel recruitment (Naimo 1995, pp. 352–354). Both acute and chronic exposures to **zinc** and **nickel** demonstrated the sensitivity of mussels to these chemicals and chronic exposures increased mussel sensitivity to zinc (Kunz et al. 2016, p. 1).

The USEPA has water quality criteria for six of the 10 chemicals tested in Wang et al. (2017, pp. 186–796). For ammonia, copper, and zinc, most of the species mean acute values were either similar to or less than the USEPA acute criteria (Wang et al. 2017, p. 786). Wang et al. (2017, p. 795) suggest that if the minimum data requirement for deriving water quality criteria required the inclusion of freshwater mussels, then water quality criteria would capture the high sensitivity of freshwater mussels to many chemicals and different exposure pathways. An example of this is the ammonia criterion that was updated to include mussels; the revised acute criterion is 1.4-fold lower than the previous acute criterion (Wang et al. 2017, p. 792).

Mussels exhibit differing sensitivities to **chloride** depending on genus, with one study using the *Epioblasma* genus, demonstrating it is the most sensitive (Gillis 2011, pp. 1702–1708). Current acute criteria may therefore not be protective of severely imperiled mussels. Furthermore, for chloride as well as other chemicals, concentrations in surface water in North America are increasing rather than decreasing (Gillis 2011, p. 1702) due to anthropogenic practices (for example, increase use of road salts; Gillis 2011, p.1702). Areas with elevated levels of chloride are acutely toxic to glochidia, if these areas are chronically exposed to chloride, population level effects will result.

Freshwater mussels are very sensitive to **ammonia** (Augspurger et al. 2003, pp. 2569–2575). Ammonia is widespread within the aquatic environment; typical sources include agricultural wastes (animal feedlots and nitrogenous fertilizers), municipal wastewater treatment plants, and industrial waste as well as precipitation and natural processes, such as decomposition of organic nitrogen (Augspurger et al. 2003, p. 2569; Goudreau et al. 1993, p. 212). Unionized ammonia is the most toxic to freshwater mussels (M. Bradley, personal communication, 2021). Sediment pore water concentrations of ammonia typically are higher than the surface water concentrations as well, which is of particular concern for freshwater mussels given the highest concentrations occur in mussel microhabitat (Augspurger et al. 2003, p. 2569). Ammonia can be acutely toxic to mussel in particular early life stages. Ammonia also causes sublethal effects, such as reduced respiration and feeding due to valve closure; impaired secretion of the byssal thread (used for substrate attachment); reduced ciliary action impairing feeding; depleted lipid, glycogen, and other carbohydrate stores; and altered metabolism (Augspurger et al. 2003, p. 2574; Goudreau et al. 1993, pp. 220–222; Mummert et al. 2003, p. 2545).

In addition to ammonia, **phosphorus and nitrogen** are the primary nutrient contaminants that occur in aquatic ecosystems when nutrient pollution is not properly managed. Nitrogen breaks down by various processes and produces nitrates, the nitrates react differently based on water hardness impacting the ionic charge and therefore impacts the bioavailability affecting freshwater mussels. The amount of nitrate within river systems is one measure that can be used to assess water quality and toxicity to freshwater mussels.

Fertilizers and animal manure are both rich in nitrogen and phosphorus. If fertilizers are not applied properly or manure waste piles are not properly managed, water quality in nearby surface or ground water can be severely impacted leading to eutrophication and algal blooms. While food quantity may increase under moderate eutrophic conditions, the resulting algal community is often of lower quality, which may lead to decreased mussel growth and reproduction (Strayer 2014, p. 280). Increased algal productivity can produce toxic algal varieties and further degrade water quality by altering ammonia, oxygen, and pH levels, leading to further reductions in mussel reproduction through lost host and early life stage mortality and probable juvenile and adult mussel die offs (Strayer 2014, p. 280).

B.1.2 Organic Compounds and Contaminants of Emerging Concern

Contaminants of emerging concern (CEC) is a term that refers to a broad and diverse group of chemicals, often organic compounds, including pesticides, personal care products, pharmaceuticals, flame retardants, plasticizers, and industrial chemicals. These chemicals are found worldwide, but little information exists on the effects of this diverse array of chemicals and exposure pathways in sediment, pore water, and surface water (Woolnough et al. 2020, p. 1626).

Pharmaceutical chemicals used in commonly consumed drugs increasingly occur in surface waters. Kolpin et al. (2002, pp. 1208–1210) detected the presence of numerous pharmaceuticals, hormones, and other organic waste products in nationwide sampling of 139 stream sites in 30 States downstream from urban development and livestock production areas. Eighty-three CECs were found in the sediment, water, and mussel samples tested from the Maumee River, indicating waterborne exposures to pharmaceuticals and sediment exposures to agricultural chemicals and personal care products were probable (Woolnough et al. 2020, p. 1631). Mussel tissues showed higher concentrations of pharmaceuticals indicating adult exposures had resulted in concentration of organic chemicals with unknown results.

Overall, mussels are considered to be less sensitive to organic compounds, but behavioral changes and reduced glochidia fitness have been noted in mussel species exposed to some agricultural chemicals, pharmaceuticals, and industrial compounds (Bringolf et al. 2007a, pp. 2086–2093; Hazelton et al. 2013, pp. 94–100; Hazelton et al. 2012, pp. 1611–1620). For example, the active ingredient in many prescription anti-depressants, which have selective serotonin reuptake inhibitors, are found in measurable concentrations in surface waters chemicals. At elevated levels these chemicals may disrupt the neuroendocrine pathways that control reproduction, impacting brooding glochidia within the marsupial gill as well as altering reproductive and avoidance behaviors (Bringolf et al. 2010, pp. 1311–1312; Hazelton et al. 2013, p. 95). Such alterations could lead to increased mortality and reduced reproduction.

Perfluoroalkyl acids (PFAAs) are another suite of organic chemicals that are prevalent and persistent in the landscape and are known to impact mussels. PFAAs repel water and oil and are found in a variety of products, including carpets, upholstery, paper, food containers, fabric, and fire suppressants (Hazelton et al. 2012, p. 1611). Perfluoroctanesulfonic acid (PFOS) and perfluoroctanoic acid (PFOA) bind to tissue, demonstrate biomagnification in aquatic food webs, and have been linked to decreased reproduction of aquatic species. Freshwater mussels are sensitive in both acute and chronic exposures to PFAAs (Hazelton et al. 2012, pp. 1611–1620). Glochidia were the most sensitive organisms tested to date in acute toxicity exposures. Exposures to glochidia in marsupia demonstrated reduced viability and reduced ability to complete metamorphosis.

Research on agricultural chemicals that are currently in use further highlights the variability of mussel sensitivities to organic chemicals. Pesticide studies indicated that mussels were tolerant to active chemicals (for example, atrazine, chlorpyrifos, permethrin) in both acute and chronic mussel exposures. Conversely, chronic exposures of glyphosate formulations currently used containing surfactants to increase herbicide efficiencies resulted in mussels being highly sensitive to these ubiquitous herbicides highlighting the complexity of assessing the impacts of the thousands of organic chemicals found in mussel environments both singularly and in more ecologically relevant complex mixtures (Bringolf et al. 2007b, pp. 2094–2100). This suggests organic chemicals and CECs should not be overlooked as possible contributors to common and rare mussel species declines.

B.1.3 Invasive Species Chemical Controls

Aquatic herbicides, algaecides, adjuvants, and lampricides are used to treat aquatic nuisance or invasive species within aquatic ecosystems. The majority of these chemicals do not have any data on toxicity to freshwater mussels. Copper is one chemical used to treat aquatic nuisance species, and depending on water chemistry, has the potential to be toxic to freshwater mussels and certain fish species (Bowman and Bush 2019, pp. 4–5; Wang et al. 2011, pp. 2115–2125).

Other suites of chemicals such as endothall salts have had some studies conducted on freshwater mussels (Archambault et al. 2015, pp. 335–348; Keller 1993, pp. 696–702); however, more analysis is necessary to understand some of the effects.

In addition to nuisance aquatic plants, invasive sea lamprey (*Petromyzon marinus*) is present in many waterways in the Great Lakes Basin. Sea lamprey treatment and assessment activities using lampricides have the potential to negatively impact freshwater mussels and their host (for example, logperch).

The USFWS Sea Lamprey Control Program uses the lampricides TFM (3-trifluoromethyl-4-nitrophenol) and Bayluscide® [active ingredient: 5-Chloro-N-(2-chloro-4-nitrophenyl)-2-hydroxybenzamide] to control sea lamprey in the Great Lakes Basin. TFM and the TFM/1% niclosamide mix is applied to streams to kill larval sea lampreys. The granular formulation of Bayluscide [Bayluscide 3.2% Granular sea lamprey Larvicide, granular Bayluscide (gB)] is applied in lake and river systems that are too large to be treated economically with the liquid lampricide formulations and to survey for larval sea lampreys in areas that are too deep to effectively electrofish with AbP-2 backpack electrofishing gear (C. Kaye, personal communication, 2020). Niclosamide, the active ingredient in Bayluscide, was first developed as a molluscide to kill snails. The granular form of Bayluscide targets benthic (bottom of river) larval sea lamprey habitat, which is the same habitat occupied by freshwater mussels and put them especially at risk when present within the vicinity of Bayluscide applications.

Boogaard et al. (2015, pp. 1634–1641) tested the toxicity of TFM on multiple life stages of the snuffbox mussel *(Epioblasma triquetra*). The study evaluated the effects of TFM on snuffbox glochidia, one week old juveniles, and logperch (host fish), as well as glochidia, one week old juveniles, and adults of the ellipse mussel (*Venustaconcha ellipsiformis*). The study also evaluated juvenile recruitment success from glochidia (larval) infested logperch exposed to multiple levels of TFM. This work demonstrated that there was minimal toxicity to the larval and juvenile stage of both the ellipse and snuffbox, as well as the adult stage of the ellipse at concentration ratios greater than what is required or typically used to kill larval sea lampreys in streams (USFWS 2013, pp. 1–44). A comparison of the results to snuffbox glochidia indicates the life stage of the two species respond similarly to TFM. Survival was high among both species at concentrations greater than what would be encountered during treatments suggesting the risk from direct exposure to TFM is low (USFWS 2013, pp. 1–44). In the natural stream environment, glochidia are distributed directly on the gills of logperch by female snuffbox. Glochidia that are inadvertently distributed into the water column (free-floating) have almost a 100 percent chance of dying (USFWS 2013, pp. 1–44). The viability test conducted during 2011 on free-floating snuffbox glochidia demonstrated that viability decreased rapidly beginning at 12 hours after extraction (USFWS 2013, pp. 1–44). These results suggest, along with the recruitment tests where juvenile fall-off was not significantly different between the exposed and control fish, that there would be greater survival of glochidia encysted on gills (as opposed to free-floating) at concentrations tested (USFWS 2013, pp. 1–44). Results from toxicity tests on one week old juveniles suggest that there is no risk up to the highest concentration ratios for the snuffbox and that ellipse juveniles may be more at risk at higher concentrations, although these concentrations would not be applied in the field (USFWS 2013, pp. 1–44).

Boogaard et al. (2015, pp. 1643–1641) also looked at the toxicity of TFM to adult logperch. Logperch were exposed to concentration levels of TFM that are typically used in the field to kill sea lampreys in streams. Exposure duration was 12 hours followed by a 12-hour post-exposure period after which mortality of logperch was assessed. Minimum lethal concentrations [MLC; concentration of TFM required to kill 99.9% of sea lamprey larvae] calculated from the pH and alkalinity of the test water (Bills et al. 2003, pp. 514–517) for sea lampreys in this study were 2.1 mg/L.

Mortality of logperch was 15% at 2.1 mg/L TFM, but 65% at 2.7 mg/L TFM (1.3 × MLC; concentration ratio = mean TFM concentration applied/predicted TFM MLC). However, several field studies and non-target mortality observations differ from these lab results including a study by Langdon and Fiske (1991, pp. 1–74) where logperch were captured at the same rate during 2 pre-treatment surveys and 1 post treatment survey in an area that had the highest mean concentration of TFM (4.7 mg/L TFM) and exposure time (11 h). Another long-term study (Schuldt et al. 1996, entire) reported 100% logperch survival in a cage study during five lampricide treatments. Until further tests are conducted and prove otherwise, logperch are considered sensitive to TFM, having the potential for high levels of mortality (85% mortality at treatments levels of 1.5 × MLC) based on laboratory results.

Toxicity tests on other host species within the Great Lakes Basin are important in understanding the potential impact of sea lamprey control on freshwater mussel communities given the critical role host species play in reproduction influencing the distribution and survival of these mussel assemblages.

A study conducted by Newton et al. (2017, pp. 370–378) investigated the risk of mortality and sub-lethal effects (probability and duration) as a function of exposure duration among adult and sub-adult mussel species exposed to environmentally relevant concentrations of niclosamide following a granular Bayluscide application. Eight species of mussels were chosen based on availability and potential overlap with larval sea lamprey habitat. At each exposure duration, mortality was estimated, and a suite of sub-lethal responses including siphoning activity, gaping valves, production of mucus, and rigid foot extension was recorded. Mortality averaged 42% in sub-adults (range, 23–54%) and 20% in adults (range, 3–44%) 21 days after exposure, over all exposure durations. For those species tested as both sub-adults and adults (*O. olivaria and V. iris*), mortality was similar between life stages for *O. olivaria* (~23%) but more than twice as high for sub-adult (mean, 38%) compared to adults (mean, 14%) for *V. iris*. There were positive associations between duration of niclosamide exposure and mortality in all four species exposed as sub-adults, and in four of the six species exposed as adults. These results were the same positive associations seen between duration of exposure and sub-lethal responses in all four species of exposed sub-adults and four of the six species exposed as adults. Results indicate that the duration of exposure plays a significant role in the magnitude among mussels. The longer mussels are exposed to niclosamide, the greater the mortality and sub-lethal effects. Both adults and sub-adults were sensitive to exposure, but sub-adults were affected sooner (Newton et al. 2017, pp. 370–378).

Fisheries and Oceans Canada (DFO) has completed a risk assessment of the effects of granular Bayluscide assessments on freshwater species at risk, including snuffbox (DFO 2021, entire). The study found that the risk to the snuffbox are of moderate concern given that there is a poor match between Snuffbox preferred habitat and larval lamprey habitat. However, any changes in current application patterns could result in very different impacts due to observed toxicity (DFO 2021, entire; T. Morris 2022, pers. comm.).

While unionids absorb lampricides and experience narcotization (gaped shell and sometimes foot extended), toxicity studies have indicated that TFM exposure would not result in acute mortality at concentrations required to kill sea lamprey during stream treatments (Kaye 2021, pp. 1–50). Booggard et al. (2004, p. 12). Bills et al. (1992) reported that 90% of pink heelsplitter survived when exposed to 3.5 mg·L-1 TFM (1.0 × MLC) for 12 hours. However, only 30% survived a 12-hour exposure of 5.25 mg·L-1 TFM (1.5 × MLC). The authors noted that static tests are a worst-case scenario and surmised that survival would be higher in a stream environment. Waller et al. (1998, pp.116–118) stated that both threehorn wartyback (*Obliquaria reflexa*) and Wabash pigtoe (*Fusconaia flava*) would survive stream treatments at TFM concentration ratios of 1.3 and 1.4 × MLC. A study conducted to test several compounds for the potential control of zebra mussels (*Dreissena polymorpha*; Bills and Waller unpublished data) found no mortality of the pimpleback (*Cyclonaias pustulosa*), three ridge (*Amblema plicata*), and pink papershell (*Potamilus ohiensis*) held in TFM concentrations up to 8.4 mg·L-1 (3.4 × MLC) for 12 hours, and 20% mortality of the deertoe (*Truncilla truncata*) in 6.7 mg·L-1 (2.7 × MLC; MLC = 2.5 mg·L-1). These concentrations were much greater than what would be typically be applied to a stream (1.1–1.8 × MLC; Kaye 2021, pp. 5–6; L. Crieger, personal communication, 2020).

Boogaard et al. (2004, pp. 1–17) reported that TFM and TFM-1% niclosamide did not produce substantial mortality among three unionid mussel species [giant floater (*Pyganodon grandis*), fragile papershell (*Leptodea fragilis*), pink heelsplitter (*Potamilus alatus*)] tested at concentrations typically applied during stream applications to kill larval sea lamprey. Both lampricides were more toxic to larval sea lamprey than to any of the unionid species tested. The giant floater experienced the highest mortality, which the authors attributed to the added stress of handling and holding conditions in river water at temperatures as high as 80° F (27 °C). They stated that the species can often experience a natural die off during mid to late summer (Boogaard et al. 2004, pp. 1–17).

Waller et al. (2003, pp. 546–550) found that acute mortality did not occur when eastern elliptio (*Elliptio complanata*) and eastern floater (*Pyganodon cataracta*) juveniles and adults were exposed to TFM up to 1.6 × MLC in a mobile bioassay trailer at the White River, tributary to the Bad River (Ashland County, Wisconsin). Acute mortality of eastern elliptio juveniles and adults did not occur when exposed to TFM-1% niclosamide up to 1.9 × MLC. Concentrations routinely applied in the Bad River system range from 1.0–1.7 × MLC (C. Gagnon, personal communication, 2020). Even at the highest concentrations, mortalities were not significantly different from the controls. However, survival was greater for eastern elliptio than for the eastern floater, and for adults relative to juveniles. Waller et al. (2003, p. 550) also found that trials conducted at lower water temperatures (55°F (13 °C) versus 70° (21 °C)) resulted in higher mussel survival.

B.2 Sedimentation

Excess sediment is listed as the most common pollutant in rivers, streams, lakes, and reservoirs and has been estimated to cause approximately US$16 billion in environmental damage every year (USEPA 2005, pp. 9–25; Du Plessis 2019, pp. 86–87). River channel erosion, precipitation runoff, and wind transport account for 30% of the total sediment load in aquatic systems, while land-use activities such as agriculture (Peacock et al. 2005, p. 548), logging (Beschta 1978, entire), mining (Seakem Group et al. 1992, p. 17), urbanization (Guy and Ferguson 1963, entire), and hydrological alteration (Hastie et al. 2001, entire) account for the remaining 70% (Du Plessis 2019, pp. 86–87). Agricultural activities have been found to produce the most significant amount of sedimentation (for example, livestock grazing/trampling near water's edge; Nolte et al. 2013, p. 296).

In 1999, Brim Box and Mossa (1999, entire) reviewed sediment impacts to unionid mussels and reported sedimentation may lead to smothering, reduced fish abundance, and declines in feeding/respiration. Authors concluded suspended sediments negatively affect mussel reproduction, growth, and survival. However, Haag (2012, entire) in reviewing the effect of sedimentation on mussel populations found many studies conducted and reported within Brim Box and Mossa (1999, entire) review lacked controls and/or focused mainly on the effects of sudden sedimentation rather than gradual accumulations of sediment. To address uncertainty, a third review was conducted in which authors evaluated the effects of suspended sediment concentration (SSC), total suspended solids (TSS), and sediment deposition and scour on the population performance (in other words, growth, survival, and reproduction) of freshwater mussels (Goldsmith et al. 2021, entire). Authors found increases in SSC and/or TSS can impact mussels by decreasing food availability, physically interfering with filter feeding and respiration, as well as impact mussel-host fish relationships.

Sedimentation can result in negative impacts to mussel reproduction. Specifically, increased sedimentation within the water column can decrease mussel clearance rates (in other words, volume of water completely cleared of particles per unit time) and in turn interfere with the ability of female mussels to capture sperm within the water column, thus reducing fertilization success (Gascho Landis et al. 2013, entire). For example, Gascho Landis et al. (2013, p. 75) in evaluating the effects of suspended solids on the pondmussel (*Ligumia subrostrate*) found when TSS concentrations were greater than 8 mg/L, there was a sharp decline in clearance rates. It should also be noted, evidence shows species with low cilia density, often lentic taxa, and short-term brooders, which use all four gills to brood glochidia, may be more likely to endure respiratory stress, particularly during brooding periods (Gascho Landis et al. 2013, p. 71).

Increased sedimentation may also negatively impact mussel-host fish relations, further impacting mussel reproductive success. This relationship may be impacted via physical abrasion of the fish gills and/or decreased visibility within the water column. For example, the success of glochidial attachment of fatmucket (*Lampsilis siliquoidea*) to largemouth bass (*Micropterus salmoides*), and metamorphic success was reduced due to concentrations of montmorillonite clay ranging from 1,250 to 5,000 mg/L (Beussink et al. 2007, pp. 15–17). This may be due to physical abrasion to gill tissues from increased suspended sediment, increased fish mucus production in an attempt to protect the gill from physical abrasion, coughing (which may dislodge glochidia from the gills,), and/or declines in keratocytes (which help with encapsulation of glochidia) (Beussink et al. 2007, entire). In addition to physical abrasion, some mussels use lures or conglutinates to parasitize their respective host fish (Barnhart et al. 2008, p. 374; Haag 2012, p. 171). Declines in visibility within the water column may lead to decreases in host fish encountering glochidia; however, no studies have been conducted to date (Goldsmith et al. 2021, p. 103). Impacts to fish population performance (growth, reproduction, and survival) were observed between 20 to 5000 mg/L, however, depending on factors such as testing a species ability to resurface after burial, clearance rate, and filtration rate (Goldsmith et al. 2021, p. 10).

Increased sedimentation may result in decreases in feeding and respiration, which could result in negative alterations to mussel's energetic metabolism and ultimately growth (Dimock and Wright 1993, p. 183; La Peyre et al. 2019, p. 5). Specifically, as sedimentation increases, clearance rates decrease and pseudofeces increase to prevent gill filaments from clogging (Bayne and Newell 1983, entire; Madon et al. 1998, p. 401). If the stressor becomes long-term, mussels may find feeding gains to be outweighed by the energetic cost of sorting food vs. non-food material (Bayne and Widdows 1978, p. 137; Madon et al. 1998, p. 401). Clearance rates were negatively impacted when TSS concentrations were >8 mg/L (Tuttle-Raycraft et al. 2017, pp. 1161-1167), and respiratory stress was prevalent when TSS was about 600 mg/L (Goldsmith et al. 2021, pp. 102 and 104). Tuttle-Raycraft et al. (2017) found that TSS reduced suspension feeding rates in freshwater mussels, with decreases in feeding five-times greater in juveniles compared to adults, indicating how vulnerability differs across life stages. Overtime, mussels may reduce clearance, nitrogen excretion, and respiration rate, as well as shift their metabolism to non-proteinaceous body stores (Aldridge et al. 1987, p. 25). This occurs when starvation sets in and may result in mussels prioritizing maintenance over reproduction and growth (Jokela and Mutikainen 1995, p. 129).

Finally, increased suspended sediment can alter river channel formation and habitat type through aggradation and degradation (Gordon et al. 2004, entire), which can lead to smothering and sometimes burial, ultimately impacting mussel survival. Impacts may affect different species and populations differently. For example, Ellis (1936, p. 39) examined the effects of silt deposition on four unionid mussel species within the Trinity River in Texas and found silt accumulations of 0.6–2.5 cm in depth resulted in approximately 90% mortality. Specifically, authors found *Lampsilis teres* to be the most sensitive, while the other three were the least sensitive (*Obliquria reflexa, Quadrula apiculata, Quadrula noblis*). Additionally, Imlay (1972, pp. 78–79) evaluating species response to smothering found sensitivities to differ between the three species being tested (*P. grandis* [least sensitive], *Ligumia recta* [second sensitive], and *F. flava* [most sensitive]). Localized bed degradation can impact mussels where suitable habitat is scoured, leading to individuals being washed away or habitat elimination (Goldsmith et al. 2021, p. 105). In the Little River in Oklahoma, mussel species richness and abundance were maximized in areas where chances for bed movement and particle entrainment (substrate particles being transported with the flow of water) were low (Allen and Vaughn 2010, entire). Richness and abundance were maximized when relative shear stress (RSS) was <1 (Allen and Vaughn 2010, p. 392).

In the Brazos and Trinity River basins in Texas mussel diversity was maximized at RSS values <1, and some species could persist at higher RSS values than others (Randklev et al. 2019, p. 392). Specifically, *Potamilus* and *Lampsilis* species were found to be more persistent than *Amblema*, *Cyclonaias*, and *Quadrula* species, which is likely due to differences in species traits (in other words, burrowing, morphology, and life history).

B.3 Water Temperature

Mussels are sedentary bottom dwelling ectotherms (dependent on external sources of body heat), and therefore exceedance of species thermal optima and decrease in flow will likely result in physiological impacts (Amyot and Downing 1997, p. 346) including altered heart rate, gape frequency, filtration rate, respiration rate (see dissolved oxygen), and reproductive success. Decreased flows may also result in increased toxicity levels within the water (for example ammonia; Khan et al. 2018, p. 2).

Additionally, mussels are obligate parasites, reliant on specific host-fish for dispersal who are also adversely impacted by altered flow and often equally sensitive to elevated water temperatures (Gates et al. 2015, p. 2). As a result of these host constraints, elevated water temperatures can quickly reach uninhabitable levels for mussel host species during periods of low flow and depending on the frequency and magnitude can have a profound negative impact on population persistence (Khan et al. 2019, pp. 13–14).

Increased water temperature and altered flow patterns negatively affect water quality and quantity impacting mussel physiological processes (for example, protein damage, fluidity of the cellular membrane, and organ function), disrupting energy balance, growth, and reproduction (Ganser et al. 2015, p. 17). For example, factors that trigger glochidial release are unknown for many species; however, it is assumed the process is triggered by a combination of water temperature and photoperiod (Kautsky 1982, p. 149; Wieland et al. 2000, p. 452; Gascho Landis et al. 2012, p. 775). Thus, if the thermal regime of a river system is altered, timing of seasonal cues may shift and impact recruitment success (Hastie and Young 2003, p. 2107; Österling 2015, p. 1; Schneider et al. 2017, p. 267). Specifically, Schneider et al. (2017, pp. 267 and 283) evaluating temperature and host dependent reproduction within *Unio crassus* (thick shelled river mussel) found the timing of glochidial release was delayed at both constantly low temperatures (in other words <10 °C) and higher-than-normal temperatures (in other words10–20 °C). Additionally, authors found moving mussels from the cold treatment (<10 °C) to natural temperatures (10–15 °C) resulted in the gravid females releasing their glochidia soon after (Schneider et al. 2017, p. 283). Authors indicate this suggests there is a temperature threshold for glochidial release. Pandolfo et al. (2010, p. 964) observed significantly lower survival in several species of freshwater mussels at 37 ºC. Similar to mussels, temperature and photoperiod are thought to influence the location, abundance, and activity level of host fish as well as their immunity strength (Martel and Lauzon-Guay 2005, p. 420; Roberts and Barnhart 1999, entire; Gascho Landis et al. 2012, p. 776). Therefore, these variables may determine how well glochidia will transform to juveniles, as well as the chance of mussel and host-fish populations co-occurring. Research shows elevated thermal regime impacts both water quality and quantity, which can have direct impacts on the population performance of freshwater mussel populations.

B.4 Dissolved Oxygen

Low dissolved oxygen is a threat to freshwater mussels and is particularly an issue in interstitial waters (waters between sand particles, sediment, gravel) (Sparks and Strayer 1998, p. 129). Low dissolved oxygen can be caused by excess sedimentation, nutrient loading, organic inputs, changes in flow, and higher temperatures (Sparks and Strayer 1998, p. 129). Alterations to flow directly affect the concentration of dissolved oxygen (DO) within a river system (Ganser et al. 2015, p. 17). Specifically, during high flow events, turbulent diffusion of atmospheric oxygen increases, while during low flow events, DO may drop to critically low levels (Chen et al. 2001, p. 209). Surface waters can be near saturation, while adjacent interstitial waters are far lower (Sparks and Strayer 1998, p. 129). Elevated water temperatures also affect dissolved oxygen concentrations in water bodies as well (Ganser et al. 2015, p. 17). Adults and juveniles that are buried in the sediment are particularly vulnerable to low dissolved oxygen for this reason (Sparks and Strayer 1998, p. 129).

The ability to maintain constant oxygen uptake during periods of low and high oxygen availability is essential to mussel population persistence. Mussels cannot maintain oxygen consumption rates when exposed to low levels of DO, so they may be forced to inefficiently bring oxygen into their bodies by activating anaerobic metabolism in their tissues (Gade and Grieshaber 1988, p. 255). While adults may be able to withstand some period of anoxia (absence of oxygen), there is the potential for these conditions to negatively impact their metabolism. Newly transformed juveniles that are entirely within interstitial waters may be exposed to prolonged periods of low dissolved oxygen that has the potential to significantly alter their behavior (for example, surfacing, gaping, extending their siphons and foot) leading to elevated levels of predation potential as well as direct mortality (Sparks and Strayer 1998, pp. 131–133).

Stegmann (2020, pp. 1–55) used hypoxia (oxygen deficiency) trials to evaluate the behavioral response of salamander mussel (*Simpsonaias ambigua*) to cooler and warmer water hypoxic conditions. Mussels did not show a preference for cool water that is hypoxic or water with normal oxygen conditions, but under warm water conditions mussels did have a significantly higher tendency to occupy hypoxic waters compared to oxygenated waters. This could be because respiratory rate increases with increasing temperature, given that the mussels tended to stop moving in hypoxic waters, it could be more due to inability to move out of these areas, which could be compounded by temperature increases (Stegmann 2020, pp. 11–14). It is possible that these mussels depleted their oxygen stores reducing their ability to move or that they reduced movement to avoid additional depletion of their oxygen stores.

The ability to deal with alterations in DO levels may differ between species and populations. Oxygen regulation ability in unionids may be related to the degree of hypoxia a species normally experiences in its habitat type (Chen et al. 2001, pp. 209–214). Additionally, this ability may be enhanced at low temperatures (Chen et al. 2001, p. 209).

B.5 Hydrological Regime

The ecological responses to altered hydrology are overall described as “chronic and cumulative and profoundly negative (Poff et al. 1997, entire; Pyron et al. 2020, p. 3),” idiosyncratic, and can vary substantially with geography, geomorphology, type of land use, and engineering practices for each specific impacted river (Pyron et al. 2020, p. 3), and further worsened by the current and expected further changes of climate conditions (Addor et al. 2014, entire; Arnell 1999, entire; Brunner et al. 2019, entire; Horton et al. 2006, entire; Laghari et al. 2012, entire; Leng et al. 2016, entire; Milano et al. 2015, entire; Brunner et al. 2020, entire). Climatic changes to the hydrological regime are caused by changes in the seasonality and intensity of annual precipitation and changes in flood and drought characteristics (for example, the seasonality and magnitude of floods; the duration of droughts), as well as the seasonal shifts in melt contributions related to reduced snow and glacier storage (Middelkoop et al. 2001, entire; Farinotti et al. 2016, entire; Beniston et al. 2018, entire; Brönnimann et al. 2018, entire; Jenicek et al. 2018, entire; Brunner and Tallaksen 2019, entire; Brunner et al. 2020, entire). Being able to quantify these types of changes may assist in improving our understanding of further future changes in climatic extremes, which is crucial for adapting river conservation practices, especially those involving the management of existing river development. Specifically, for freshwater mussel species, drought and flood conditions can shift energy allocation toward maintenance (for example, respiration) and therefore, may negatively impact the growth of individuals (Jokela and Mutikainen 1995, p. 129).

B.5.1 Drought

Varying temperature sensitivities can lead to feedback cycles that increase mortality during low flows and high temperatures. For example, Khan et al. (2020, entire) evaluating the upper thermal limits of three adult freshwater mussel species (threeridge [*Amblema plicata]*, Guadalupe orb [*Cyclonaias necki]*, and false spike [*Fusconaia mitchelli]*) from the Guadalupe River in Texas, found thermal tolerance differences between species, with the most sensitive being *F. mitchelli*. The authors then related species thermal tolerance thresholds to daily discharge measurements to determine whether subsistence flows (represents infrequent, natural low flow events that occur for a seasonal period of time) were sufficient to offset thermal tolerance exceedances for the mussel species; however, summer subsistence flow standards inadequately addressed exceedance of upper thermal tolerances for their focal species (Khan et al. 2020, p. 14). Therefore, authors concluded current flow standards were insufficient to protect mussel populations during low flows and severe droughts.

During periods of low flow and temperature exceedance, water quality may degrade as contaminants become more concentrated. This may be problematic for freshwater mussels because they are particularly sensitive to ammonia (Augspurger et al. 2003, p. 2569; Spooner and Vaughn 2008, entire). As surface water temperatures increase, toxicity of ammonia increases, which may result in sublethal or lethal impacts to mussels (USEPA 2013, p. 6). For example, Augspurger et al. (2003, p. 2571) examining current water quality guidance for protection of freshwater mussels from ammonia exposure found concentrations as low as 0.7 ppm total ammonia nitrogen were lethal to juveniles and concentrations as low as 2.4 ppm total ammonia nitrogen were lethal to glochidia. Authors concluded current U.S. EPA criteria for continuous concentration of total ammonia (1.24 mg/L) may not be protective of mussels.

Thermal tolerance and avoidance strategies are thought to differ among species as well as population. For example, Gough et al. (2012, entire) assessed the linkage between physiological tolerance, behavioral response, and survival of three species of freshwater mussels subjected to drought: pondhorn (*Uniomerus tetralasmus)*, rough fatmucket (*Lampsilis straminea)*, and giant floater. Authors observed and identified strategies each mussel species used to deal with drought and consequently thermal intolerance (Gough et al. 2012, p. 2357). The three strategies observed included: tracking (i.e, track receding water; intolerant), track and then burrow (semi-tolerant), and burrowing (tolerant). Both *U. tetralasmus* and *L. straminea* burrowed in response (shallowly – approximately 3–4cm), while *P. grandis* rarely burrowed. Survival results suggest drought and elevated water temperatures pose the greatest threat to intolerant trackers, while tolerant burrowers are the most resistant to drought conditions. This suggests mussel species capable of burrowing in response to stress may have a greater ability to persist.

B.5.2 Prolonged Stream Drying

Prolonged stream drying occurs during periods of extreme drought as a result of climate change and may occur across river systems at varying levels depending on the rate in which climatic impacts are accelerated (Gates et al. 2015, p. 622; Aldous et al. 2011, p. 233), but can also occur as a result of land use activities such as water withdrawal for oil and gas extraction, irrigation for agriculture, and other municipal/industrial purposes (Poff et al. 1997, pp. 772–774). Although seasonal drying occurs as a natural component to the hydrological regime, these periods of drought may prolong, increase in frequency and severity, and become unpredictably timed as climatic conditions are expected to change as a result of rising surface temperatures and other factors (Gates et al. 2015, p. 622; Mukherjee et al. 2018, p. 1).

Low water levels may be endured for short periods of time (Pyron et al. 2020, p. 5), though such lower flows can cause stagnant pools to form, which overtime, can become unsuitable for freshwater mussels and their host fish, especially during the summer months, as water temperatures increase and dissolved oxygen decreases (Gates et al. 2015, p. 622). A completely dry streambed not only can eliminate habitat for freshwater mussels, but it also has the ability to fragment population connectivity.

B.5.3 Inundation

Stream inundation typically occurs as a result of water impoundment and retention from dams, further exacerbated by extreme flooding via climate change (Zeiringer et al. 2018, p. 72; Hastie et al. 2003, pp. 42–43). Dams are the most obvious direct modifiers of hydrological regime (Zeiringer et al. 2018, p. 72). Dams capture both high and low flows, as well as accumulate sediment, and are responsible for coarsening (thicker and heavier substrate particles) streambeds (Zeiringer et al. 2018, p. 72). Reservoirs and other types of artificially ponded areas provide poor conditions for freshwater mussels (for example, increased siltation and sediment deposit; temperature changes), and can result in direct smothering when large amounts of sediment are deposited along the bed. Deep water in particularly large reservoirs is additionally known to be cold and can often be devoid of necessary nutrients. If cold enough (<11 °C (52 °F)) growth of any freshwater mussel occupants could be stunted; these individuals likely never reproduce or may reproduce less frequently (Vaughn and Taylor 1999, pp. 915–916).

B.5.4 Increased Flashiness

Increased stream flashiness is another result of extreme flooding via climate change and can impact associated river habitats by destabilizing and disrupting natural substrate transportation by means of increased water velocity, further worsened by the overwhelming presence of impervious surfaces as a consequence of development; stream destabilization has the ability to undercut stream banks, blow out crucial riffle habitats, and wash scour substrate (Hinck et al. 2011, p. 6; Gangloff and Feminella 2007, p. 69; Zeiringer et al. 2018, p. 70). We expect for freshwater stream and river habitats within or near urban areas to be most affected by flashiness as a result of frequent surface runoff, though we understand that extreme flooding events have the ability to impact any reach throughout a specific river system. Impacts to native biota tend to be localized; though as development increases across the natural landscape into the future, we should expect for the effects of increased flashiness to spread and to become more severe. Miller and Lyon (2021, p. 7) also found a correlation between cropland drainage tiles and increase flashiness in streams during rain events, making drainage tile runoff another potential contributor to stream destabilzation, especially in agricultural areas.

B.6 Connectivity

Artificial barriers within streams and rivers (for example, dams, road crossings, water control structures, etc.) pose a great number of threats to freshwater mussels and are considered one of the primary reasons for their decline (Downing et al, 2010, pp. 155–160; Vaughn and Taylor, 1999, p. 915).

Artificial barriers affect freshwater mussels through direct effects (such as water temperature and flow changes and habitat alteration) and indirect effects (such as changes to food base and host fish availability). Hydroelectric dams and similar water control barriers can create additional stressors by fluctuating flows to abnormal levels on a daily basis or at inappropriate times of year (Poff et al. 1997, pp. 772–774). Abnormally high stream flow can displace juvenile mussels and make it difficult for them to attach to the substrate (Holland-Bartels 1990, pp. 331–332; Layzer & Madison 1995, p. 335). Altered flow can destabilize the substrate, which is a critical requirement for mussel bed stability (Di Maio and Corkum 1995, p. 663). Barriers can also exacerbate the effects of drought, resulting in the stranding of mussels and drying of mussel beds (Fisher and LaVoy 1972, pp. 1473–1476). Barriers to host fish movement can also cause changes to genetic diversity for most mussel species (Hoffman et al. 2017, p. 9617).

Movement and presence of host species is critical to development and distribution of mussels (Watters 1992, pp. 485-486; Haag and Warren 1998, pp. 303–305). The presence of barriers has been linked to the extirpation of freshwater mussels (Vaughn and Taylor 1999, pp. 915–917; Watters 1996, p. 79) and reduction in density and species richness of fish assemblages and mussel beds (Gore and Bryant 1986, p. 333; Bain et al. 1988, pp. 389–390; Kinsolving and Bain 1993, p. 531; Scheidegger and Bain 1995, pp. 129–134). Haag and Williams (2014, pp 46-47) discuss the sensitivity of mussels to human alterations to the landscape, including dams. The systematic destruction of riverine habitat by dams and channelization is often described as the predominate cause of mussel extinctions in North America (Haag 2012, pp 328-330).

Unpaved road stream crossings impact ecosystems including, but not limited to, water quality degradation, changes in flow, and obstruction to host passage, all of which can limit access to certain stretches of river that are either not accessible or degraded to a point that lack of habitat essentially causes a barrier.

B.7 Invasive Species

B.7.1 Zebra Mussels (Dreissena polymorpha)

The zebra mussel (*Dreissena polymorpha*) is a freshwater bivalve native to the Black, Caspian, and Azov Seas and was likely introduced to North America in the 1980s via commercial cargo ships traveling from the north shore of the Black Sea to the Great Lakes (McMahon 1996, p. 358). Due to the species ability to passively drift at the larval stage and attach to boats, the zebra mussel rapidly dispersed throughout the Great Lakes and major river systems and now inhabits all the Great Lakes, all large navigable rivers within the eastern United States, and many lakes within the Great Lakes region. Currently, zebra mussels are established within the upper Mississippi, lower St. Croix, Ohio, and Tennessee Rivers overlapping much of the current range of native freshwater mussel species and likely have already reduced mussel species populations in heavily infested waters.

Zebra mussels have a profound effect on the ecosystems they invade through biofouling (accumulating on surfaces, including native mussels) and significantly reducing the amount of phytoplankton that native mussels need for food (Holland 1993, p. 622; Fahnenstiel et al. 1993, p. 471; Caraco et al. 1997, p. 597). With a 90% filter efficiency rate and the ability to filter particles less than 1 micrometer in diameter (with preference for larger particles), zebra mussels have been found to be more efficient at filtration than unionids (Sprung and Rose 1988, p. 526; Noordhuis et al. 1992, p. 108).

The invasion of freshwater habitats within the United States poses an imminent threat to mussel fauna (Ricciardi et al. 1988, p. 615). Zebra mussel invasion can result in the loss of entire native mussel beds through direct attachment to mussel shells (Strayer et al. 1999, pp. 75–80). By attaching themselves in large numbers to native mussel beds, the invasive zebra mussels negatively impacts the native species' locomotion, valve-movement, and energy stores, depleting food concentrations to levels too low to support reproduction or survival of native species (Strayer et al. 1999, pp. 75–80). Because zebra mussels filter phytoplankton at higher concentrations than native freshwater mussels, habitat for native freshwater mussels also may degrade over time with an increased deposit of zebra mussel pseudofeces (undigested waste material passed out of the incurrent siphon) that foul benthic habitat. Additionally, zebra mussels may impact native mussel fauna by filtering their sperm and/or glochidia from the water column, thus negatively altering reproductive potential (77 FR 14913).

While it is well documented that the zebra mussels have significant negative effects on freshwater mussels in lakes and large rivers, it should be noted that zebra mussels appear to coexist with mussels in small and medium sized streams (for example, the Clinton, Huron, and Grand River watersheds in Michigan) (D. Zanatta 2022, pers. comm.). Therefore, it is unclear how much of a deleterious effect zebra mussels pose to mussels in small and medium sized streams (D. Zanatta 2022, pers. comm.).

B.7.2 Asian Clam (Corbicula fluminea)

The Asian clam (*Corbicula fluminea*) is a freshwater bivalve native to tropical southern Asia west to the eastern Mediterranean, Africa, and southeast Asian islands south into central and eastern Australia (Morton 1986, p. 114). The species was first reported within the United States in 1938 along the banks of the Columbia River, Washington (Counts 1986, pp. 18–19). While the mechanism for dispersal within the United States is unknown, the species is currently found in 46 states as well as Lake Erie, Lake Michigan, and Lake Superior (USEPA 2008, p. 35).

The most prominent effects the introduction of the Asian clam has had on native mussel fauna and habitats include biofouling, altering benthic substrates, and outcompeting (especially juvenile mussels) for food, nutrients, and space (Leff et al. 1990, p. 415; Neves and Widlak 1987, p. 6). Additionally, it has been suggested Asian clam may filter native freshwater mussel sperm, glochidia, and/or newly metamorphosed juveniles reducing native freshwater mussel reproductive potential (Strayer 1999, p. 82; Yeager et al. 2000, p. 255). Asian clam actively disturb sediment altering benthic substrates and ultimately reduce habitat for juvenile native mussels (Strayer 1999, p. 82).

Research suggests invasion of Asian clam tends to occur in areas where native freshwater mussel density is low or declining (Strayer 1999, pp. 82–83; Vaughn and Spooner 2006, pp. 332–336). It appears Asian clam cannot successfully invade dense, healthy mussel beds in small-scale habitats (Vaughn and Spooner 2006, pp. 334–335). However, while Asian clam may not be a factor in the decline of native freshwater mussels in dense beds, the invasive species has the potential to result in the decline of populations that are stressed or in decline through competition for resources and space (Vaughn and Spooner 2006, pp. 335–336).

B.7.3 Invasive Carps

"Invasive carp" typically refers to five invasive fish species originating from Asia and Europe: the black carp (*Mylopharyngodon piceus*), grass carp (*Ctenopharyngodon Idella*), bighead carp (*Hypophthalmichthys nobilis*), common carp (*Cyprinus carpio*), and silver carp (*Hypophthalmichthys molitrix*) (Berg 1949, entire; Lee et al. 1980, entire; Shireman and Smith 1983, entire; Li and Fang 1990, pp. 244–250; Page and Burr 1991, entire; Robins et al. 1991, p. 243; Balon 1995, p. 5.; Nico et al. 2005, p. 337). As a group, invasive carps were introduced to the United States via stocking for fishing and control purposes (such as biological control of vegetation and phytoplankton, and other organisms) in the 1960s and 1970s, and escaped into freshwater systems (DeKay 1842, Part IV; Cole 1905, entire; Guillory and Gasaway 1978, p. 105; Freeze and Henderson 1982, p. 197; Li and Fang 1990, pp. 244–250; Robins et al. 1991, p. 243; Nico et al. 2005, p. 337). Currently these species are reported in many states across the American Midwest, though the Great Lakes Basin and the Mississippi and Missouri Rivers are particularly impacted (Bailey and Smith 1981, pp. 1539–1561; Pflieger 1997, p. 372; Burr et al. 1996, entire; Nico et al. 2005, p. 337).

Invasive carps negatively impact native aquatic ecosystems by a) preying on and subsequently reducing juvenile and adult unionid and snail populations, many of which are considered endangered or threatened (Nico et al. 2005, p. 337) and/or preying on the eggs of other fish species, negatively impacting species recruitment (Shireman and Smith 1983, entire; Chilton and Muoneke 1992, pp. 284–287; Miller and Beckman 1996, pp. 338–340); b) uprooting and destroying native vegetation, resulting in increased turbidity and deterioration of habitat

(Shireman and Smith 1983, entire; Bain et al. 1990, p. 553; Chilton and Muoneke 1992, pp. 294-298; Laird and Page 1996, pp. 13–14); and c) outcompeting native fish and mussel populations that rely on the same food sources, particularly plankton and plant foods (Shireman and Smith 1983, entire; Chilton and Muoneke 1992, pp. 294-298; Laird and Page 1996, pp. 13–14). Predation and feeding habits of these carp species have the potential to restructure benthic communities.

B.7.4 Rusty Crayfish (Faxonius rusticus)

The rusty crayfish (*Faxonius rusticus*) is a freshwater crustacean native to the Ohio River basin across tributaries in Ohio, Indiana, Kentucky, and northern Tennessee, as well as Lake Erie (Creaser 1931, entire; Hobbs 1974, entire; Momot et al. 1978, pp. 10–35; Hobbs et al. 1989, p. 300; Taylor 2000, p. 140). The species was likely introduced to areas outside its native range both unintentionally (through dumping of angler bait buckets and use of the species in schools and biological supply houses) and intentionally (by commercial crayfish harvesters and as a means to remove nuisance weeds) (Kilian et al. 2012, p. 1469; Gunderson 2008, entire; Wilson et al. 2004, p. 2256; Magnuson et al. 1975, p. 67).

The introduction of rusty crayfish can cause significant population declines in native unionid mussel populations through direct predation resulting in a cascade of impacts to food web dynamics (Klocker and Strayer 2004, pp. 174–175). Currently, the species is found in 20 states and can live at high densities (Klocker and Strayer 2004, p. 168). Thus, the increase and spread of this predator population can result in negative impacts to threatened unionid populations inhabiting the same area (Klocker and Strayer 2004, pp. 174–175).

B.7.5 Spiny Waterflea (Bythotrephes longimanus)

The spiny waterflea (*Bythotrephes longimanus*) is a large cladoceran native to the Baltic Nations, Norway, northern Germany, the European Alps, the British Isles, the Causcasus region, and Russia (USFWS 2013, p. 1). The species was likely introduced from ship ballast water and diapausing eggs from sediment in ballast tanks (Berg et al. 2002, p. 275; Evans 1988, p. 235). Currently, the species is found in all the Great Lakes and many inland lakes within the region. Specifically, densities have been reported to be low in Lake Ontario, southern Lake Michigan, and offshore areas of Lake Superior, moderate to high in Lake Huron, and very high in the central basin of Lake Erie (Barbiero et al. 2001, p. 147; Vanderploeg et al. 2002, p. 1222; Brown and Branstrator 2004, pp. 1–8).

The species is responsible for significant declines and shifts in plankton communities and directly competes with small fish and bivalves that rely on these food stocks (USEPA 2008, p. 37). Because the species has high generation turnover, population densities can rapidly increase, negatively affecting mussels within the region (Brown 2008, pp. 1–8). Therefore, when occupying the same waterway, the spiny waterflea is considered a threat to native freshwater mussel populations.

B.7.6 Brown Trout (Salmo trutta)

The brown trout (*Salmo trutta*) is a fish species native to Europe, northern Africa, and western Asia (Page and Burr 1991, p. 42). The species was first reported in the United States in 1833 and since then, has been stocked in virtually all states (Courtenay et al. 1984, pp. 41–77; MacCrimmon et al. 1970, pp. 811–818).

Since its introduction, the species has contributed to the decline of native fish species, especially other salmonids, through direct predation, displacement, and food competition (Taylor et al. 1984, pp. 322–373). Competition with native fish species has the potential to impact host-fish stocks and ultimately impact freshwater mussel's reproductive potential. Due to mussel's unique reproductive strategy, without the presence of host, mussel species cannot reproduce. Currently, natural reproduction of brown trout is low in many states; however, many states maintain fish populations by restocking. Therefore, brown trout pose an indirect threat to unionid populations inhabiting the same communities due to their predation of host-fish populations.

B.7.7 Quagga Mussel (Dreissena rostriformis bugensis)

The quagga mussel (*Dreissena rostriformis bugensis*) is a small freshwater bivalve native to the Dneiper River drainage of Ukraine and Ponto-Caspian Sea (Mills et al. 1996, p. 271). The species was likely introduced through ballast water within the Great Lakes, and due to its high potential for rapid adaptation and ability to passively drift, the species was able to rapidly expand and colonize the United States (Mills et al. 1996, p. 275). Currently, the quagga mussel is found within the lower Great Lakes and harbor and nearshore areas of Lake Superior.

Similar to zebra mussels, the quagga mussel can be harmful to aquatic ecosystems through biofouling and use of the same food resource as freshwater unionids (Karatayev et al. 2015, p. 104). While less information is available regarding the impact of quagga mussels on native freshwater mussels (Lucy et al. 2014, p. 241), information suggests the quagga mussel may have smaller impacts on native freshwater mussels than the zebra mussel (Karatayev et al. 2015, p. 14; Sherman et al. 2013, p. 208). Zebra mussels are much more commonly found on native freshwater mussel shells than quagga mussels even in areas where quagga mussels are more abundant than zebra mussels (Karatayev et al. 2015, p. 104). Yet, if affixed to the shell of a native freshwater mussel, quagga mussels can impact native freshwater mussel locomotion, ability to gape, and food storage. Additionally, quagga mussels have the potential to remove large quantities of phytoplankton and suspended particulate matter from the water, thus decreasing the food source and altering the food web (Claxton and Mackie 1998, p. 2010). Because quagga mussels filter high concentrations of phytoplankton, the quality of habitat will likely degrade due to an increase in pseudofeces. Finally, quagga mussels may impact native mussel fauna by filtering their sperm and/or glochidia from the water column, thus negatively altering reproductive potential.

Despite the threats the quagga mussel may pose, it was found the number of dreissenids (the family of mussels that includes zebra mussels) attached to native freshwater mussels was lower in lakes dominated by quagga mussels suggesting the ongoing replacement of zebra mussels by quagga mussels within the Great Lakes may reduce impacts to native freshwater mussels (Karatayev et al. 2015, p. 104). Research suggests if occupying the same reach as native freshwater mussels, the quagga mussel has the ability to negatively impact native freshwater mussels by outcompeting the native mussels for resources (in other words, food and space); however, research also suggests the replacement of zebra mussels by quagga mussels may reduce impact to native freshwater mussels and aid in species recovery (Karatayev et al. 2015, p. 104).

B.8 Mussel Disease

Declines and large-scale die-offs of mussel assemblages within otherwise healthy streams across large geographic regions have emerged as a very concerning risk factor (Haag and Williams 2014, pp. 45–60; Haag 2019, pp. 43–60; Waller and Cope 2019, pp. 26–42). Die-offs have been observed in Europe as well as both the western and eastern U.S. (Waller and Cope 2019, p. 27). In some cases (for example, Clinch River), dies-offs have occurred several years in a row. The mysterious documented decline in mussel populations in the U.S. between the 1970s and 1990s could be the result of a widespread virus, bacteria, fungi, parasite, or a suite of diseases affecting only freshwater mussels (Haag and Williams 2014, pp. 44–46; Haag 2019, pp.44–45; Waller and Cope 2019, p. 26). More recently, unexplained mussel die-offs have been documented in the eastern U.S. in the Ohio and Tennessee River basins in the Clinch River and Big Darby Creek (Richard et al. 2020, p. 1–10; Waller and Cope 2019, p. 27). The die-off in Big Darby Creek affected all mussel species (Waller and Cope 2019, p. 27). In the Clinch River, the first die-off in 2016 affected only pheasantshell (*Actinonaias pectorosa*) though die-offs in 2017, 2018, and 2019, impacted a wider variety of species and additional sites (Waller and Cope 2019, pp. 27–28).

Little is known about mussel health, the role of microbiota and pathogens in mussel health, which makes it very difficult to understand how these factors may be impacting freshwater mussel populations. In 2018, the Freshwater Mollusk Conservation Society held a workshop: to increase awareness of, and encourage expanded research on, freshwater mollusk health and the potential role of disease by (1) identifying knowledge gaps in assessing mollusk health, (2) providing information on health assessment and diagnostic tools for mollusks, (3) aligning sampling and relocation protocols with those for health and disease assessment, and (4) promoting interdisciplinary cooperation and communication to advance knowledge of freshwater mollusk health (Bradley and Waller 2019, p. 25). The long-term outcomes of these goals will be critical in trying to address and potentially manage mussel health and disease issues given that mussel die-offs have the potential to result in population-level impacts.

B.9 Potential Catastrophic Risk Events

Coal mining - Coal mining has the potential to result in accidental spills and contaminant runoff. Acid mine and saline drainage (AMD) is a major threat to aquatic ecosystems and is created from the oxidation of iron-sulfide minerals such as pyrite, forming sulfuric acid (Sams and Beer 2000, p. 3). AMD may be associated with high concentrations of aluminum, manganese, zinc, and other constituents (Tennessee Department of Environment and Conservation (TDEC) 2014, entire).

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) has played a significant role in reducing AMD during mining operations, though un-reclaimed areas mined prior to SMCRA continue to generate AMD. Abandoned mines are the source of pollution in more than 5,600 mi (9,102 km) of impaired streams in Pennsylvania; in West Virginia mine drainage affects 17 percent of stream miles; and in Kentucky surface mining has been identified as a source of impairment for approximately 775 mi (1,247 km) of streams (Pennsylvania Department of Environmental Protection 2016, p. 51). Catastrophic events, such as black water release events and fly-ash spills, have occurred in some river systems (for example, upper Tennessee River) resulting in the extirpation of mussel populations within the watershed (Ahlstedt et al. 2016, p. 8).

Impacts from coal mining may result in direct mortality due to acute toxicity of introduced contaminants as well as impact growth and reproduction leading to population level changes in the form of local extirpations or significant population declines.

Oil and gas - Oil and gas exploration and extraction can result in accidental spills, discharges, and increased sedimentation. Discharge of untreated or poorly treated brine wastewater and inadvertent release during drilling of frack fluids high in chlorides and other chemicals can result in conditions that are acutely toxic to mussels (Patnode et al. 2015, p. 62). Excess sedimentation results when there is bank slippage and mudslides during pipeline construction, open trenching operations, construction of access roads, and well pads (Ellis 1936, p. 29; Anderson and Kreeger 2010, p. 2). Excessive suspended sediments and contaminants resulting from inadvertent releases or runoff can be acutely toxic, result in sublethal effects such as impairing feeding processes, and degrade and destroy suitable habitat for mussels.

B.10 Mussel Conservation Programs and Efforts

B.10.1 Culture Activities

The Genoa National Fish Hatchery (GNFH), located in Genoa, Wisconsin, has been working with sheepnose for more than a decade, with most of the early effort dedicated to developing a cultured population of Golden Shiners, the fish host best-suited for hatchery propagation of sheepnose (M. Bradley, USFWS, pers. comm. 2022). Only one culture event has resulted in successful rearing of subadult sheepnose where juvenile mussels transformed and dropped off the fish and grew in substrate in a pair of mussel cages in the St. Croix River. Intensive culture has proven difficult for this species, with systems at GNFH being suited to culturing Lampsilines and demonstrating poor new juvenile survival (M. Bradley, USFWS, pers. comm. 2022).

The Virginia Department of Wildlife Resources (DWR) Aquatic Wildlife Conservation Center (AWCC) mussel hatchery facility, located in Marion, Virginia has conducted work to head-start and augment sheepnose populations. In 2016, the facility released three sheepnose individuals (cohort year 2011) into the Clinch River just upstream of Cleveland, Russell County, Virginia (Tim Lane, Virginia DWR, pers. comm. 2022). The three specimens were sourced from Cleveland Island bloodstock. Attempts were made to relocate the three individuals each year between 2018 and 2021, with recaptures of two of the three individuals showing growth (Sarah Colletti, Virginia DWR, pers. comm. 2022); refer to Appendix E for further discussion. Subsequent culture attempts have resulted in the production of small numbers of sheepnose; however, these individuals have not successfully grown to release size (Sarah Colletti, Virginia DWR, pers. comm. 2022). The facility is currently holding broodstock from the Clinch River, with plans to attempt additional culture in 2022 to augment the same site.

The Kentucky Department of Fish and Wildlife Resources Center for Mollusk Conservation, located in Frankfort, Kentucky, has also conducted work to headstart and release sheepnose mussel. In 2019, the facility released 90 individuals (cultured in 2017) into the Tennessee River, near river mile 17 (M. McGregor, Kentucky DFWR, pers. comm. 2022). Additionally, the facility successfully transformed sheepnose *in vitro* in 2017 utilizing Rabbit serum. The Center for Mollusk Conservation continues to hold sheepnose for future culture efforts, with plans including culturing sheepnose from Green River and possibly Licking River broodstock, pending successful collection.

The Cumberland River Aquatic Center (C-RAC), located in Gellatin, Tennessee, has conducted propagation studies for sheepnose mussel using both fish and *in-vitro* with rabbit serum (Hua 2019, pp. 4-5). The facility currently holds broodstock from the Clinch River, with plans to continue propagation work in 2022 (D. Hua, TWRA, pers. comm. 2022).

A combination of laboratory studies and field observations have confirmed the identification of more than 30 host fish species for sheepnose; however, natural infestation has only been documented in two species (Sauger and Mimic shiner) (Hove et al. 2015, p. 6-8; Wolf et al. 2012, P. 7; Guenther et al. 2009, p. 20). Further, a recent study conducted by Hove etl al. (2015, entire) suggests sheepnose may be a cyprinid host specialist, with the authors further investigating ideal holding water temperatures to promote increased juvenile mussel releases and brooding behavior. The identification of additional host fish species and ideal propagation conditions through laboratory trials, including fish holding temperatures and techniques for identifying the reproductive condition of gravid sheepnose females, will help promote increased juvenile production through propagation efforts (Hove et al. 2015). Refer to Sections 2.4 and 2.4.4 for further discussion.

B.10.2 Habitat Modifications

The recent removal of dams within the extant range of sheepnose may have the potential to support range expansion. The Green River (KY) Lock and Dam 4 failed in 1965, followed by the removals of Lock and Dam 6 in 2017 and Lock and Dam 5 in 2021. Removal of these dams was primarily conducted to address public safety concerns, in addition to providing recreational and ecosystem benefits. Removal of the dams was coordinated by a partnership, including the U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, The Nature Conservancy, Kentucky Department of Fish and Wildlife Resources, Mammoth Cave National Park, and Kentucky Waterways Alliance (Chapman 2019, accessed June 25, 2020, Labashosky 2017, accessed July 8, 2020). Additionally, the Six Mile Dam (OH) on the Walhonding River was owned by the State and removed in 2020 as a restoration project through the Ohio Department of Natural Resources (EnviroScience 2010, p. 5). Sheepnose recruitment has been documented above Lock and Dam 5 on the Green River (KY) and the Six Mile Dam on the Walhonding River (OH), with non-reproducing individuals identified below each of these dams (LEC 2019; 8 ESII 2019, p. 6-11). This information suggests that the recent removal of these dams, along with any future dam removals, may have the potential to result in range expansion of sheepnose within the associated systems (EnviroScience 2010, p. 5), in addition to facilitating movement of sheepnose's natural host fish species. Refer to Appendix E for further discussion of the completed dam removals.

B.10.3 Genetics

Genetic research specific to sheepnose is limited; however, a recent study by Schwartz and Roe (2022, entire) has provided new knowledge for a subset of the extant sheepnose populations regarding the identification of genetically isolated sheepnose populations, genetic diversity within sheepnose populations and sub-populations and the gene flow in-between populations. The research suggests management efforts should focus on conserving areas of existing suitable habitat and reestablishing connections between sub-populations to increase and maintain genetic diversity (Schwartz and Roe 2022, p. 10). However, the authors cautioned against the potential effects of propagation, reintroduction, and translocation activities between populations that may negatively impact local adaptations (Schwartz and Roe 2022, p. 10). Refer to Section 2.1 and Appendix A for further discussion of this study.

B.10.4 Recovery Planning

The Service will be cooperating with state, federal, and local agencies, universities, and other partners, beginning in 2022, to develop and implement a propagation and reintroduction plan for this species in order to comply with the Service's controlled propagation policy. As such, we will be using the International Union for Conservation of Nature (IUCN) guidelines to facilitate our assessment of ecological, social, and economic risks, and to aid development of collection, release, and monitoring strategies. Reintroducing populations to former parts of the species' historical range has the potential to increase redundancy by adding new populations and will help to mediate the effects of habitat fragmentation. For example, the Illinois River (extirpated) provides a linkage between populations inhabitating the Kankakee and Mississippi River systems and has experienced water quality and biological condition improvements since enactment of the Clean Water Act (1972), resulting in this stream being a potential candidate for reintroduction following further assessment. Dispersing to new locations may also help mediate effects of invasive species, such as zebra mussels, particularly if reintroductions take place in areas where the threat of zebra mussels or other invasive species are low. Augmenting existing populations will make populations more resilient to stochastic events and may help address the threat of small population genetics.

B.10.5 Other Activities

Section 7 consultation was completed in 2016, for activities associated with the construction of a new Interstate-74 bridge between Iowa and Illinois within Pool 15 of the Upper Mississippi River and demolition of the existing bridge, including a large-scale mussel relocation (refer to Section 2.3.1.2). As part of the mussel relocation, long-term studies are being conducted to assess the success of sheepnose relocations, including individual survival, growth, and movement post-relocation (ESI, 2018, p. 22). The first monitoring events of the relocation sites within Pool 15 of the Upper Mississippi River took place in 2017, 2018, and 2020. Monitoring of the relocation areas will continue in the years 2023 and 2026. The results of this study may help improve and inform and increase survival of future sheepnose relocation, translocation, stocking, and reintroduction efforts.

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APPENDIX C. METHODS FOR CURRENT CONDITION DEMOGRAPHIC FACTOR ANALYSIS

C. 1 Cumulative Population Size

The Cumulative Population Size takes into account all live or fresh dead specimens collected from a population within last 20 years (2000-2020). As such, this metric is highly dependent on the number and frequency of search efforts conducted and survey methodologies used. Further, this metric may be skewed by intensive search efforts, such as relocation events, and regular monitoring of the same areas where the same individual(s) may be encountered multiple times. It was assumed that some mixture of survey types and methodologies have been conducted within most (if not all) extant sheepnose populations within the last two decades, therefore, lessening the effects of these events on the overall assessment results. However, where known and based on expert opinion, the condition category for this metric was adjusted in some instances to offset the effects on the overall total resulting from of large relocation events and repeated monitoring of the same individuals. In these instances a justification is provided (Appendix E, Table E.1) to describe the condition(s) resulting in the condition category modification.

Due to the limitations of the Cumulative Population Size metric described above, we considered estimating or categorizing population size based on available density estimates, the average number of individuals collected per survey effort, or population trend overtime. However, limitations associated with varying survey methodologies and level of effort, differing data collected per survey event, and the lack of data for surveys where sheepnose were not detected precluded further consideration of these approaches.

C.2 Reproduction and Recruitment

For the purposes of this assessment, evidence of recruitment was defined as the collection of individuals estimated to be five years of age or younger or gravid adult females. The amount of information collected on recruitment and methodology used to determine age of individuals varied extensively amongst the data reviewed, with these differences likely resulting in some level of variation in age estimation. It is common for malacologists to consider specimens of five-years of age or younger as “juveniles” when reporting findings. This is often estimated in-field by means of counting external annuli, resulting in an approximate age determination. Although sexual maturity of sheepnose has been confirmed at five years of age (Hove et al. 2015, p. 5), we continued to consider the collection of individuals estimated to be ≤ 5 years of age or identified as a “juvenile” as an indicator of recent recruitment. In some instances, specimen shell lengths were reported in-place of age estimations. We assessed available records where both an estimated age and shell length were reported to define a range of shell lengths within each age class. Although there was some overlap in shell length between age classes, we considered shell lengths of ≤ 58 mm as indicative of individuals aged five-years or younger for this assessment.

Sexual dimorphism is not known from sheepnose (Ortman 1919, p. 66); therefore, gravidity of adults is rarely examined outside of propagation purposes. This information was considered, where available, as an indicator of a population's reproduction potential. In many instances, records did not contain information regarding specimen age, length, or gravidity, and therefore, were not considered as part of the reproduction and recruitment assessment.

Specimen detectability further influences the ability to observe natural recruitment. The smallest specimen shell length collected, as reported through the assessed data, was 12 mm (n=1). The next smallest reported individual had a shell length of 24 mm (n=1). Of the records where both estimated ages and shell lengths were reported, the youngest were estimated to be approximately three years of age, with shell lengths ranging from 24 to 29 mm. Therefore, these data suggest that even if recruitment is occurring, the likelihood of detecting individuals less than three years of age is low. The survey methodology employed (i.e. quantitative versus qualitative sampling) further influences the detectability of younger specimens.

We considered a population to have a high Reproduction and Recruitment condition if evidence of reproduction or recruitment (presence of juveniles and/ or gravid females) had been observed within the population at least once per decade over the past 20 years (2000-2020), indicating persistent and on-going reproduction. Further, at least one juvenile had to be detected within a population within the most recent five years (2015-2020) for a population to be considered actively recruiting and assigned "high" condition. Although detectability of juveniles five years of age or younger is low, all of the populations currently considered in "high" condition met this criteria. In some instances, a population did not meet an individual condition category criteria due to lack of survey data gathered and/or reported. In these instances, available information and expert opinion were used to assign a condition category with an associated justification (Appendix E, Table E.1).

C.3 Population Distribution

The Population Distribution is defined as the stream segment length between the upstream-most and downstream-most live or fresh dead specimen collection locations, taking into account all occurrence records between the years 2000 and 2020. In some instances, local resource managers provided estimations of upper and lower bounds of the occupied reaches and in other instances, available information for a population was limited to point location occurrence data. While estimates of each population's occupied reach are helpful to understand the full extent of a waterbody the species is believed to occupy, in an effort to standardize what is considered a population's occupied reach for the purposes this analysis, this metric was informed solely by occurrence records dated 2000 through

2020 within each HUC8. Once mapped, the upper and lower occupied reach bounds were determined by buffering the upstream- and downstream-most point location records by approximately 0.5 miles in an attempt to account for potential unsearched areas beyond known occurrence locations. Limited exceptions to this rule were made when additional information was available documenting the search and lack of detection of sheepnose beyond areas of documented occurrence. If uncertainty was present for an occurrence record location to the extent that it would influence the assigned condition category, the location uncertainty was quantified (estimated) and described. If only a single specimen had been collected from a population between 2000 and 2020, the population was automatically assigned to the "<1 mile" category and a 0.5-mile buffer was applied upstream and downstream of the occurrence location.

One or more large impoundments bisect occupied reaches within a subset of the extant HUC8s. In instances where an impoundment was present within the 0.5-mile buffer, but no additional occurrence records were available beyond the impoundment, the impoundment was considered the upstream or downstream extent of the occupied reach regardless of the 0.5-mile buffer. However, if one or more large impoundments separated multiple occurrence records within a HUC8, the full extent between the upstream-most and downstream-most record was included within the population’s defined occupied reach. Although impoundments present within a HUC and bisecting known occupied reaches may affect the long-term persistence of a population, these effects were not accounted for within the demographic current condition assessment, but were captured within the habitat risk portion of this assessment.

C.4 Year of Last Observation

The Year of Last Observation is defined as the most recent year a live or fresh dead specimen has been collected from the population. Although, this metric is not directly correlated to the population demographics, it provides a level of confidence that the population continues to persist. Detection of live or fresh dead specimens is often dependent on the frequency and level of survey efforts being carried out within the boundaries of each population; however, with continued river and shoreline development and increased interest and documentation of the species since its listing as a federally endangered species in 2012, it is assumed some level of search effort has been conducted within each of the extant sheepnose populations in recent years.

C.5 Scoring

We defined a total of four demographic categories (Cumulative Population Size, Reproduction and Recruitment, Population Distribution, and Year of Last Observation) to assess the demographic condition of each population, as described above and with Table 4.3. Additive scoring was used across the four categories to generate an overall demographic score for each population. Definitions associated with high, moderate, low, or functionally extirpated conditions are provided for each of the four condition categories within Table 4.3. Populations were assigned 3 points for each category meeting the “high” condition definition, 2 points for “moderate” condition, 1 point for “low” condition, and 0 points for a condition of “functionally extirpated.” Points across the four demographic condition categories were summed for each population with an additive score of 0-3 representing an overall condition of “functionally extirpated,” a score of 4-7 representing an overall “low” demographic condition, a score of 8-10 representing an overall “moderate” condition, and a score of 11-12 representing an overall “high” condition (Table C.1).

Table C.1. Overall demographic condition cumulative scoring.

Cumulative Score	**Overall Demographic Condition**
11-12	High
8-10	Moderate
4-7	Low
0-3	Functionally Extirpated

APPENDIX D. METHODS FOR CURRENT CONDITION RISK FACTOR ANALYSIS

We developed a rule set to guide how to assess overall current condition for the five risk factors. If any one of the risk factors is high, then the overall population condition is categorized as high risk, based on the importance of each risk factor in influencing the survival and persistence of freshwater mussels. If none of the risk factors are high, then we used an additive approach to assessing the overall population condition. Using the scores in Table 4.4, for additive scores 11-15, the overall population condition is categorized as high risk, scores 8–10, the overall population condition is categorized as moderate risk and for additive scores 5–7, the overall population condition is categorized as low risk (Table D.9). Refer to Table 4.4 for a description of how individual risk factors were assigned points.

D.1 Water Quality/Contaminants

Contaminants

We evaluated a suite of chemicals based on the availability of acute toxicity data that indicated that freshwater mussels are sensitive to these chemicals. In the absence of toxicity data specific to the sheepnose, we used toxicity studies from other freshwater mussel species as a surrogate, with the assumption that the sheepnose would be either equally or more sensitive than the species tested. The majority of species tested (largely non-listed) were found to have similar sensitivities. However, in at least one case a listed mussel species has shown increased sensitivity to a primary contaminant. Primary contaminants were identified as the chemicals posing the greatest risk to freshwater mussels. The primary contaminants we evaluated were ammonia, chloride, nitrate, and copper (Table D.1).

We developed a rule set to guide how we evaluated contaminant risk metrics. If any of the primary contaminant risk metrics were determined to be high for the population, then the overall contaminant risk for that population is considered at high risk. If none of the risk metrics were high, then we applied the same rule for moderate risk: if any of the primary contaminant risk metrics are moderate, then the overall contaminant risk is considered moderate. If all of the primary contaminant risk metrics are low, then we used the secondary risk metrics to evaluate the risk for contaminants using an additive scoring approach.

Secondary contaminants are chemicals that also have an effect on freshwater mussels, but limited research covering relatively few species of mussels indicates these contaminants may not be as lethal to mussels as other aquatic organisms. Therefore, in our assessments, secondary contaminants alone do not present as high a risk to freshwater mussels as the primary contaminants for which mussels are the most sensitive (Table D.1). Based on our rule set, any secondary risk metrics that were considered high received 3 points, moderate risk was assigned 2 points, and low risk was assigned 1 point. The six secondary risk metric scores were added together to get a total score for the population. A total score of 15–18 across all secondary contaminant risk metrics (lead, potassium, sulfate, zinc, aluminum, and cadmium) results in an overall contaminant risk of high; a score of 9–14 is an overall contaminant risk of moderate; and 6–8 is an overall contaminant risk of low. The cutoffs for the risk metrics for secondary contaminants were based on where the majority of contaminants fall within that risk category.

We also qualitatively analyzed chemicals that pose a risk to freshwater mussels (e.g. Contaminants of Emerging Concern), but for which we do not have acute toxicity data that establish thresholds for quantitative evaluation (See Appendix B.1.2).

To evaluate the risk posed by primary and secondary contaminants, we began by obtaining ambient water quality data from 2000–2020 available from the National Water Quality Monitoring Council's Water Quality Portal and filtered results to include only samples collected from surface waters of reservoirs, streams, rivers, impoundments, and ditches to focus on samples from possible mussel habitat. We further filtered the data to include only samples collected within 12-digit HUC watersheds immediately draining into extant rivers. There was not enough data to make meaningful assessments of occupied reaches within extant streams and rivers. We then established thresholds (i.e. LD50, or the dose at which 50% of mussels died during laboratory tests) for high, moderate, and low risk for each contaminant based on a review of the literature, input from contaminant experts within the Service, and toxicity studies on aquatic organisms (Table D.1) and compared the Water Quality Portal data to the risk thresholds.

Since the toxicity of certain contaminants are influenced by water chemistry, we also queried the Water Quality Portal for measurements of hardness, pH, and temperature that were collected concurrently with samples analyzed for concentrations of primary and secondary contaminants to adjust for watershed and site-specific conditions. For example, the toxicity of metals such as copper are influenced by hardness, which impacts the bioavailability of metals in water. Ammonia toxicity, on the other hand, is impacted by pH and temperature. There was not enough hardness data to calculate water quality criteria for metals specific to each data point, so we averaged the hardness for individual watersheds in the study area to calculate hardness-dependent water quality criteria at the HUC8 scale. For watersheds in which pH and temperature data collected concurrently with ammonia samples were available, we calculated site-specific water quality criteria for ammonia. For watersheds lacking concurrent ammonia, pH, and temperature data, we used the same approach as we used for metals and averaged the pH and temperature across each watershed. We provide brief rationales for the water quality criteria we used to compare to ambient water quality data in Table D.2.

Limitations of the data

Some uncertainty is associated with assessing contaminants risks to the sheepnose; while efforts were made to provide assessments protective of endangered mussels, considerable knowledge gaps remain on which to base evaluations. For example, the data represent a snapshot of water quality. As a result, we were not able to compare concentrations of contaminants to chronic water quality. Assessments were limited largely to acute LD50s due to limited datasets for chronic mussel sensitivity as well as limited ambient water quality measurements on which to compare effects.

The Environmental Protection Agency guidelines indicate that freshwater aquatic life should be protected if the 24-hour average (acute) and four-day average concentrations (chronic) do not respectively exceed the acute and chronic criteria (Stephen et al. 1985). This would require an average of 4 consecutive ambient water quality samples, yet current data are limited to single sampling events corresponding to acute testing. LD50s were used in this assessment to allow comparisons to other risk assessments. However, the authors acknowledge there is concern that LD50s may not be protective of species of special concern, and further understanding of chronic exposure and of sublethal effects (that is, reproductive, behavioral) would also be valuable to better understand the full impact of contaminants.

We also have relatively few data points for occupied reaches of extant rivers. Instead, we conducted our assessment at the watershed scale and conditions at that scale may not be representative of conditions where mussels are. Another impact of limited data is that we were not able to calculate specific water quality criteria for metals based on hardness and had to rely on averages of hardness across whole watersheds. This may result in water quality that are overly conservative or too high.

Additionally, water quality criteria for freshwater mussels were developed in controlled laboratory studies using common species. Threatened and endangered species may be more or less sensitive than laboratory test organisms. Sensitivity of the sheepnose to the assessed chemicals was not available for comparisons to current water quality conditions as toxicology data for rare species is limited. Use of mussel data from common species is generally accepted. Wang and others (2017) have shown the fatmucket (*Lampsilis siliquoidea*) to be a suitable surrogate for several species with fatmucket sensitivities within 2–3-fold of that of other assessed species and chemicals. However, there are known notable exceptions that suggest this may not be appropriate for all species. Research by Gillis (2011) indicates the federally endangered northern riffleshell (*Epioblasma torulosa rangiana*) is 8x more sensitive to chloride than fatmucket.

Finally, our contaminants assessments are limited to surface water borne contaminants and do not account for additional pathways of exposure through food, and most notably sediments and pore water, where a considerable portion of both juvenile and adults may experience exposure to contaminants. Such data for environmental levels and associated mussel sensitivity are currently limited. Despite these limitations, we believe our analysis provides valuable insight into potential limiting factors and threats to freshwater mussels with respect to contaminants.

Temperature and Dissolved Oxygen

As stated in Appendix B (Sections B.3 and B.4), suitable water temperature and dissolved oxygen levels are essential to sheepnose population persistence. Anthropogenic activity coupled with climate change may result in shifts in mussel species natural range and water temperature to which they are exposed (Caissie 2006, entire). The shifts in temperature and dissolved oxygen beyond suitable ranges can negatively impact growth, reproduction, and survival.

Thermal sensitivity can vary within a species depending on the life stage. The Salamander Mussel appears to not be sensitive to thermal changes within propagation facilities (M. Bradley, USFWS, personal communication, August 2021). Sand and muck occupied by Salamander Mussel has been observed to be cooler than the surrounding water in the Chippewa River, Wisconsin, indicating a possible relationship with habitat and groundwater ingress (M. Bradley, personal communication, August 2021).

While we do not know the thermal lethal temperature for sheepnose, there has been extensive research on other species of mussel across life stages. This research indicates there is likely a thermal lethal limit for sheepnose. Ganser et al. (2013, entire) found negative impacts to survival, heart rate, and growth of juvenile freshwater mussels when exposed to elevated temperatures over time. Survival of fatmucket was affected at temperatures as low as 19.6°C. Ganser et al. (2015, entire) conducted a similar study using adult mussels representing four different species and found the higher the temperature the greater the oxygen consumption. Oxygen consumption is impacted by temperature thereby impacting metabolic activity that affects survival and growth. It has been suggested that mussel assemblages may already be living near their upper thermal limits (Ganser et al. 2013, p. 1168).

Additionally, the ability to deal with alteration in DO levels may differ between species and even populations. Chen et al. (2001, entire) examined how oxygen consumption is impacted by low dissolved oxygen and temperature in nine different species that inhabit different habitats. Chen et al. (2001, entire) concluded that oxygen consumption is related to the normal amount of hypoxia (low oxygen) a species experiences in the natural environment and is improved when temperatures are lower (16.5° C). As such, we concluded that because no research has been completed for the thermal sensitivity or DO limits of sheepnose or closely related relatives, it would be difficult to quantify temperature and dissolved oxygen in a meaningful way to incorporate in the resiliency analysis of populations.

Table D.1. Indicator descriptions for the four primary contaminant risk metrics[1] and the six secondary risk metrics[2] used to evaluate the overall contaminant risk to sheepnose populations. ([3] See EPA Aquatic Life Ambient Water Quality Criteria for Ammonia - Freshwater 2013, Tables 5b and 6 for pH and temperature normalized criteria.)

Current Condition Indicator - Contaminants	**Ammonia[1]**	**Chloride[1]**	**Nitrate[1]**	**Copper[1]**
Description of Indicator	Temperature and pH normalized[3] ammonia concentration in surface water within HUC12s draining into extant rivers from 2000 - 2020.	Chloride concentration in surface water within HUC12s draining into extant rivers from 2000 - 2020.	Nitrate concentration in surface water within HUC12s draining into extant rivers from 2000 - 2020.	Copper concentration in surface water within HUC12s draining into extant rivers from 2000 - 2020.
High Risk (3 points)	Water quality concentration exceeds acute toxicity levels >2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels >2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels >2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels >2% of samples (2000 - 2020).
Moderate Risk (2 points)	Water quality concentration exceeds acute toxicity levels to mussels <2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels to mussels <2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels to mussels <2% of samples (2000 - 2020.	Water quality concentration exceeds acute toxicity levels to mussels <2% of samples (2000 - 2020).
Low Risk (1 point)	Water quality concentrations at levels below acute toxicity to mussels (2000 - 2020).[3]	Water quality concentrations at levels below acute toxicity to mussels (2000 - 2020).	Water quality concentrations at levels below acute toxicity to mussels (2000 - 2020).	Water quality concentrations at levels below acute toxicity to mussels (2000 - 2020).

Table D.1. (continued) Indicator descriptions for the four primary contaminant risk metrics[1] and the six secondary risk metrics[2] used to evaluate the overall contaminant risk to sheepnose populations.

Current Condition Indicator - Contaminants (cont.)	**Lead[2]**	**Potassium[2]**	**Sulfate[2]**
Description of Indicator	Hardness normalized lead concentrations in surface water within HUC12s draining into extant rivers from 2000 - 2020.	Potassium concentration in surface water within HUC12s draining into extant rivers from 2000 - 2020.	Sulfate concentration in surface water within HUC12s draining into extant rivers from 2000 - 2020.
High Risk (3 points)	Water quality concentration exceeds acute toxicity levels >2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels >2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels >2% of samples (2000 - 2020).
Moderate Risk (2 points)	Water quality concentration exceeds acute toxicity levels to mussels <2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels to mussels <2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels to mussels <2% of samples (2000 - 2020).
Low Risk (1 point)	Water quality concentrations at levels below acute toxicity to mussels (2000 - 2020).	Water quality concentrations at levels below acute toxicity to mussels (2000 - 2020).	Water quality concentrations at levels below acute toxicity to mussels (2000 - 2020).

Table D.1. (continued) Indicator descriptions for the four primary contaminant risk metrics[1] and the six secondary risk metrics[2] used to evaluate the overall contaminant risk to sheepnose populations.

Current Condition Indicator - Contaminants (cont.)	**Zinc[2]**	**Aluminum[2]**	**Cadmium[2]**
Description of Indicator	Hardness normalized zinc concentration in surface water within HUC12s draining into extant rivers from 2000 - 2020.	Aluminum concentration in surface water within HUC12s draining into extant rivers from 2000 - 2020.	Hardness normalized cadmium concentration in surface water within HUC12s draining into extant rivers from 2000 - 2020.
High Risk (3 points)	Water quality concentration exceeds acute toxicity levels >2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels >2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels >2% of samples (2000 - 2020).
Moderate Risk (2 points)	Water quality concentration exceeds acute toxicity levels to mussels <2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels to mussels <2% of samples (2000 - 2020).	Water quality concentration exceeds acute toxicity levels to mussels <2% of samples (2000 - 2020).
Low Risk (1 point)	Water quality concentrations at levels below acute toxicity to mussels (2000 - 2020).	Water quality concentration at levels below acute toxicity to mussels (2000 - 2020).	Water quality concentrations at levels below acute toxicity to mussels (2000 - 2020).

Table D.2. Rationale for water quality criteria used to compare with ambient water quality data. The Analyte column lists the contaminant we analyzed, the Acute Value column provides the acute value (water quality criteria) we compared with ambient water quality, the Basis column lists the mussel species used to derive the water quality criteria (if applicable), the Source column identifies the reference, and the Rationale provides our reasoning for choosing the specific acute value for each contaminant.

Analyte	Acute Value	Basis	Source	Rationale
Ammonia	Temperature and pH dependent	11 genera representing 16 species of freshwater mussels (including 4 federally listed species: *Epioblasma capsaeformis*, *Lampsilis rafinesqueana*, *Lampsilis higginsii*, and *Lampsilis abrupta*)	USEPA 2013	Mussels are the most sensitive taxa to ammonia. Sixteen species of mussels were used to derive the EPA criteria; since listed species are present in the dataset and mussels were among the most sensitive species used to derive the EPA acute value, we used the acute value (based on temperature and pH) for comparison to ambient water concentrations.
Aluminum	29,492 ug/L	*Lampsilis siliquoidea*	Wang et al. 2016; Wang et al. 2018 as cited in EPA 2018	Mussels are not among the most sensitive species (top 4). The EPA formula for hardness-dependent aluminum criteria were based on Daphnia, which we felt was overly conservative for mussels. As a result, we used lowest acute value for mussels (*Lampsilis siliquodea)* listed in EPA 2018.
Cadmium	35.73 ug/L	*Lampsilis siliquoidea*	Wang et al. 2010 as cited in USEPA 2016	Mussels are not among the most sensitive species (top 4). The EPA formula for hardness-dependent cadmium criteria were based on fish (trout), which we felt was overly conservative for mussels. As a result, we used lowest acute value for mussels (*Lampsilis siliquoidea*) listed in USEPA 2016.
Chloride	244 mg/L	9 genera representing 12 species of freshwater mussels (including 1 federally listed species: *Epioblasma torulosa rangiana*)	Gillis 2011	Mussels are sensitive to chloride and as a result, we used the lowest acute value for freshwater mussels from Gillis 2011.

Table D.2. (continued) Rationale for water quality criteria used to compare with ambient water quality data. The Analyte column lists the contaminant we analyzed, the Acute Value column provides the acute value (that is water quality criteria) we compared with ambient water quality, the Basis column lists the mussel species used to derive the water quality criteria (if applicable), the Source column identifies the reference, and the Rationale provides our reasoning for choosing the specific acute value for each contaminant.

Analyte	Acute Value	Basis	Source	Rationale
Copper	11.33 ug/L	2 genera representing 2 species of freshwater mussels (*Actinonaias pectorosa* and *Utterbackia imbecillis*)	EPA 2007	Mussels are not among the most sensitive species (top 4) upon which EPA water quality criteria are based, but are nonetheless sensitive to copper. Water chemistry data needed to use the Biotic Ligand Model to calculate site-specific thresholds for aquatic organisms was limited. Therefore, ambient copper concentrations were compared to the lowest genus mean acute value for mussel species in USEPA 2007 at standard biotic ligand model chemistry.
Lead	(EXP(0.9859 *(LnH)+0.4892))*CFc^D	*Lampsilis siliquoidea*	Michigan EGLE 2020	We used Michigan Department of Environment, Great Lakes, and Energy (EGLE) formula using average hardness across each HUC8.
Nitrate	41 mg/L	*Lampsilis siliquoidea*	Monson 2010	EPA and Michigan EGLE acute values were not available so we used the draft criteria from Minnesota Pollution Control Agency.
Potassium	31 mg/L	*Amblema plicata*	Wang et al. 2017	EPA and Michigan EGLE acute values were not available. We therefore used 31 mg/L, which was the lowest acute value of 5 species tested in Wang et al. 2017.
Sulfate	1,378 mg/L	4 genera representing 5 species of freshwater mussel (*Margaritifera falcata*, *Amblema plicata*, *Utterbackia imbecillis*, *Lampsilis siliquoidea*, and *Megalonaias nervosa*)	Wang et al. 2017	EPA acute values were not available, so we used acute values derived for freshwater mussels in Wang et al. 2017.
Zinc	(EXP(0.8473 *(LnH)+0.884))*0.978^D		Michigan EGLE 2020	EPA acute values for freshwater mussels were not available, so we used Michigan EGLE formula which accounts for hardness.

D.2 Landscape

To evaluate the effects of various land use activities and the resulting risk to each population, we assessed a suite of landscape metrics derived from the 2016 National Landcover Dataset (NLCD) (Jin et al. 2019, entire). The NLCD depicts land cover across the United States through an overlay of 30-meter by 30-meter grids (in other words raster cells). Each grid represents a classification of land cover. Specific metrics were selected to determine overall landscape risk: mean imperviousness and urban and agriculture cover within the HUC8, and percent vegetative and canopy cover remaining within a riparian buffer; (Table D.3). These categories and the criteria for risk scoring were derived from EPA's Health Watersheds Assessment and existing species status assessment for other freshwater mussel species (Josh Hundley, USFWS, pers. Comm. October 13, 2021). Vegetive cover refers to the area on the ground that is comprised of vegetation while canopy cover refers to the area of the landscape that is shaded by vegetation. To determine the current condition of our mussel population, we examined these four categories to analyze the impact sedimentation may have on the population performance (in other words growth, reproduction, and survival) of our species.

Vegetative and canopy cover (%) are considered as they have the potential to reduce erosion through the following ways: (1) provides cover from direct erosive precipitation; (2) improves the porosity and capacity of the soil so greater infiltration may occur; and (3) slows runoff allowing sediment to drop out (USEPA 1990, p. IV-1; Abari et al. 2017, p. 375). Thus, preserving vegetative and canopy cover as well as revegetating areas can serve as an indicator of how well a site is protected from erosion or can act as a means of erosion control. Beyond sediment removal and erosion control, riparian forest cover protects water quality and buffers extreme water temperature through moderation of shade (Broadmeadow and Nisbet 2004, p. 286).

Additionally, percent urban and agricultural land use can serve as indicators of the quantity of sediment that rivers and streams may experience. When developing urban settings, much of the disturbed soil becomes sediment in streams. This alteration of land from permeable to impervious land can result in increased flooding and washing of sediment and other contaminants into waterways (Guy 1970, p. E7). Additionally, the development of agricultural land may increase the sediment load in areas due to livestock grazing near the water's edge (increases impaction and erosion of soil) and may increase stream temperature and further increase sediment load due to the clearing of trees and other riparian vegetation to make room for more crops (decreases vegetative cover and allows for more runoff; Broadmeadow and Nisbet 2004, p. 286; Nolte et al. 2013, p. 296).

We used an additive scoring approach to determine the overall risk to a population posed by the landscape risk factor for these metrics. A population that is at overall low risk due to current landscape condition has a score of 5–7; a population that is at overall moderate risk due to landscape condition has a score of 8–10; and a population that is at an overall high risk due to landscape condition has a score of 11–15. These metric scores were then used to categorize the overall risk to the population posed by landscape factors (Table 4.4).

Urban imperviousness is available at the same 30m by 30m resolution as NLCD 2016 data with each raster cell representing the percent imperviousness at that location, ranging from 0% impervious to 100% impervious (meaning that no water would be absorbed on that surface; Yang et al. 2003, entire). We used ArcGIS Pro to calculate the average imperviousness value of all raster cells at the 8-digit HUC scale to calculate the average imperviousness of the landscape for each population.

We calculated the percent of vegetative cover within the riparian zone of extant river for each population by using the EPA’s Watershed Index Online Riparian Zone Mask as a mask to extract NLCD 2016 raster cells within the riparian zone (USEPA 2016). This dataset buffers aquatic features by approximately 100m to obtain a mask of the riparian zone. Land cover types we considered to be “vegetative” include: 41 – Deciduous Forest; 42 – Evergreen Forest; 43 – Mixed Forest; 52 – Shrub/Scrub; 71 – Grassland; 90 - Woody Wetlands; 95 – Emergent Herbaceous Wetlands. We calculated the total number of cells representing land (as opposed to water) as well as the number of cells representing vegetative cover to calculate the percent of all land cells that represent vegetative cover within the riparian zone of extant rivers for each population.

We calculated the amount of agricultural and developed land cover for populations by using NLCD 2016 and the Zonal Histogram tool to count the total number of raster cells within a HUC8 representing each land cover type (Jin et al. 2019, entire). We then tallied the total amount of raster cells representing land, agricultural land cover (81 – Pasture/Hay; 82 – Cultivated Crops), and developed land cover (21 – Developed, Open Space; 22 – Developed, Low Intensity; 23 – Developed, Medium Intensity; 24 – Developed High Intensity) to calculate the percent cover of each.

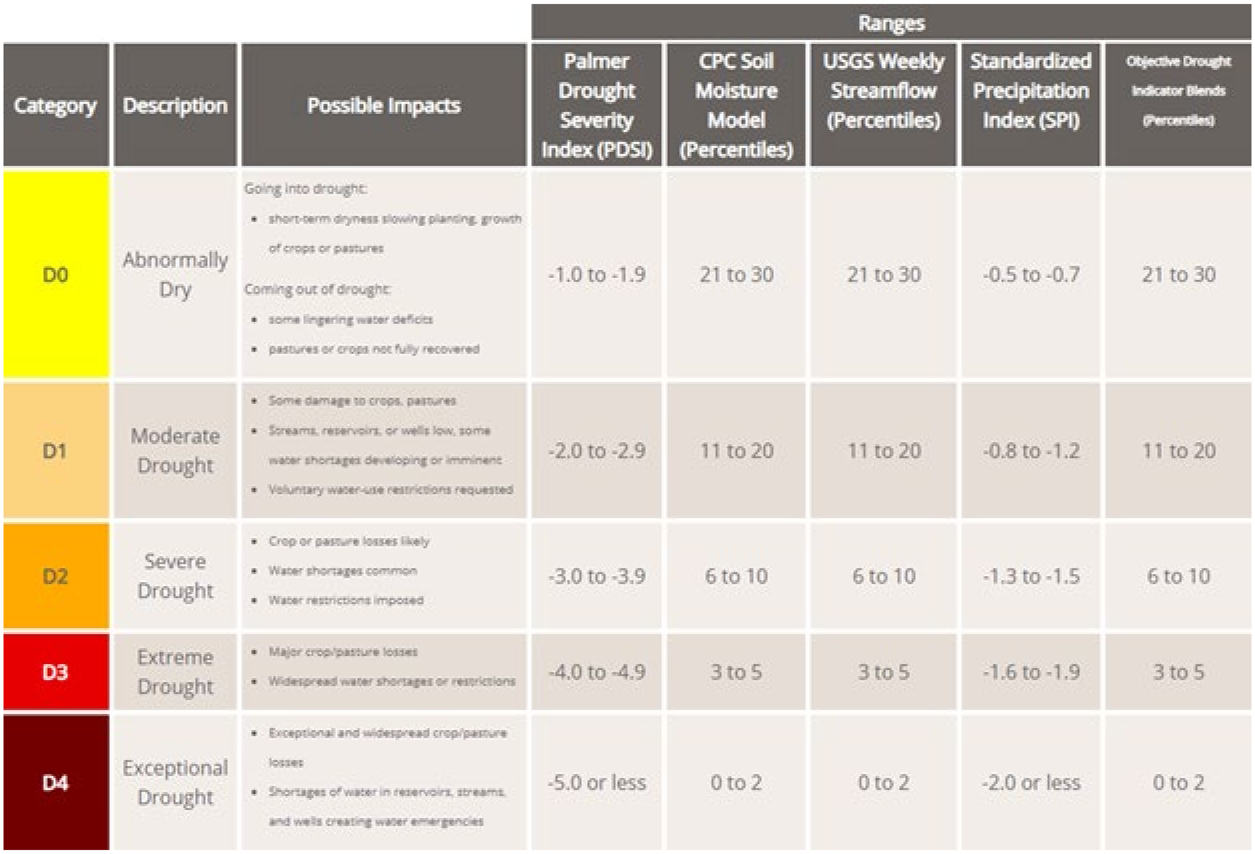
To measure the amount of canopy cover within the riparian buffer of extant rivers, we downloaded the NLCD 2016 USFS Tree Canopy Cover raster dataset (Coulston 2012, entire). The value of each raster cell in the Tree Canopy Cover dataset represents the percent canopy cover at that location. We then used the Zonal Statistics as Table tool to calculate the average value of all Tree Canopy Cover raster cells to find the average tree canopy in the riparian buffer using the EPA’s Watershed Index Online Riparian Zone Mask as the zone representing the riparian buffer (USEPA 2016).

Table D.3. Indicator descriptions for the five landscape risk metrics used to evaluate the overall landscape risk to sheepnose populations.

Current Condition Indicator - Landscape	**% Imperviousness, Mean in WS (2016)**	**% Vegetative Cover remaining in 108m riparian buffer**	**% Urban in WS (2016)**	**% Ag in WS (2016)**	**% Canopy Cover remaining in 108m riparian buffer**
Description of Indicator	Percent of the HUC8 with developed impervious cover. Calculated as the mean value of percent in the HUC8.	Calculated as the forest area in the riparian zone divided by the total area of the riparian zone.	Percent of the HUC8 classified as urban cover. Calculated as urban area divided by HUC8 area.	Percent of the HUC8 classified as agriculture. Calculated as agriculture area in the HUC8 divided by HUC8 area.	The mean value of NLCD canopy cover in the 108m riparian buffer of occupied rivers.
High Risk (3 points)	>15	<50	>10	>40	<50
Moderate Risk (2 points)	10–15	50–75	5–10	25–40	70–50
Low Risk (1 point)	<10	>75	<5	<25	>70

D.3 Hydrological Regime

To assess the condition of the hydrologic regime, we used the U.S. Drought Monitoring Data (USDM) to evaluate drought risk. The USDM classifies drought into five categories: D0, D1, D2, D3, and D4 (Figure D.1.). Per our assessment of risk to the sheepnose (see 3.1.4), categories with USGS weekly streamflow below 5% of the median of "daily" percentiles for 7-day average flow of the weekly median stream flow were included in our analysis (in other words Extreme Drought [D3] and Exceptional Drought [D4]). To evaluate the frequency of drought that each population experienced, we examined weekly percent drought data from 4 January 2000 to 4 January 2021 (Accessed on May 28, 2021). The specific metrics for high, moderate, and low risk are outlined in Table D.4.



Category	Description	Possible Impacts	Ranges Palmer Drought Severity Index (PDSI)	CPC Soil Moisture Model (Percentiles)	USGS Weekly Streamflow (Percentiles)	Standardized Precipitation Index (SPI)	Objective Drought Indicator Blends (Percentiles)
D0	Abnormally Dry	Going into drought: • short-term dryness slowing planting, growth of crops or pastures Coming out of drought: • some lingering water deficits • pastures or crops not fully recovered	-1.0 to -1.9	21 to 30	21 to 30	-0.5 to -0.7	21 to 30
D1	Moderate Drought	• Some damage to crops, pastures • Streams, reservoirs, or wells low, some water shortages developing or imminent • Voluntary water-use restrictions requested	-2.0 to -2.9	11 to 20	11 to 20	-0.8 to -1.2	11 to 20
D2	Severe Drought	• Crop or pasture losses likely • Water shortages common • Water restrictions imposed	-3.0 to -3.9	6 to 10	6 to 10	-1.3 to -1.5	6 to 10
D3	Extreme Drought	• Major crop/pasture losses • Widespread water shortages or restrictions	-4.0 to -4.9	3 to 5	3 to 5	-1.6 to -1.9	3 to 5
D4	Exceptional Drought	• Exceptional and widespread crop/pasture losses • Shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less	0 to 2	0 to 2	-2.0 or less	0 to 2

Figure D.1. U.S. Drought Monitor severity classification system.

Table D.4. Indicator descriptions for the drought risk metric used to evaluate the overall hydrological regime risk to sheepnose populations.

Current Condition Indicator – Hydrological Regime	**Drought**
Description of Indicator	Consecutive weeks of extreme to exceptional drought (below 5% of the median of "daily" percentiles for the 7-day average flow) and multi-year droughts classified as extreme or exceptional.
High Risk	Flows <5th percentile for greater than 6 consecutive weeks annually; extreme and exceptional droughts occur for 3 or more consecutive years.
Moderate Risk	(1) Flows <5th percentile for greater than 4 consecutive weeks but less than 6 consecutive weeks annually; extreme and exceptional droughts occur less than 3 consecutive years. OR (2) Flows <5th percentile for greater than 6 consecutive weeks annually; extreme and exceptional droughts occur for less than 3 consecutive years.
Low Risk	Flows < 5th percentile for less than 4 consecutive weeks annually

D.4 Connectivity

We evaluated the number of dams and the density of unpaved road stream crossings to evaluate connectivity within each population (HUC8, Table D.5). The number of dams within a population was evaluated using the 2012 National Anthropogenic Barrier Dataset (Ostroff et al. 2013, entire). We then used ArcGIS Pro to count the number of dams within each population.

Unpaved road stream crossings impact ecosystems through degradation of water quality, changes in flow, and obstruction to host passage, physically limiting access to certain stretches of river or are degraded to a point that lack of habitat essentially causes a barrier. Density of unpaved stream crossings per kilometer of stream was evaluated using spatial datasets from state transportation agencies. Most states had comprehensive road data while others only contained state-maintained roads. We filtered each state's data to include only unpaved roads (as unpaved stream crossings were considered barriers to fish passage in status assessments for other freshwater mussel species) and merged the data to create a single unpaved road layer (USFWS 2020). Next, we filtered the NHD Flow Line shapefile to retain only features with Geographic Names Information System (GNIS) names and classified as streams and rivers, artificial paths, and canals and ditches (FTypes 460, 558, and 336, respectively). We calculated the total kilometers NHD features in each watershed. Then, we identified all crossings of unpaved roads and NHD features, summed the number of crossings in each watershed, and divided the number of crossings by the kilometers of named stream in the watershed to calculate the density of unpaved road crossings. For both connectivity metrics, we used values from status assessments of other freshwater mussel species to determine low, medium, and high risk (USFWS 2020).

To determine the overall risk posed by loss of connectivity for each population, we decided that if one of the two metrics was high risk and the other moderate risk, then the overall risk condition for the population would be high. If one was moderate risk and the other low risk, then the overall risk condition for the population would be moderate. If one metric was low and one metric high, then the overall risk condition would be moderate.

Table D.5. Indicator descriptions for the risk metrics used to evaluate the overall connectivity risk to sheepnose populations.

Current Condition Indicator - Connectivity	**Count Dams**	**Unpaved road stream crossing density**
Description of Indicator	The number of dams in the HUC8.	The number of unpaved road crossings in the HUC8 divided stream length (in km) in the HUC8.
High Risk	>30	> 0.40
Moderate Risk	10–30	0.21–0.40
Low Risk	<10	0–0.20

D.5 Invasive Species

We assessed the impact of invasive species with the use of Optimized Hotspot Analysis in ArcGIS Pro 2.8.0. We downloaded invasive species occurrence data (both incidental/opportunistic observations and conducted presence/absence surveys) for the zebra mussel, Asian clam, five species of invasive carps (silver, bighead, black, grass, common), rusty crayfish, spiny waterflea, brown trout, quagga mussel, and hydrilla for our occupied HUC12 watersheds from the USGS nonindigenous aquatic species database.

Instead of running individual hotspot analyses for each species, we chose to group and categorize species by their common impact to sheepnose where they occur (Table D.6). We prepared the downloaded data by first merging invasive species into categories (Table D.6), then aggregating the positive (the species is present) occurrence records by occupied HUC12 watersheds for each HUC8 occupied by freshwater mussel species. Afterwards, we tested each aggregated invasive species category for significant clustering using Spatial Autocorrelation (Table D.6).

Each invasive species category had a low, but positive Index, a high positive ZScore and a near or at 0 PValue, indicating that any hot and/or cold spots created by the analysis tests are statistically significant. The results of these optimized hotspot analyses will indicate higher than normal numbers of significant clustering via hot spots (confidence level/Gi Bin of 1 to 3) and lower than normal numbers of significant clustering via cold spots (-1 to -3). Confidence levels of 0 are insignificant (Table D.7). Risk levels were based on the presences of hotspots in the analysis (Table D.8, See Appendix B (Section B.7) for additional information).

Table D.6. Invasive species grouped and categorized by impacts on mussel species.

Category	Impact	Species
Direct competition	Competition pressure for resources; often can outcompete and displace	zebra mussel; quagga mussel; Asian clam; spiny waterflea
Reduction of reproductive potential	Displaces host species via competition and predation (including eggs)	invasive carps; brown trout; rusty crayfish
Disturbance to ecosystems and/or reduction of habitat quality	Feeding habits are known to alter habitat by increasing siltation, uprooting/displacing native vegetation/algae-grazing snails, altering benthic substrates, etc.	zebra mussel; quagga mussel; Asian clam; invasive carps; brown trout; rusty crayfish; hydrilla
Direct harm/predation	Includes smothering and predation	zebra mussel; invasive carps

Table D.7. Results of the Global Moran's I (Spatial Autocorrelation) for each invasive species category.

Category	Index	ZScore	PValue
Direct competition	0.127125	11.101837	0
Reduction of reproductive potential	0.100776	7.789087	0
Disturbance to ecosystems and/or reduction of habitat quality	0.124509	11.156017	0
Direct harm/predation	0.077981	5.874854	40

Table D.8. Indicator descriptions for the risk metric used to evaluate the overall invasive species risk to sheepnose populations.

Current Condition Indicator - Invasive Species	**Invasive Species**
Description of Indicator	Optimized Hotspot Analysis using invasive species occurrence data for occupied HUC and categorized by common impacts to mussel species.
High Risk	Hot spots were identified in HUC regardless of number or confidence levels
Moderate Risk	Invasive species incidences were identified to occur in HUC, though no hot spots were identified AND/OR cold spots were identified in HUC regardless of number or confidence levels
Low Risk	No invasive species incidences were identified to occur in HUC; there are no hot or cold spots identified

D.6 Catastrophic Events

To evaluate the risk posed by coal mining we analyzed whether coal mining activities were present within the HUC8. If there were no known coal mining activities within the HUC8, coal mining was considered a low catastrophic risk to that population and if there were known coal mining activities within the HUC8, the population was considered at high risk of a catastrophic event.

To evaluate the risk posed by oil and gas exploration and extraction we analyzed the presence of oil and gas wells present within a HUC8. If there were no known oil and gas exploration/ extraction activities within the HUC8, then oil and gas activities were considered a low catastrophic risk to that population; if there were known oil and gas activities within the HUC8, then the population was considered at high risk of a catastrophic event.

Similarly, to evaluate the risk posed by oil and gas pipelines, we analyzed the presence of pipeline stream crossings within each HUC8. If no pipeline crossings were present in the HUC, we considered that HUC8 at low risk for a catastrophic event due to pipeline spills; if there were crossings present, the population was considered at high risk.

D.7 Scoring

Table D.9. Overall risk factor scoring

Risk Factor 1	Risk Factor 2	Risk Factor 3	Risk Factor 4	Risk Factor 5	Total Score	Total Risk
1	1	1	1	1	5	Low
1	1	1	1	2	6	Low
1	1	1	2	2	7	Low
1	1	2	2	2	8	Moderate
1	2	2	2	2	9	Moderate
2	2	2	2	2	10	Moderate
2	2	2	2	3	11	High
2	2	2	3	3	12	High
2	2	3	3	3	13	High
2	3	3	3	3	14	High
3	3	3	3	3	15	High

APPENDIX E. CURRENT CONDITION

E.1 Upper Mississippi River Basin Representation Unit

Mississippi River mainstem

HUC8: Buffalo-Whitewater
State(s): Minnesota, Wisconsin
Year of Last Live or Fresh Dead Observation: 2009
Notes: All recent records have been limited in distribution to Pools 4 and 5. Two live sheepnose have been collected in recent years during Minnesota Department of Natural Resources statewide surveys, including the collection of one adult specimen in each 2007 and 2008 (B. Sietman, MN DNR, pers. comm. 2021a, 2021b; A. Scheunemann, MN DNR, pers. comm. 2020). Additional live records have been reported from 2005 (D. Heath, pers. comm. 2008) and 2009 (J. Weinzinger, pers. comm. 2020). A subsequent survey was completed in Pool 5 in 2019, limited to the West Newton Chute. Although a rich mussel assemblage was identified, sheepnose was not collected (B. Sietman, MN DNR, pers. comm. 2021b). Larger-scale survey efforts are not known to have occurred in within the Buffalo-Whitewater HUC8 since the mid-2000s, potentially contributing to the lack of more recent records (B. Sietman, pers. comm. 2021b). Recent evidence of recruitment has not been reported.

HUC8: La Crosse-Pine
State(s): Minnesota, Wisconsin
Year of Last Live or Fresh Dead Observation: 2001
Notes: This population is represented by the collection of a single juvenile specimen (1.3 inches (33 mm)) within Pool 7 in 2001 (MN DNR 2002, p. 16; D. Kelner, pers. comm. 2021). This collection represents the only record of recent recruitment within the Mississippi River upstream of Pool 15.

HUC8: Grant-Little Maquoketa
State(s): Iowa, Wisconsin
Year of Last Live or Fresh Dead Observation: 2012
Notes: Recent records are limited to the collection of four adult individuals between river miles 593-594 within Pool 11 in 2012 (USACE 2012, p. 22, p. 30). Sheepnose comprised an overall relative abundance of 0.1 percent (USACE 2012, p. 26). Subsequent surveys have been conducted within the vicinity of the 2012 record in 2016 (Ecological Specialists, Inc. 2017a, p. 11), 2017 (USACE 2017, p. 8), 2019 (ESII 2019a, p. 27) and 2020 (USACE 2021, p.7-8), with no findings of live or fresh dead specimens.

HUC8: Copperas-Duck

State(s): Iowa, Illinois

Year of Last Live or Fresh Dead Observation: 2020

Notes: Collectively, the population occupies a reach of more than 30 miles; however, recent records within individual pools are rare and isolated, with the exception of Pool 15. Despite more recent searches, live records within Pool 14 are limited to the collection of one fresh dead individual in 2005 by Ecological Specialists, Inc. (J. Kath, pers. comm. 2019) and the 2006 collection of a single live specimen (R. Vinsel, pers. comm. 2020) within the Cordova Essential Habitat Area, designated for Higgins eye pearlymussel (*Lampsilis Higginsii*). Sheepnose have occasionally been observed throughout Pool 15, with large numbers recently collected during surveys associated with the reconstruction of the Interstate 74 bridge. A total of 107 sheepnose individuals were relocated from the bridge construction area in 2016 to two upstream sites within Pool 15 (ESI 2017b, p. 10-12). Specimens collected included one approximately four-year-old juvenile, documenting the first evidence of recruitment in the Mississippi River since an approximately three-year-old individual was collected in Pool 7 in 2001 (ESI 2017b, p. 10, 42; MN DNR 2002, p. 16). Other relocated specimens included one approximately six-year-old, with the remaining ranging from nine to ≥ 20 years of age (ESI 2017b. p. 42, 47). Sheepnose comprised a relative abundance ranging from 0.06 percent (Iowa piers) to 0.076 percent (Illinois piers) (ESI 2017b, p. 40, 45). Post relocation monitoring was completed in 2017, 2018 and 2020, with additional monitoring events scheduled for 2023 and 2026. Re-capture rates of sheepnose varied between sites, with 47.2 to 93.4 percent recaptured in 2017 (ESI 2018, p. 22). The goal of the 2018 monitoring event was to re-capture 10 percent of the relocated individuals; 5.7 and 14.8 percent were recaptured from each of the two sites (ESI 2019, p. 17). Observed mortality has been limited to the collection of one dead individual in 2018 (ESI 2019, p. 17). Recent collection records in Pools 16 and 17 are limited. Two specimens were collected in 2003 by Helms and Associates in Pool 16, downstream of Buffalo, Iowa (R. Vinsel, pers. comm. 2020), and one live specimen was collected within Andalusia Slough by Ecological Specialists, Inc. in 2015 (J. Kath, pers. comm. 2019). Additionally, monitoring sampling of the Buffalo Slough EHA located between RMs 470-471 has occurred in 2004, 2014 and 2018. At least one live specimen was collected in 2004 through qualitative sampling. One additional live specimen was collected through quantitative sampling in 2014, comprising 0.5% of the catch (EcoAnalysts, Inc. 2019a, p. 202); it was not reported whether additional live specimens were encountered during qualitative sampling. One specimen was collected within Pool 17 in 2010, near Muscatine, Iowa (R. Vinsel, pers. comm. 2020).

Chippewa and Flambeau Rivers

HUC8: Upper Chippewa

State(s): Wisconsin

Year of Last Live or Fresh Dead Observation: 2017

Notes: Sheepnose is known to be extant through much of the Chippewa River. The Upper Chippewa is one of two sheepnose populations within the Chippewa River and extends upstream from Holcombe, Wisconsin. The Upper Chippewa population is thought to span more than 30 miles; however, recruitment has not been documented for more than 20 years. Relatively large numbers of individuals have historically been collected from this population, including Balding's collection of 37 individuals from one site in 1997, 19 live individuals collected from approximately two sites in 1995, 13 live individuals collected across approximately four sites in 1993, and 40 live individuals collected across approximately 7 sites in 1992 (L. Kitchell, pers. comm. 2020). Lower numbers of sheepnose have been collected on several occasions within the past 20 years, most recently documented within the Upper Chippewa in 2017 with the collection of nine individuals (WI DNR unpublished database). Collectively, the populations within the Chippewa River are considered some of the best range-wide (77 FR No. 49, p. 14925).

HUC8: Lower Chippewa
State(s): Wisconsin
Year of Last Live or Fresh Dead Observation: 2020
Notes: Sheepnose is known to be extant throughout much of the Chippewa River. The Lower Chippewa is one of two sheepnose populations within the Chippewa River, extending from Holcombe, Wisconsin, downstream to the Chippewa River's confluence with the Mississippi River. The population is known from a 30+ mile reach; however, recent records are primarily concentrated from Eau Claire, Wisconsin to the Mississippi River confluence. Sheepnose was most recently documented within the Lower Chippewa in 2020 (WI DNR unpublished database). Additional recent records have included the collection of 12 adults by J. Weinzinger in 2016; 20 and 40 adults by N. Eckert in 2015 and 2014, respectively; 20, 18 and 14 adults by M. Bradley in 2018, 2019 and 2020 respectively; one individual collected by Beaver Creek Reserve Staff in 2012; and the collection of 23 healthy females for host fish trials in 2008 by M. Davis. Recruitment has occasionally been documented within this population, including the collection individuals with lengths as small as 41 mm in 2016 (Eckert et al. 2017, p. 3), with additional juveniles ranging in age from five to seven collected in 2002 by D. Heath (L. Kitchell, pers. comm. 2020). Adult gravid females were collected by the MN DNR in 2008 (L. Kitchell, pers. comm. 2020). Collectively, the populations within the Chippewa River are considered some of the best range-wide (77 FR No. 49, p. 14925).

HUC8: Flambeau
State(s): Wisconsin
Year of Last Live or Fresh Dead Observation: 2017
Notes: The Flambeau River is a tributary to the Chippewa River. This population is primarily concentrated below the lowest dam, near its confluence with the Chippewa River (lower 8 miles (13 km)) (77 FR No. 49, p. 14925). The Upper Chippewa, and

potentially Lower Chippewa, are likely serving as source populations for the Flambeau (77 FR No. 49, p. 14925). Sheepnose was most recently collected from the Flambeau in 2017 (L. Kitchell, pers. comm. 2020; WI DNR unpublished database). Indication of recruitment was last documented in 1994, with "relatively young" individuals collected among 15 specimens (D. Kelner, pers. comm. 2002, as cited in Butler 2002, p. 10).

Wisconsin River

HUC8: Castle Rock
State(s): Wisconsin
Year of Last Live or Fresh Dead Observation: 2017
Notes: Sheepnose is declining in the Wisconsin River. As described in 77 FR No. 49 (p. 14925), historical records for sheepnose are available throughout the lower 335 miles (539 km) of the 420-mile (676-km) Wisconsin River (D. Heath, pers. comm. 2010). Currently, sheepnose is primarily confined to RM 133.7 downstream (a reduction of over 201 river miles (232 km)). Castle Rock is one of two populations within the Wisconsin River, and extends upstream from Portage, Wisconsin. Sheepnose was most recently collected from the Castle Rock population in 2017 (L. Kitchell, pers. comm. 2020). This population has been described to potentially occupy a reach of 10-30 miles (L. Kitchell, pers. comm. 2020); however, recent evidence of recruitment has not been documented from either Wisconsin River population. The Wisconsin Department of Natural Resources plans to revisit this population in 2022.

HUC8: Lower Wisconsin
State(s): Wisconsin
Year of Last Live or Fresh Dead Observation: 2016
Notes: Sheepnose mussel is declining in the Wisconsin River. As described in 77 FR No. 49 (p. 14925), historical records for sheepnose area available throughout the lower 335 miles (539 km) of the 420-mile (676-km) Wisconsin River (D. Heath, pers. comm. 2010). Currently, sheepnose is primarily confined to RM 133.7 downstream (a reduction of over 201 river miles (232 km)). The Lower Wisconsin is one of two populations in the Wisconsin River, and extends downstream from Portage, Wisconsin to its confluence with the Mississippi River. In July 2002, researchers found 20 live specimens in a dense mussel bed near Port Andrew (B. Seitman, pers. comm. 2011). Sheepnose was most recently collected from the Lower Wisconsin population in 2016 (EcoAnalysts 2019a, p. 145). Monitoring of the Orion Higgins eye Essential Habitat Area has resulted in the quantitatve collection of one individual in 2002, six individuals in 2012, and two individuals in 2016. An additional one or more live specimens have been collected through qualitative sampling at the Orion EHA over the past two decades; however, a number was not reported (EcoAnalysts 2019a, p. 145). This population is thought to span

a reach of more than 30 miles; however, recent records have been documented within a reach between 10 to 30 miles. Recent evidence of recruitment has not been documented from either Wisconsin River population (L. Kitchell, pers. comm. 2020). The Wisconsin Department of Natural Resources plans to revisit this population in 2022.

Rock River

HUC8: Lower Rock
State(s): Illinois
Year of Last Live or Fresh Dead Observation: 2007
Notes: Recent records within the Rock River are limited to the collection of one individual in 2007, approximately two miles southwest of Como, Illinois (J. Tiemann, pers. comm. 2011; J. Kath, pers. comm. 2019). This is the only known collection of sheepnose from the Rock River within the past approximately 60 years (77 FR No. 49, p. 14925). Sampling was conducted in 2009; however, collections were limited to one relic shell (J. Kath, pers. comm. 2019). It is assumed this population may be approaching extirpation.

Kankakee River

HUC8: Kankakee
State(s): Illinois
Year of Last Live or Fresh Dead Observation: 2020
Notes: Historically, sheepnose was known from the lower two-thirds of the Kankakee River (Wilson and Clark 1914, p. 47; Lewis and Brice 1980, p. 4), but has since become extirpated from the channelized portion (Butler 2002, p. 11). The Kankakee population is now primarily restricted to Will County, downstream of Kankakee, Illinois (J. Tiemann, pers. comm. 2020); however, records within the past two decades have documented limited occurrences extending from just upstream of the Aroma Forest Preserve (RM 41.8), downstream to the Interstate 55 bridge crossing (RM 5.5) (R. Vinsel, pers. comm. 2020). Low numbers of sheepnose have been observed within the Kankakee River nearly annually over the past 20 years, with a few collections containing larger numbers of individuals. However, discussions are on-going between the Service and IL DNR regarding a potential population and recruitment assessment within the Kankakee (S. Cirton, pers. comm. 2021). As described in 77 FR No. 49 (p. 14925-14926), "A mussel relocation effort for a pipeline crossing in the Kankakee River in July 2002 found 11 sheepnose individuals, representing 0.32 percent of the total mussels relocated (Helms 2004, p. D-1). Subsequent monitoring of the site in 2004 and 2007 located four new individuals. One individual collected in 2004 measured 1.6 inches (40 mm) and was estimated to be a juvenile of 3 years of age" (Helms 2004, p. 10). However, a survey within this area in 2011 did not encounter sheepnose (K. Roe, pers. comm. 2011).

Additional work associated with the pipeline was coordinated in 2016, including the relocation of eight sheepnose in 2017 to an area immediately downstream of the Interstate 55 bridge (S. Cirton, pers. comm. 2021). All eight sheepnose were tagged, including one juvenile measuring 56.10 mm in length (EnviroScience 2020, Tables 4 and 5). Post-relocation monitoring is scheduled to occur at every-other year intervals over a 10-year timeframe (EnviroScience 2020, p. 1). The first year of non-intrusive monitoring was completed in 2019, resulting in re-detection of five of the eight sheepnose originally tagged, including the juvenile; however, specimen conditions were not confirmed (EnviroScience 2020, Table 5).

A 2018 survey effort associated with the construction of a public water intake pipeline resulted in the collection of 10 sheepnose individuals, comprising a relative frequency of 0.2% (EnviroScience 2018, p. 8); a relocation effort is scheduled for 2021 (B. Metzke, pers. comm. 2021). Sheepnose was most recently collected from the Kankakee in 2020, including the collection of 14 individuals within the footprint of a pipeline project alignment (Arcadis 2020, p. 7-8) adjacent to the public water intake pipeline. Shell lengths ranged from 59 to 98 mm (Arcadis 2020, Appendix D), indicating the presence of multiple age classes. A relocation associated with this project is anticipated (S. Cirton, pers. comm. 2021). Fish studies conducted as part of the 2019 and 2020 survey efforts identified several laboratory-identified sheepnose host fish species, including bluntnose minnow, common shiner, emerald shiner, bullhead minnow, mimic shiner, and spotfin shiner (EnviroScience 2018, p. 14; EnviroScience 2020, Table 1).

Meramec and Bourbeuse Rivers

HUC8: Meramec
State(s): Missouri
Year of Last Live or Fresh Dead Observation: 2019
Notes: Within the Meramec River, sheepnose is known from a reach spanning portions of Jefferson and Franklin Counties, Missouri (A. Roberts and S. McMurray, pers. comm. 2019); however, collections within the past two decades have been limited to an approximately 60-mile reach. In 2002, a site associated with a railroad crossing in St. Louis County at river mile (RM) 28 yielded 13 live specimens over three days of sampling, including at least one gravid female (A. Roberts, pers. comm. 2021; S. McMurray, pers. comm 2020). Larger numbers of individuals were subsequently observed in 2003 with 16 live individuals collected near Castlewood State Park (RM 27) (S. McMurray, pers. comm 2020) and 2008 with 20 live individuals collected near the Pacific Palisades Conservation Area (RM 49) (S. McMurray, pers. comm 2020). Additional lower numbers of individuals have been observed from the population nearly annually since. The Meramec was last surveyed in 2019, resulting in the collection of

three individuals, including one juvenile (A. Roberts and S. McMurray, pers. comm. 2019; A. Roberts, pers. comm. 2021). The Meramec population is considered stable and represents one of the best populations range-wide (Butler 2002, p. 11; 77 FR No. 49, p. 14926; A. Roberts and S. McMurray, pers. comm. 2019). Although this population is considered stable and recruiting, its distribution has shrunk by half over the past 30+ years (Butler 2002, p. 11; 77 FR No. 49, p. 14926).

HUC8: Bourbeuse
State(s): Missouri
Year of Last Live or Fresh Dead Observation: 2018
Notes: Sheepnose was most recently documented within the Bourbeuse River in 2018 and is thought to occupy an approximately 90-mile reach spanning upstream from just above the Meramec River confluence (A. Roberts and S. McMurray, pers. comm. 2019; 77 FR No. 49, p. 14926; Buchanan 1980, p. 34). Although low numbers of individuals have consistently been collected over time, a survey across multiple sites in 1980 and a re-survey in 1997 indicated a decrease in range of 18 river miles (29 km) (Buchanan 1980, p. 34; Roberts and Bruenderman 2000, p. 39; 77 FR No. 49, p. 14926). Further, recent records of live and fresh dead specimens from 2000-present have been concentrated within the lower approximately 57 miles of the river. Evidence of recruitment was most recently documented in 2006, with the collection of one approximately five-year old individual (S. McMurray, pers. comm 2020). The current status of the Bourbeuse population is considered unknown (A. Roberts and S. McMurray, pers. comm. 2019). The Bourbeuse and Meramec represent a population cluster (77 FR No. 49, p. 14926).

E.2 Ohio River Basin Representation Unit

Ohio River mainstem

HUC8: Lower Ohio
State(s): Illinois, Kentucky
Year of Last Live or Fresh Dead Observation: 2015
Notes: Recent collections have been limited in distribution from the Olmstedt Lock and Dam (RM 964.5), upstream to Brookport, Illinois (RM 937), with the exception of one live individual collected below the dam in 2005 (RM 698) (A. Ford, pers. comm. 2019a). Low numbers of specimens have occasionally been observed upstream of the Olmsted dam during recent years, with the most recent being the collection of one live specimen by T. Slack, et al. in 2015 (J. Kath, pers. comm. 2019). Evidence of recruitment has not been documented in recent years.

HUC8: Lower Ohio-Little Pigeon
State(s): Indiana, Kentucky
Year of Last Live or Fresh Dead Observation: 2018
Notes: In recent years, the species has been collected throughout the Lower Ohio-Little Pigeon, with the exception of the upstream-most reach beyond Cannelton, Indiana (RM 725). Sheepnose was most recently collected by Lewis Environmental Consulting, LLC in 2018, and the population is considered to be increasing (M. Reed, pers. comm. 2019; L. Pruitt, pers. comm. 2019; B. Fisher, pers. comm. 2019). Although juvenile specimens have not recently been collected from the Lower Ohio-Little Pigeon, indications of recruitment have been observed through the collection of gravid females in 2017 (LEC 2017, p. 8) and 2018 (LEC 2018, p. 8). The mussel community ranges from 13 to 24 species (M. Reed, pers. comm. 2019; L. Pruitt, pers. comm. 2019).

HUC8: Silver-Little Kentucky
State(s): Indiana, Kentucky
Year of Last Live or Fresh Dead Observation: 2019
Notes: In recent years, the species distribution has been limited to the collection of three individuals from an approximately six-mile long reach (RM 549-555) during a mussel survey and delineation of the Brooksburg, Indiana mussel beds within the McAlpine Pool in 2019 (LEC 2019, p. 23), in addition to the collection of one individual in 2007 at the head of Eighteen-mile Island, just downstream of Westport, Kentucky (RM 581.6) (A. Ford, pers. comm. 2019a). Recent evidence of recruitment has not been documented from this reach.

HUC8: Ohio Brush-Whiteoak
State(s): Kentucky, Ohio
Year of Last Live or Fresh Dead Observation: 2020
Notes: Recent collections have been concentrated to the downstream approximately 25 river miles of the Ohio Brush-Whiteoak, below the Meldahl Lock and Dam. A large-scale qualitative assessment was conducted in 2014 in response to a diesel fuel discharge from the Beckford Station (RM 452.6) within the Markland Pool (ESII 2015, p. 1). This assessment occurred between approximate RM 452.6 to 463.4 and resulted in the collection of one specimen from an upstream reference site (p. 11) and 48 specimens downstream from the spill, representing approximately 0.3 percent of the total catch (p. 19) and including one juvenile estimated to be four years of age (p. 29). Evidence of fresh dead individuals was not observed (ESII 2015, p. 21). This study further noted the presence of sauger (potential host fish, see Section 2.4.4) within the study area (ESII 2015, p. 33). This effort was followed by a 2016 quantitative assessment across 10 percent of the original survey area, focusing on the high-quality habitat areas (ESII

2017a, p.5). This assessment resulted in the collection of one live sheepnose from the reference site comprising 0.8 percent of the total catch (ESII 2017a, p. 18), and 10 live specimens from areas downstream of the 2014 spill representing approximately 0.3 percent of the total catch (p. 13). Collectively, these efforts identified a healthy and diverse mussel resource within the Ohio Brush-Whiteoak, likely supporting several thousand sheepnose individuals (ESII 2017a, p. 25). There was no evidence of significant mortality related to the 2014 spill event identified during either of the 2014 or 2016 efforts (ESII 2017a, p. 34). More recent observations have included the collection of 5 adult individuals in 2017 (ESII 2017b, p. 6-7) and 25 individuals in 2020 (Stantec 2020, p. 9,16), including at least one juvenile with a length of less than 40 mm (p. 18). A small number of individuals were collected in 2016 and 2017 and transferred for propagation.

HUC8: Little Scioto-Tygarts
State(s): Kentucky, Ohio
Year of Last Live or Fresh Dead Observation: 2019
Notes: Recent sheepnose collections are limited to a reach below the Greenup Lock and Dam, between RM 342 and 348.5. One individual was collected in each 2012 (R. Vinsel, pers. comm. 2020) and 2019 (A. Ford, pers. comm. 2019a) between RM 342-343, and two additional live specimens were collected near RM 348.5 in 2002 (J. Navarro, pers. comm. 2021). Recent evidence of recruitment is not known from Little Scioto-Tygarts.

HUC8: Raccoon-Symmes
State(s): Ohio, West Virginia
Year of Last Live or Fresh Dead Observation: 2020
Notes: Recent collections have been broadly distributed throughout the Raccoon-Symmes, downstream of the R.C. Byrd dam (RM 279); recent records have not been identified upstream of the R.C. Byrd dam. WV DNR and FWS established a 60 by 80-meter, three-random-start long-term monitoring site at RM 284 (K. Eliason, pers. comm. 2021). Mussel densities were estimated at 8.2 mussels per square meter; however, no sheepnose were observed during the monitoring. Transect surveys (100 x 1-meter) conducted in 2013 and 2016 found 23 species, including a total of three sheepnose. Sheepnose are found in low numbers throughout the Raccoon-Symmes, with less than 20 individuals collected in recent efforts. The species has most recently been identified through multiple efforts in 2019 and 2020, with research work reporting a total of nine sheepnose individuals in 2020 (A. Boyer, pers. comm. 2020; J. Miller, Marshall University 2020, as provided through K. Eliason, pers. comm. 2021). Although recent recruitment has not been documented, it is presumed, given the population size (WV DNR partners 2016, pers. comm.).

HUC8: Upper Ohio-Shade
State(s): Ohio, West Virginia
Year of Last Live or Fresh Dead Observation: 2019
Notes: Recent records are primarily limited in distribution to the upper Belleville Pool (RM 172-178), with the exception of three individuals collected downstream, near the Jackson-Wood County line in 2000 (RM 206.4) (R. Vinsel, pers. comm. 2020). The downstream-most extent within the Belleville Pool is currently considered RM 178; however, the occupied extent could be expanding downstream following a mussel kill in 1999, resulting from a purported release from a ferro-alloy manufacturing facility (J. Clayton, pers. comm. 2020; USFWS et al. 2007, p. 1). Sheepnose was most recently collected from the Belleville Pool in 2019, represented by one approximately 8-year-old specimen (EcoAnalysts 2019b, p. 4). Although recent recruitment has not been documented, it is presumed, given the population size (WV DNR partners 2016, pers. comm.). In recent years, survey efforts have resulted in the collection of up to 35 freshwater mussel species (WV DNR partners 2016, pers. comm.).

HUC8: Little Muskingum-Middle Island
State(s): Ohio, West Virginia
Year of Last Live or Fresh Dead Observation: 2020
Notes: Recent records are limited to below the Willow Island dam (RM 162.3) downstream to approximate RM 167.6, with one to two individuals collected per survey effort. Sheepnose was most recently collected from the Little Muskingum-Middle Island population in 2020 by Lewis Environmental Consulting, including two adult specimens with estimated ages of 8 and 13 years old (C. Lawlis, pers. comm. 2020a, 2020b). Recent evidence of recruitment has not been documented.

Allegheny River

HUC8: Middle Allegheny-Tionesta
State(s): Pennsylvania
Year of Last Live or Fresh Dead Observation: 2014
Notes: As described in the Final Rule (p. 14926), "Historical populations of sheepnose were located in the Allegheny in the section of the river that are now Pools 5-8 (C. Urban, pers. comm. 2011). In their surveys conducted from 2005-07, Smith and Meyer (2008, p. 33), found no sheepnose in Pools 4-7. All of these populations have been extirpated leaving only the population in the middle Allegheny located above Pool 9 and below the Kinzua Dam (C. Urban, pers. comm. 2011). This remaining population has shown recent recruitment and is considered improving (R. Villella, pers. comm. 2008). Sampling efforts from 2006-08 at 63 sites over 78 miles (125 km) of river produced sheepnose at 18 sites. A total of 244 individuals of 7 different age classes were collected

(R. Villella, pers. comm. 2008) providing ample evidence of recent recruitment." More recently sheepnose was collected in 2010 from the vicinity of the Hunters Station during a collection and translocation effort for clubshell and northern riffleshell mussels (A. Boyer, pers. comm. 2021). Currently, the Allegheny sheepnose population is believed to be small and limited in distribution from approximately Oil City to Tionesta, PA (N. Welte, pers. comm. 2020). Updated information obtained since the Final Rule was published is limited to one occurrence record. At least one live or fresh dead specimen was collected at Hunters Station Bridge, Forest County, Pennsylvania in 2014; however, the number of individuals collected was not reported (M. McGregor, pers. comm. 2021).

Kanawha River

HUC8: Upper Kanawha

State(s): West Virginia

Year of Last Live or Fresh Dead Observation: 2017

Notes: The sheepnose population within the Kanawha River is limited to the unimpounded portion of the river, occupying a reach approximately five miles in length, extending downstream from Kanawha Falls (approximate RM 91-96). Sheepnose was most recently observed in 2019 (J. Clayton, pers.comm. 2019), with evidence of recent recruitment documented through the collection of individuals measuring 30.1, 50 and 58.6 mm in length in 2017 (K. Eliason, pers. comm. 2021). A 625-square meter area has been re-surveyed three times between 2005 to 2015 by the WV DNR, including tagging 19 individuals (WV DNR partners 2016); only one dead individual has been recovered. A supplementary survey of this site is scheduled for 2022, followed by a full survey in 2025 (K. Eliason, pers. comm. 2022).

Licking River

HUC8: Licking

State(s): Kentucky

Year of Last Live or Fresh Dead Observation: 2019

Notes: Historically, sheepnose occupied the lower half of the Licking River, extending downstream to its confluence with the Ohio River, potentially representing a population cluster with the Ohio River (77 FR No. 49, p. 14926). More recently the species has been known from a limited number of sites near the middle Licking River (M. McGregor, pers. comm. 2008). Records within the last two decades span a distance of more than 30 river miles, including portions of Nicholas, Bath, and Flemming Counties. Recent collections have been limited to no more than one live or fresh dead specimen encountered per survey effort, with the exception of three live individuals collected in 2006 near Johnson Ford Road (RM 152.6) (A. Ford, pers. comm. 2019a; M. McGregor, pers. comm. 2021). Recent evidence of recruitment has not been observed within the Licking River.

Green River

HUC8: Upper Green

State(s): Kentucky

Year of Last Live or Fresh Dead Observation: 2020

Notes: At the time the Final Rule was published, the population was thought to be distributed across an approximately 25-mile reach, extending from the vicinity of Mammoth Cave National Park, upstream into Hart County (77 FR No. 49, p. 14926). However, recent occurrence records indicate the population has since expanded to a distribution of more than 90 miles. The current occupied reach extends approximately three miles upstream from the Barren River confluence (RM 154), upstream into Hart County, near the Hart-Green County line (RM 246). This expansion may be further facilitated by recently completed dam-removal projects on the Green River, targeted to address a combination of public safety concerns, recreational benefits, and ecosystem benefits (Labashosky 2017, accessed July 8, 2020). A partnership, including the U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, The Nature Conservancy, Kentucky Department of Fish and Wildlife Resources, Mammoth Cave National Park, and Kentucky Waterways Alliance coordinated the removals of Lock and Dam 6, formally located in Mammoth Cave National Park, in 2017 (Chapman 2019, accessed June 25, 2020; Labashosky 2017, accessed July 8, 2020), followed by the removal of Lock and Dam 5, located near the Edmonson-Warren County line, in 2021. Although sheepnose has recently been documented both upstream and downstream of Lock and Dam 5, the presence of several age classes ranging from <5 to 25 years of age (C. Lewis, pers. comm. 2016) indicates this population will continue to increase and expand. Sheepnose has most recently been collected from the Upper Green in 2020 (M. McGregor, pers. comm. 2021). Additional collections in 2019 included observations of multiple age classes and the collection of an approximately four-year-old juvenile (A. Ford, pers. comm. 2019a).

Tippecanoe River

HUC8: Tippecanoe

State(s): Indiana

Year of Last Live or Fresh Dead Observation: 2020

Notes: At the time the Final Rule was published (2012), the sheepnose population within the Tippecanoe River was known from an approximately 45-mile reach (77 FR No. 49, p. 14927). The species is now known to occupy a reach of approximately 120-miles, with the exception of a roughly 35-mile stretch containing Lake Freeman. Occupied areas are divided into upstream and downstream sections, separated by the Lake Freeman Impoundment. Sheepnose has most recently been identified from the section upstream of the Lake Freeman impoundment in 2018 and 2020, including the collection of multiple juveniles and adults (B. Fisher, pers. comm. 2021; M. Reed, pers. comm. 2019 (B. Fisher, BEF18041, 18117, 18115, 18118, 18119)). Sheepnose hasn't been identified from the reach downstream of the Lake Freeman impoundment since one fresh dead specimen was collected in 2013 (B. Fisher, pers. comm. 2021; M. Reed, pers. comm. 2019 (B. Fisher, BEF13099)). Recent recruitment has not been documented downstream of the Lake Freeman impoundment.

Muskingum River

HUC8: Muskingum
State(s): Ohio
Year of Last Live or Fresh Dead Observation: 2011
Notes: This population is believed to be limited to a 10 to 20 mile reach extending upstream from the Ohio River confluence to the Beverly Dam; however, only one record for sheepnose within the Muskingum River has been reported in the last two decades. One approximately 16-20 year old individual was collected below the Devloa Dam (Lock and Dam 2,) in 2011 between RM 5 and 6 (ESI 2012, p. 23). Previously, six individuals were collected in 1992 (Watters and Dunn 1993-194, p. 253-254; 77 FR No. 49, p. 14927). Recruitment has not been documented in the Muskingum River since the mid-1980s (Watters and Dunn 1993-1994, p. 240; 77 FR No. 49, p. 14927).

Walhonding River

HUC8: Walhonding
State(s): Ohio
Year of Last Live or Fresh Dead Observation: 2020
Notes: The population within the Walhonding was identified as unknown at the time the Final Rule was published (77 FR, No. 49, p. 14027); however, a survey was since completed in 2019 associated with the proposed removal of the Six Mile Dam (RM 9), downstream of Warsaw, Ohio. This survey resulted in the collection of 31 live specimens above the dam and one live specimen below the dam (ESII 2019b, p. 4). Shell lengths ranged from 44.5 to 123.5 mm, providing evidence of multiple age classes and recent recruitment (ESII 2019b, Appendix C). Sheepnose were found to comprise a relative frequency of 1.13 above the dam and 0.23 below the dam (ESII 2019b, p. 9). Dam removal was completed in 2020. The removal included a phased draw-down and mussel rescue-relocation (Fleece 2021, presentation; Stantec 2021, p. 1). A total of 127 sheepnose were relocated to an upstream site, with specimens representing multiple age classes including juveniles (Fleece 2021, presentation; Stantec 2021, p. 9, 19). Additional monitoring was scheduled to be conducted in 2021. The former Six Mile Dam was under ownership of the State, and removal was conducted due to structural defects and dam

failure concerns through the Ohio Department of Natural Resources (Stantec 2021, p. 1). Sheepnose is currently known to occupy a roughly 8-mile reach extending downstream from Warsaw, Ohio (RM 11); however, this extent is likely to expand downstream as the river stabilizes following the 2020 removal of the Six Mile Dam.

E.3 Tennessee River Basin Representation Unit

Tennessee River mainstem

HUC8: Lower Tennessee
State(s): Kentucky
Year of Last Live or Fresh Dead Observation: 2020
Notes: Recent records indicate sheepnose continue to occupy the full extent of the Lower Tennessee and were last observed in 2020 (M. McGregor, pers. comm. 2021). A 2017 survey included the collection of 10 adult specimens ranging in age from 8 to 13 years (assumed live) (A. Ford, pers. comm. 2019a). Although recent records of recruitment have not been identified, C. Lewis collected a “young” individual below the Kentucky Dam during monitoring surveys in 2005 (D. Hubbs, pers. comm. 2005) and evidence of gravid females was observed in 2019 (M. McGregor, pers. comm. 2021).

HUC8: Lower Tennessee-Beech
State(s): Tennessee
Year of Last Live or Fresh Dead Observation: 2017
Notes: In surveys conducted between 2011 and 2012, Tennessee Wildlife Resource Agency (TWRA) collected four specimens from two reaches: Swallow Island Bluff (RMs 170-170.3) and Wolf Island (RM 192) (D. Hubbs, undated report, p. 5-6.). This search resulted in a catch-per-unit effort of 0.16 and 0.06 individuals per hour, respectively, and estimated ages ranging from 8 to 16 (72 to 97 mm total length) (D. Hubbs, undated report, p. 5). More recently, one adult individual (assumed live), estimated to be nine years of age, was collected in 2017 near RM 191 (A. Ford, pers. comm. 2019a). Although recent occurrence records including recruitment have not been identified, D. Hubbs (pers. comm. 2005) reported the collection of sub-adult specimens below the Pickwick Dam during monitoring surveys, in addition to the collection of a specimen less than 10 years of age near RM 170 in 2012 by TWRA (D. Hubbs, pers. comm. 2017).

HUC8: Pickwick Lake
State(s): Alabama
Year of Last Live or Fresh Dead Observation: 2018
Notes: Sheepnose distribution within Pickwick Lake is thought to be restricted to Wilson Dam tailwaters, from the dam (TRM 259.3) to approximately 2.5 miles downstream of Sevenmile Island (RM 245.5) (A. Ford, pers. comm. 2021). Annual quantitative

monitoring was conducted below the Wilson Dam between 2008 through 2017 to monitor the mussel community response to adjustments in the water release regime at the dam (A. Ford, pers. comm. 2021). A total of 27 species were collected during the monitoring period, including the endangered *Pleurobema plenum* and *Lampsilis abrupta*; however, no sheepnose were collected. Low numbers of sheepnose were occasionally collected between 2001 to 2008 (J. Garner, unpublished records (A. Ford, pers. comm. 2021.)). More recently, searches for *Plethobasus cicatricosus* between 2017-2018 resulted in the collection four sheepnose individuals between RMs 246 and 259 (Garner 2018, p. 2). Two additional *Plethobasus spp.* specimens were collected and swabbed for *cicatricosus/cyphyus* genetic confirmation. All *Plethosbasus spp.* were relocated to approximate RM 249 for propagation stock (Garner 2018, p. 5; J. Garner, pers. comm. 2021). Recent evidence of recruitment within Pickwick Lake has been limited to the collection of one approximately 5-year-old individual in 2005 by J. Garner (A. Ford, pers. comm. 2016). Additionally, J. Garner observed an adult specimen discharging a conglutinate while handling in 2003 (A. Ford, pers. comm. 2016).

HUC8: Wheeler Lake
State(s): Alabama
Year of Last Live or Fresh Dead Observation: 2004
Notes: Occurrence records within the past two decades (2000-2020) are limited to the collection of thirteen sheepnose individuals from areas surrounding the U.S. 231 bridge piers (approximate RM 333.4) in 2004. These specimens were among 65,840 mussels relocated from areas surrounding the bridge piers, along with four additional federally endangered mussel species (A. Ford, pers. comm. 2019b). Sheepnose were relocate slightly upstream near the head of Hobb's Island. Recent evidence of recruitment has not been documented within Wheeler Lake.

Holston River

HUC8: Holston
State(s): Tennessee
Year of Last Live or Fresh Dead Observation: 2007
Notes: The sheepnose population is currently thought to be restricted to the Cherokee tailwaters (R. Butler, pers. comm. 2005). The Tennessee Valley Authority conducted a mussel survey between Nance Ferry and Monday Island (RM 14.6), Jefferson and Knox Counties, Tennessee in 2002 (77 FR No. 49, p. 14927; Tennessee unpublished database). This effort resulted in the collection of 206 specimens from 16 of the 20 sites sampled and representing an overall relative abundance of 18.2 percent (Butler 2002, p. 21-22). Although sheepnose was found to be the second most abundant species overall, this collection was comprised of extremely old individuals without evidence of recruitment,

indicative of a remnant population approaching extirpation (77 FR No. 49, p. 14927; Tennessee unpublished database). One additional specimen was incidentally collected in 2007 near RM 25; however, extensive survey efforts have not occurred since 2002 (J.T. Baxter, pers. comm. 2010).

Clinch River

HUC8: Upper Clinch, Tennessee, Virginia
State(s): Tennessee, Virginia
Year of Last Live or Fresh Dead Observation: 2020
Notes: Currently, sheepnose occupies a reach of approximately 100 river miles, spanning the Tennessee-Virginia state line, and including portions of Hancock County, Tennessee, and Scott and Russell County, Virginia. Varying numbers of sheepnose have been collected nearly annually from the Upper Clinch throughout the past two decades, including some larger sampling events. As described in 77 FR No. 49 (p. 14927), "Sampling efforts in 2005 and 2006 reported densities from two sites (RM 223.6 and 213.2) in Scott County Virginia, of 0.226 and 0.064 individuals per sq. ft (0.021 and 0.006 per sq. m), respectively (N. Eckert, pers. comm. 2008). Relative abundance for sheepnose at these locations was 1.5 percent and 1.0 percent, respectively." A "musselrama" event was conducted at Slant, Scott County, Virginia in 2005, 2010, and 2015 (R. Hylton, B. Evans and M. Bradley, pers. comm. 2016). High numbers of sheepnose were collected in 2005, and one individual was collected during qualitative sampling in 2015. Total species richness observed ranged from 19 to 27. Approximately five to seven juvenile individuals (<5 years of age) along with at least three adults were collected at Clinchport in 2015 (R. Hylton, B. Evans and M. Bradley, pers. comm. 2016). Additional "musselrama" quantitative and qualitative survey work was completed between 2017 and 2019 at Sycamore Island (RM 207), Speers Ferry (RM 211), and Clinchport (RM 213.5) (R. Agbalog, USFWS, pers. comm. 2021). Quantitative surveys resulted in the collection of four individuals across three survey events (2017, 2019, 2019) from Sycamore Island, including one juvenile. Individual lengths measured 12, 61, 88, and 90 mm. Sheepnose density across the three events ranged from 0.05 to 0.06 per sq. meter (SE = 0.02-0.03). One individual (27 mm) was collected from Clinchport in 2019, comprising a density of 0.01 per sq. meter (SE = 0.01) and zero sheepnose were collected from Speers Ferry Fall in 2017. Qualitative sampling resulted in the collection of one individual from Sycamore Island Falls in 2017 with a relative abundance of 0.051, two individuals from Speers Ferry Fall in 2017 with a relative abundance of 0.115, and 51 individuals from Clinchport Fall in 2019, with a relative abundance of 1.160. Total species richness across the three sites ranged from 23 to 31. As described in USFWS 2020 (p. 29), "More recently, surveys were conducted at nine sites across a 30-mile reach of the unimpounded portion of the Clinch River within Hancock County, Tennessee

between 2018 and 2019. Twenty sheepnose specimens were collected from five of the nine sites, with a relative abundance of 1.8% (Hubbs 2019, p. 29). Evidence of recruitment was identified (Hubbs 2019, p. 7). Four of these individuals were transferred from Clinch River Mile 177.0 to the Tennessee Wildlife Resources Agency's Cumberland River Aquatic Center (TWRA C-RAC) for propagation (Hubbs 2019, p. 5). Live specimens are becoming more rare within the upstream reach of the population, with a 2019 survey in Clinchport, Virginia finding fewer than 10 individuals; however, densities tend to vary across years and survey locations (R. Agbalog, USFWS, pers. comm. 2019). Additionally, the Virginia DWR AWCC facility has propagated and released three individuals at Bennett Island near Cleveland, Virginia in 2016 with PIT tags for future monitoring (T. Lane, pers. comm. 2022; S. Colletti, pers comm. 2022; R. Agbalog, USFWS, pers. comm. 2019)." Attempts were made to relocate the three individuals each year between 2018 and 2021, with one individual detected in 2019 (45.5mm), 2020 (48.1 mm), and 2021 (54.5 mm), and a second individual detected in 2021 only (56.8 mm) (S. Colletti, pers. comm. 2022).

As described in FWS 2020 (p. 29), "A significant mussel die-off event has been on-going in the Clinch River since 2016, downstream of the Tennessee-Virginia state line (Richard 2016, p. 2-16). The cause of the die-off is currently unknown and impact assessments are on-going (D. Hubbs, pers. comm. 2017);" however, evidence suggests this event has not resulted in population-level declines for sheepnose (T. Lane, pers. comm. 2021). Refer to Appendix B for further discussion.

Powell River

HUC8: Powell

State(s): Tennessee, Virginia

Year of Last Live or Fresh Dead Observation: 2019

Notes: Sheepnose within the Powell occupy a reach spanning the Tennessee-Virginia state line, including roughly 15 RMs into Scott County, Virginia and 10 RM into Hancock County, Tennessee; however, the species is becoming increasingly rare in portions of the Powell River due to a combination of threats primarily resulting from coal mining and land development/ modification activities (Johnson et al. 2012, p. 88). An extensive survey effort was conducted between 2008-2009 to facilitate understanding of the effects anthropogenic stressors have had on the mussel community, once supporting up to 46 species of mussels (Johnson et al. 2012, p. 83-84). The effort resulted in the collection of 29 species, including the collection of 102 sheepnose individuals from 13 of 21 sample sites (Johnson et al. 2012, p. 86, 94-96). Collection locations included sites within both Virginia and Tennessee, between RMs 104.8- 198.8 (Johnson et al. 2012, p. 86, 94-95). Numbers of individuals collected per site ranged from 1 to 33, with a percent relative abundance of 0.68 (p. 94-96). The smallest individual collected was a length of 58 mm (Johnson et al. 2010, p. 96), indicating recent recruitment. Additional records over the past two decades include collections ranging from 1 to 5 specimens. Sheepnose have most recently been found within the Powell River (VA) in 2013, including three specimens collected near Fletcher Ford in Virginia (R. Hylton, B. Evans and M. Bradley, pers. comm 2016), 2016 and 2019. Sheepnose densities vary between years and locations, with higher densities found in the Tennessee reach (T. Lane, pers. comm. 2013-2014 (2021); R. Agbalog, pers. comm, 2019.).

Duck River

HUC8: Lower Duck
State(s): Tennessee
Year of Last Live or Fresh Dead Observation: 2003
Notes: Recent records are limited to the collection one approximately 10-year-old live individual below the Columbia Dam by Tennessee Valley Authority biologists in 2003 (Ahlstedt et al. 2017, p. 63). Prior to this collection, sheepnose was thought to be extirpated from the Duck River, as the species had not been collected for more than 100 years (Ahlstedt et al. 2017, p. 63; 77 FR No. 49, p. 14928).

E.4 Lower Mississippi River Basin Representation Unit

Big Sunflower River

HUC8: Big Sunflower
State(s): Mississippi
Year of Last Live or Fresh Dead Observation: 2005
Notes: Currently, sheepnose is only known from a limited reach in Sunflower County, north of Indianola, Mississippi (Jones et al. 2019, p. 205). Although museum and archeological records indicate this population was once abundant (77 FR No. 49, p. 14928), the species was most recently collected from the Big Sunflower River in 2005, represented by one live specimen (P. Hartfield and M. Wagner, pers. comm. 2019). The population was last surveyed in 2018, with no live or fresh dead specimens encountered (P. Hartfield and M. Wagner, pers. comm. 2019). Recent evidence of recruitment is limited to the collection of the shell of one freshly dead juvenile in 2003 (Jones et al. 2019, p. 205).

E.5 Current Condition Summary

Table E.1. Summary of Extant Population Current Demographic Condition

Stream	HUC 8	HUC 8 ID	State(s)	Year of Last Observation	Population Distribution (river miles)	Cumulative Population Size (2000-2020)	Reproduction and Recruitment[2]	Demographic Current Condition*
Upper Mississippi River Basin								
Mississippi River	Buffalo-Whitewater	07040003	MN, WI	Low	Moderate	Low	Fx	Low
Mississippi River	La Crosse-Pine	07040006	MN, WI	Low	Fx	Fx	Low	Fx
Mississippi River	Grant-Little Maquoketa	07060003	IA, WI	Moderate	Fx	Fx	Fx	Fx
Mississippi River	Copperas-Duck	07080101	IA, IL	High	High	High	High	Moderate**
Chippewa River	Upper Chippewa	07050001	WI	High	High	Moderate	Fx	Low*
Chippewa River	Lower Chippewa	07050005	WI	High	Moderate	High	High	High
Flambeau River	Flambeau	07050002	WI	High	Low	Moderate	Fx	Low
Wisconsin River	Castle Rock	07070003	WI	High	Low	Low	Fx	Low
Wisconsin River	Lower Wisconsin	07070005	WI	High	Moderate	Moderate	Fx	Low
Rock River	Lower Rock	07090005	IL	Low	Fx	Fx	Fx	Fx
Kankakee River	Kankakee	07120001	IL	High	High	Moderate	High	High
Bourbeuse River	Bourbeuse	07140103	MO	High	High	Moderate	Low	Moderate
Meramec River	Meramec	07140102	MO	High	High	Moderate	High	High
Ohio River Basin								
Ohio River	Lower Ohio	05140206	IL, KY	High	High	Low	Fx	Low
Ohio River	Lower Ohio-Little Pigeon	05140201	IN, KY	High	High	Moderate	Low^[2]	Moderate
Ohio River	Silver-Little Kentucky	05140101	IN, KY	High	High	Fx	Fx	Low
Ohio River	Ohio Brush-Whiteoak	05090201	KY, OH	High	Moderate	Moderate	Moderate^[1]	Moderate

Table E.1 (continued). Summary of Extant Population Current Demographic Condition

Stream	HUC 8	HUC 8 ID	State(s)	Year of Last Observation	Population Distribution	Cumulative Population Size (2000-2020)	Reproduction and Recruitment[2]	Demographic Current Condition
Ohio River	Little Scioto-Tygarts	05090103	KY, OH	High	Low	Low	Fx	Low
Ohio River	Raccoon-Symmes	05090101	OH, WV	High	High	Moderate	Fx***	Low*
Ohio River	Upper Ohio-Shade	05030202	OH, WV	High	High	Low	Fx***	Low*
Ohio River	Little Muskingum-Middle Island	05030201	OH, WV	High	Low	Low	Fx***	Low
Allegheny River	Middle Allegheny-Tionesta	05010003	PA	Moderate	Moderate	High	Low	Moderate
Green River	Upper Green	05110001	KY	High	High	High	High	High
Kanawha River	Upper Kanawha	05050006	WV	High	Low	Moderate	Moderate^[1]	Moderate
Licking River	Licking	05100101	KY	High	30+	Low	Fx	Low
Muskingum River	Muskingum	05040004	OH	Moderate	Fx	Fx	Fx	Fx
Walhonding River	Walhonding	05040003	OH	High	Low	High	Moderate^[1]	Moderate
Tippecanoe River	Tippecanoe	05120106	IN	High	High	High	High	High
Tennessee River Basin								
Tennessee River	Lower Tennessee	06040006	KY	High	Moderate	Moderate	Moderate^[3]	Moderate
Tennessee River	Lower Tennessee-Beech	06040001	TN	High	Moderate	Low	Low	Low
Tennessee River	Pickwick Lake	06030005	AL	High	Low	Low	Low	Low
Tennessee River	Wheeler Lake	06030002	AL	Fx	Low	Low	Fx	Fx
Clinch River	Upper Clinch. Tennessee, Virginia	06010205	TN, VA	High	High	High	High	High
Duck River	Lower Duck	06040003	TN	Fx	Fx	Fx	Fx	Fx
Holston River	Holston	06010104	TN	Low	Moderate	High	Fx	Low
Powell River	Powell	06010206	TN, VA	High	High	High	Low	Moderate

Table E.1 (continued). Summary of Extant Population Current Demographic Condition

Stream	HUC 8	HUC 8 ID	State(s)	Year of Last Observation	Population Distribution (river miles)	Cumulative Population Size (2000-2020)	Reproduction and Recruitment[2]	Demographic Current Condition
Lower Mississippi River Basin								
Big Sunflower River	Big Sunflower	08030207	MS	Low	Moderate	Fx	Low	Low

Fx = Functionally Extirpated (refer to Section 4.2.1)

*Rule: If recruitment = Functionally Extirpated, population condition cannot be Moderate or High.

**Adjusted overall score from high to moderate due to the large number of individuals that were collected during the Interstate-74 bridge relocation being comprised of mostly older/aging adults with only one juvenile and low levels of younger age classes collected. Further, three large dams bisect the occupied reach. Collections have been limited to one <1 mile occupied reaches per pool, with the exception of Pools 15 (1-10 miles) and 16 (1-10 miles). Although at low levels, this population appears to be reproducing (2003, 2016).

***No recent evidence of juveniles or gravid individuals, but multiple age classes present

^ Available records do not match category definition (Table 4.3).

^[1]Assigned moderate condition due to lack of evidence of persistent recruitment.

^[2]Assigned low condition due to evidence of recent gravid females, but no evidence of juveniles in last 20 years.

^[3] Assigned moderate condition due to juvenile collection in 2005 and gravid female collection in 2019, with surveys indicating variable age classes present.

Table E.2. Summary of Extant Population Current Risk Condition

Stream	HUC 8	HUC 8 ID	State(s)	Water Quality	Landscape	Hydrological Regime	Connectivity	Invasive Species	Overall Current Risk
Upper Mississippi River Basin									
Mississippi River	Buffalo-Whitewater	07040003	MN, WI	Low	Moderate	Moderate	Moderate	High	High
Mississippi River	La Crosse-Pine	07040006	MN, WI	Moderate	Moderate	Moderate	Moderate	High	High
Mississippi River	Grant-Little Maquoketa	07060003	IA, WI	High	Moderate	Moderate	Low	High	High
Mississippi River	Copperas-Duck	07080101	IA, IL	High	Moderate	Moderate	Moderate	High	High
Chippewa River	Upper Chippewa	07050001	WI	Low	Low	Moderate	Moderate	Moderate	Moderate
Chippewa River	Lower Chippewa	07050005	WI	Moderate	Moderate	Moderate	Moderate	High	High
Flambeau River	Flambeau	07050002	WI	High	Low	Moderate	Moderate	Moderate	High
Wisconsin River	Castle Rock	07070003	WI	High	Moderate	Low	Moderate	High	High
Wisconsin River	Lower Wisconsin	07070005	WI	Moderate	Moderate	Moderate	Moderate	High	High
Rock River	Lower Rock	07090005	IL	High	High	Moderate	Moderate	High	High
Kankakee River	Kankakee	07120001	IL	High	Moderate	Moderate	Moderate	High	High
Bourbeuse River	Bourbeuse	07140103	MO	Low	Moderate	Moderate	High	High	High
Meramec River	Meramec	07140102	MO	High	Moderate	Moderate	High	High	High
Ohio River Basin									
Ohio River	Lower Ohio	05140206	IL, KY	High	Moderate	Moderate	Moderate	High	High
Ohio River	Lower Ohio-Little Pigeon	05140201	IN, KY	High	Moderate	Moderate	Moderate	Moderate	High
Ohio River	Silver-Little Kentucky	05140101	IN, KY	High	Moderate	Moderate	Moderate	Moderate	High
Ohio River	Ohio Brush-Whiteoak	05090201	KY, OH	High	Moderate	Moderate	Moderate	Moderate	High
Ohio River	Little Scioto-Tygarts	05090103	KY, OH	High	Moderate	Moderate	Moderate	Moderate	High

Table E.2 (continued). Summary of Extant Population Current Risk Condition

Stream	HUC 8	HUC 8 ID	State(s)	Water Quality	Landscape	Hydrological Regime	Connectivity	Invasive Species	Overall Current Risk
Ohio River	Raccoon-Symmes	05090101	OH, WV	High	Moderate	Low	Moderate	Moderate	High
Ohio River	Upper Ohio-Shade	05030202	OH, WV	High	Moderate	Low	Moderate	High	High
Ohio River	Little Muskingum-Middle Island	05030201	OH, WV	High	Moderate	Low	Moderate	High	High
Allegheny River	Middle Allegheny-Tionesta	05010003	PA	High	Moderate	Low	Moderate	Moderate	High
Green River	Upper Green	05110001	KY	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Kanawha River	Upper Kanawha	05050006	WV	High	Moderate	Low	Low	Moderate	High
Licking River	Licking	05100101	KY	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Muskingum River	Muskingum	05040004	OH	High	Moderate	Low	Moderate	High	High
Walhonding River	Walhonding	05040003	OH	Moderate	Moderate	Low	Moderate	Moderate	Moderate
Tippecanoe River	Tippecanoe	05120106	IN	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Tennessee River Basin									
Tennessee River	Lower Tennessee	06040006	KY	High	Moderate	Moderate	Moderate	Moderate	High
Tennessee River	Lower Tennessee-Beech	06040001	TN	Moderate	Moderate	Moderate	High	Moderate	High
Tennessee River	Pickwick Lake	06030005	AL	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Tennessee River	Wheeler Lake	06030002	AL	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Clinch River	Upper Clinch, Tennessee, Virginia	06010205	TN, VA	Moderate	Moderate	Moderate	Moderate	High	High
Duck River	Lower Duck	06040003	TN	Moderate	Moderate	Moderate	High	Moderate	High
Holston River	Holston	06010104	TN	High	Moderate	Moderate	High	High	High

Table E.2 (continued). Summary of Extant Population Current Risk Condition

Stream	HUC 8	HUC 8 ID	State(s)	Water Quality	Landscape	Hydrological Regime	Connectivity	Invasive Species	Overall Current Risk
Powell River	Powell	06010206	TN, VA	Moderate	Moderate	Moderate	Moderate	High	High
Lower Mississippi River Basin									
Big Sunflower River	Big Sunflower	08030207	MS	High	Moderate	Moderate	Low	Moderate	High

Table E.3 Current condition summary of demographic, risk factor, and catastrophic event analysis for extant sheepnose mussel populations rangewide.

Stream	HUC 8	HUC 8 ID	State(s)	Current Demographic Condition*	Overall Current Risk	Risk of Catastrophic Event Coal	Risk of Catastrophic Event Oil and Gas
Upper Mississippi River Basin							
Mississippi River	Buffalo-Whitewater	07040003	MN, WI	Low	High	Low	High
Mississippi River	La Crosse-Pine	07040006	MN, WI	Fx	High	Low	High
Mississippi River	Grant-Little Maquoketa	07060003	IA, WI	Fx	High	Low	High
Mississippi River	Copperas-Duck	07080101	IA, IL	Moderate	High	Low	High
Chippewa River	Upper Chippewa	07050001	WI	Low	Moderate	Low	High
Chippewa River	Lower Chippewa	07050005	WI	High	High	Low	High
Flambeau River	Flambeau	07050002	WI	Low	High	Low	High
Wisconsin River	Castle Rock	07070003	WI	Low	High	Low	High
Wisconsin River	Lower Wisconsin	07070005	WI	Low	High	Low	High
Rock River	Lower Rock	07090005	IL	Fx	High	Low	High
Kankakee River	Kankakee	07120001	IL	High	High	Low	High
Bourbeuse River	Bourbeuse	07140103	MO	Moderate	High	Low	High
Meramec River	Meramec	07140102	MO	High	High	Low	High
Ohio River Basin							
Ohio River	Lower Ohio	05140206	IL, KY	Low	High	Low	High
Ohio River	Lower Ohio-Little Pigeon	05140201	IN, KY	Moderate	High	High	High

Table E.3 (continued). Current condition summary of demographic, risk factor, and catastrophic event analysis for extant sheepnose mussel populations rangewide.

Stream	**HUC 8**	**HUC 8 ID**	**State(s)**	**Current Demographic Condition***	**Overall Current Risk**	**Risk of Catastrophic Event Coal**	**Risk of Catastrophic Event Oil and Gas**
Ohio River	Silver-Little Kentucky	05140101	IN, KY	Low	High	Low	High
Ohio River	Ohio Brush-Whiteoak	05090201	KY, OH	Moderate	High	Low	High
Ohio River	Little Scioto-Tygarts	05090103	KY, OH	Low	High	Low	High
Ohio River	Raccoon-Symmes	05090101	OH, WV	Low	High	High	High
Ohio River	Upper Ohio-Shade	05030202	OH, WV	Low	High	Low	High
Ohio River	Little Muskingum-Middle Island	05030201	OH, WV	Low	High	High	High
Allegheny River	Middle Allegheny-Tionesta	05010003	PA	Moderate	High	High	High
Green River	Upper Green	05110001	KY	High	Moderate	Low	High
Kanawha River	Upper Kanawha	05050006	WV	Moderate	High	High	High
Licking River	Licking	05100101	KY	Low	Moderate	High	High
Muskingum River	Muskingum	05040004	OH	Fx	High	Low	High
Walhonding River	Walhonding	05040003	OH	Moderate	Moderate	Low	High
Tippecanoe River	Tippecanoe	05120106	IN	High	Moderate	Low	High
Tennessee River Basin							
Tennessee River	Lower Tennessee	06040006	KY	Moderate	High	Low	High
Tennessee River	Lower Tennessee-Beech	06040001	TN	Low	High	Low	High
Tennessee River	Pickwick Lake	06030005	AL	Low	Moderate	Low	High
Tennessee River	Wheeler Lake	06030002	AL	Fx	Moderate	Low	High
Clinch River	Upper Clinch, Tennessee, Virginia	06010205	TN, VA	High	High	High	High
Duck River	Lower Duck	06040003	TN	Fx	High	Low	High

Table E.3 (continued). Current condition summary of demographic, risk factor, and catastrophic event analysis for extant sheepnose mussel populations rangewide.

Stream	**HUC 8**	**HUC 8 ID**	**State(s)**	**Current Demographic Condition***	**Overall Current Risk**	**Risk of Catastrophic Event Coal**	**Risk of Catastrophic Event Oil and Gas**
Holston River	Holston	06010104	TN	Low	High	Low	High
Powell River	Powell	06010206	TN, VA	Moderate	High	High	High
Lower Mississippi River Basin							
Big Sunflower River	Big Sunflower	08030207	MS	Low	High	Low	High

*Fx = Functionally Extirpated (refer to Section 4.2.1)

APPENDIX F. METHODS FOR FUTURE CONDITION RISK FACTORS

F.1 Contaminants

Because there is not currently a way to directly predict the presence or concentrations of contaminants in surface waters, we used land cover as a proxy for future condition (Table 5.2). The presence and concentration of certain contaminants, including ammonia, are correlated with specific land cover types, and land cover is an important variable in predicting the occurrence of contaminants in surface waters (Baker 2003, entire; Kiesling et al. 2019, entire; Rothenberger et al. 2009, entire; Zhongwei et al. 2009, entire). Although the strength of the relationship between land cover and occurrence of contaminants may vary by geography due to large ranges in concentrations and laboratory reporting methods, we believe our approach to qualitatively predict where concentrations of contaminants may increase or decrease due to projected changes in land cover to be reasonable based on these studies and what we know about sources of contaminants.

We used the FORE-SCE land cover change model to project how land cover may change in the future relative to current condition under a worst-case (IPCC Special Report on Emissions Scenarios (SRES) A2) and best-case (SRES B1) scenario and assumed the occurrence and concentration of contaminants would increase or decrease relative to current condition along with increases or decreases in the percent cover of certain land cover types. For example, ammonia has both agricultural and industrial applications and is a component of municipal effluent discharges (USEPA 2013, pp. 5–7) and urban and agricultural land cover has been positively correlated with concentrations of ammonia (Baker 2003, pp. 2–3; and Rothenberger et al. 2009, p. 520). Therefore, we would expect the presence and concentrations of ammonia in surface water to increase with projected increases in the percent cover of developed and agricultural land cover types, although we cannot predict by exactly how much.

Similarly, urban and agricultural land cover also has a statistically significant relationship to concentrations of chloride (Zhongwei et al. 2009, p. 76) as sources of chloride include deicing salt, urban and agricultural runoff, and discharges from wastewater treatment facilities (USEPA 1988, p. 1). Therefore, we would also expect chloride to increase where developed and agricultural land cover types are projected to increase.

Anthropogenic inputs of copper, lead, and other metals into surface waters come primarily from mining and manufacture of alloys, metal products, electrical equipment (Baker 2003, pp. 2–3; Zhongwei et al. 2009, p. 76). We associated metals with developed land cover types (Tchounwou et al. 2012, pp. 3–18).

F.1.a Water Quality and Climate Change

Within coming years, climate change will likely amplify these impacts as global surface temperatures are expected to rise greater than 1.5 ˚C, relative to 1850 to 1900 for all RCP scenarios except RCP2.6, with some regions projected to experience even larger impact

(Intergovernmental Panel on Climate Change [IPCC], 2013, p. 20). As surface temperatures increase, decreases in precipitation may occur, likely resulting in elevated stream temperature, decreased dissolved oxygen, and decreased flows (Sinokrot and Gulliver 2000, pp. 349–359; van Vliet et al. 2013, pp. 450–464). Morrill et al. (2005, pp. 139–146) studied the empirical relationship between stream and air temperature and how these relationships impact water temperature and potential changes in dissolved oxygen. For every 1˚C increase air temperature, water temperature increased 0.6–0.8 ˚C for the majority of streams, but few of these streams had a linear relationship of 1:1 for air/water temperature trend. Based on this modeling, an increase in air temperature of 3–5 ˚C would cause surface water temperature to increase 2–3 ˚C (Morrill et al. 2005, pp. 139–146).

Dissolved oxygen levels are lower at higher water temperatures, so as stream temperatures increase, dissolved oxygen will decrease. We used the USGS NCCV (https://www2.usgs.gov/landresources/lcs/nccv/maca2/maca2_counties.html) to assess potential increases in air temperature for the emission scenarios RCP4.5 and RCP8.5. Under RCP8.5, the mean change in air temperature across the range of sheepnose is projected to be approximately between 2.86–4.02 ˚C. Under RCP4.5, the mean temperature change is projected to be approximately 1.9–2.77 ˚C. Based on these climate projections, stream temperature will likely increase in many geographic areas, and dissolved oxygen will decrease, severely impacting aquatic ecosystems and freshwater mussels.

F.2 Landscape

To project landscape conditions under Future Scenario 1, we used the Forecasting Scenarios (FORE-SCE) model (Sohl et al. 2007, entire) SRES A2 to predict future land cover for agriculture and development in HUC8s, and vegetative cover in the riparian buffer. For landscape conditions under Future Scenario 2, we used SRES Scenario B1. We calculated the percent of land cover for each HUC in 2050 and 2070.

Because the projected data from SRES is based on modeling, and our current condition was calculated using NLCD 2016 dataset, we calculated the percent change using modeled land cover in 2005, 2050, and 2070 and applied the percent change to the NLCD 2016 data. Using the modeled 2005 historic data, we calculated the percent change for each land cover in 2050 and 2070. We then applied the percent change to the current condition to get a projected percentage of land cover types for each HUC in 2050 and 2070. We used agricultural land cover to project out the percent of agriculture within HUCs. We assumed that as development increases, percent urban and percent imperviousness would increase at commensurate rates. We used the change in vegetation cover within the riparian buffer for vegetative cover and assumed the rate of change in vegetation would apply to the change in canopy cover within the riparian buffer.

F.3 Hydrological Regime

Although we used U.S. Drought Monitor data to quantitatively evaluate current condition, we could not use these data to project future conditions because not all of the indices used to derive drought category can be modeled or predicted. Rather, we used projections of the Cumulative Severe Drought Index (CDSI) developed by the U.S. Forest Service to determine qualitatively how drought severity may change in the future (Peters and Iverson 2015, p. 57).

The CDSI uses Palmer Drought Severity Index (PDSI) values calculated for individual spatial grids (in other words, raster cells) across the continental United States, assigns weights to each PDSI drought category, and sums the weighted occurrences across time. The more severe drought categories receive higher weighting. For example, if a raster cell has a calculated PDSI value between -2.0 to -2.99 (indicating moderate drought) for a single occurrence in a given period of time, a weight of 1 is applied to that raster cell for that occurrence for total CDSI value of 1 (that is, 1 occurrence multiplied by a weight of 1). If for the next occurrence the PDSI value decreases to between -3.0 to -3.99 (indicating severe drought), a weight of 2 is applied for that occurrence and the total CDSI value for that period encompassing both occurrences is 3. This process allows weighted occurrences to be summed up over different time periods, facilitating comparison of many locations over multiple time periods (Peters and Iverson 2019, p. 21). We used CDSI projections for the continental United States from Peters and Iverson (2019, p. 21) in the form of in 4km x 4km resolution rasters.

To account for variability among climate models, Peters and Iverson (2019, p. 21) developed four overarching future scenarios: Warm Wet, Hot Wet, Hot Slightly Dry, and Hot Dry. We used the book end scenarios of Warm Wet and Hot Dry to compare CDSI values for the current time period (1980–2009) to the time period 2040–2069. This time period was chosen to be as consistent as possible with our other current and future condition analyses – data was not available that matched our current and future time periods exactly. We calculated the average CDSI value of all raster cells within a HUC8 corresponding to a population in the current time period across all scenarios to create an average baseline and compared those values with the projected averaged CDSI values for that watershed between 2040 and 2069 to determine how drought severity may change under both the Warm Wet and Hot Dry scenarios. Increasing CDSI values indicate increasing drought severity.

The results indicate that in the modeled future (2040–2069), averaged CDSI (drought severity index) values increased in almost all watersheds (99%) under the Warm Wet scenario and in most watersheds (58%) under the Hot Dry scenario. The average percent change in CDSI was +111% under the Warm Wet scenario and +35% under the Hot Dry scenario. These watershed-scale results comport with the regional-scale results presented in Peters and Iverson (2019, entire) which suggest that drought severity may decrease relative to current conditions in the immediate future (2010–2039) due to increased precipitation, but may also become more frequent and intense during the second half of the century.

Due to the conditions of the projected scenarios in the foreseeable future, we included the Warm Wet scenario in Scenario 1 and Hot Dry scenario in Scenario 2 even though the results of the models for the second half of the century would place them opposite. While projections of temperature, precipitation, and other drought-related factors vary across models, and thus methods for projecting drought inherently carry some amount of uncertainty, these models (Peters and Iverson 2019, entire; Mishra and Cherkauer 2010, entire; Cook et al. 2014, entire; Wehner et al. 2011, entire; Zhao and Dai 2017, entire; Cook et al. 2020, entire) all indicate a tendency towards increasing drought relative to current conditions after mid-century.

F.4 Connectivity

In some areas of sheepnose, barriers have been removed from river systems. We assumed construction of new barriers is unlikely. Therefore, under Scenario 1, we projected no change from the current number of dams. For Scenario 2, we assumed that the rate at which barriers were removed in the last 2 decades would continue into the future for two decades. Therefore, we projected dam removals out to 2040 based on the number of dams removed between 2000–2020.

To assess future changes in unpaved road density, we used the Global biodiversity model for policy support's U.S. Global Roads Inventory Project's (GRIP). For Future Scenario 1 we used socio-economic pathway 5 (SSP5: 27.3%; projections for increases in all road type length (km) in the U.S. by 2050 [Meijer et al. 2018, Table S6]). For Future Scenario 2, we used GRIP Scenario SSP3 (3.2%; which projects a 3.2% increase in road density [Meijer et al. 2018, Table S6]). These projections assume that unpaved road density will increase at the same rate as all road types in the U.S. The GRIP Scenarios extend to 2050. We applied the SSP percent increase to the current density to get a projected unpaved road density in 2050 for each HUC8 (considered the population).

F.5 Invasive Species

We assessed the risk of negative impacts because of invaders worsening in the future by identifying the number of hot spots that occur in neighboring HUC8 watersheds (HUC8 watershed was the level considered for populations and associated analyses) directly adjacent to each HUC8 population included in the current condition risk assessment (Table 5.2). We included neighboring watersheds assuming there was risk of dispersal into current populations. We do not consider a future in which invasive species impacts are improved (dropped from high risk to moderate risk, or from moderate risk to low risk), but instead one in which these impacts likely worsen (bumped from low risk to moderate risk, or from moderate risk to high risk); however, we do also consider a future in which the risk in any population may remain unchanged (remains unchanged from current condition) and does not increase because of mitigation efforts, minimal invader access (for example, being upstream from an impacted neighboring HUC8 watershed), or any other reason.

We consider any HUC8 population with one or more neighbors with a hotspot in any invasive species category (for example, direct competition, reduction of reproductive potential, disturbance to ecosystems, direct harm/predation) to increase in risk (from low risk to moderate risk, or from moderate risk to high risk) sometime in the future (Table F.1).

Table F.1. Indicator descriptions used to evaluate the risk of invasive species impacts worsening or remaining unchanged in current populations in the future.

Future condition indicator – Invasive Species	**Metrics/description**
Description of Indicator	**Optimized Hotspot Analysis using invasive species occurrence data for occupied HUC8 and categorized by common impacts to mussel species**
High Risk (3 points)	Increases from Moderate Risk; hot spots were identified in one or more neighboring HUC regardless of number or confidence levels. No cold spots were identified to occur in any neighboring HUC8
Moderate Risk (2 points)	Increases from Low Risk; hot spots were identified in one or more neighboring HUC regardless of number or confidence levels. No cold spots were identified to occur in any neighboring HUC8
Low Risk (1 point)	No hotspots were identified to occur in any neighboring HUC8 AND/OR cold spots were identified in one or more neighboring HUC8 regardless of number or confidence levels

Scenario 1 will be the hotspot and neighbor analysis from current condition (Table 5.2). If there is a hotspot neighbor to any occupied HUC8 population, we are making the assumption the frequency and abundance necessary to cause that hotspot would mean the dispersal into these populations is sufficient to move them into a moderate or high risk category.

Future Scenario 2 is the same invasive rate as it is now (Table 5.2).

For the HUC8 populations that remained unchanged from the current condition risk assessment, we hypothesize that there are other factors potentially influencing increased risk that we are unable to determine (for example, barrier to invasion, flow dynamics, habitat suitability, etc.). It is also possible that a lack of detections in the neighboring HUC8 watersheds due to a lack of survey effort/ detections is not reflective of the true current risk posed by neighboring HUC8 watersheds. Once again this is not something that we are able to determine.

F.6 Catastrophic Events

We relied on U.S. Energy Information Administration (EIA) analyses to qualitatively project how the risk of catastrophic events may change in the future. The EIA's Annual Energy Outlook 2021 provides analyses of the energy market for policy makers and public understanding (EIA 2021, p. 2). Energy consumption in the U.S. is expected to increase over the next 30 years. The primary sources of that energy, however, are dependent on oil and gas supplies and prices.

In a low oil and gas supply case, electricity generation from natural gas decreases by a third by 2030 and stays level. In a high oil and gas supply case, electricity generation from natural gas more than doubles by 2050. Similarly, production of crude oil and gas plant liquids increases until 2040 and levels off under a high oil and gas supply scenario and decreases slightly in a low oil and gas supply scenario. In both scenarios, electricity generation from coal spikes in the near-term but continues a downward trend (EIA 2021, pp. 8–19).

We make the assumption that energy infrastructure (for example, pipelines, wells, and mines) increases and decreases along with consumption and production and that those changes are geographically explicit. For example, under the high oil and gas supply case, the EIA projects that production of crude oil will increase, and we assume that the number of pipelines may also increase. Furthermore, we assume that increase would occur only in areas with existing pipeline infrastructure. In other words, if an 8-digit HUC currently has no pipelines running through it, we would not assume the risk of an oil spill increases in this watershed because there was no related infrastructure to begin with.

For pipelines and oil and natural gas wells, the worst-case scenario for catastrophic events would be the high oil and gas supply scenario where production and consumption increase, and the risk of a catastrophic event also increases. The best-case scenario would be the low oil and gas supply scenario where production and consumption decrease and the risk of a catastrophic event decreases. Since electricity generation from coal is expected to decrease in either scenario, we consider a worst-case scenario to be no change in risk and the best-case scenario to be a reduction in risk.

APPENDIX G. FUTURE CONDITION

G.1 Scenario 1

Upper Mississippi River Basin Representation Unit

All 13 of the Upper Mississippi River basin populations are projected to experience an overall high level of risk under Scenario 1. As such, we project that eight populations will become extirpated under Scenario 1: Buffalo-Whitewater, La Crosse-Pine, Grant-Little Maquoketa, Upper Chippewa, Flambeau, Castle Rock, Lower Wisconsin, and Lower Rock (Table G.4, Figure 5.1). Of these eight populations, five are currently in low demographic condition and three are currently considered to have a demographic condition of functionally extirpated. Of the remaining populations, three are projected to be in low condition (Lower Chippewa, Kankakee, Meramec), all of which are currently in high condition, and two populations are projected to have a demographic condition of functionally extirpated, both currently in moderate condition. None of the Upper Mississippi River basin populations are projected to be in moderate or high condition under Scenario 1. We highlight the projected changes for populations within the Upper Mississippi River basin for Scenario 1 in the following paragraphs, Table G.1, and Tables G.5 – G.10.

- **Water Quality/Contaminants:** Under Scenario 1, the Flambeau, Grant-Little Maquoketa, Castle Rock, Copperas-Duck, Lower Rock, Kankakee, and Meramec populations are predicted to continue to experience high risk associated with water quality impairment. The remaining six populations are currently experiencing low to moderate risk associated with water quality impairment. We do not have the data to determine whether increases or decreases in the four chemicals would meet or exceed threshold levels, thereby affecting the overall risk category. Instead, we were able to project only whether the contaminant risk would be increasing or decreasing for a specific contaminant. Under Scenario 1, we project concentrations for each of the four primary contaminants (ammonia, chloride, copper, and nitrate) will increase into the future for all populations within the Upper Mississippi River basin, as indicated by the projected increase in urban and agricultural landcover, with one exception. The Upper Chippewa population is projected to experience a decrease in copper concentrations (Table G.5).
- **Landscape:** The Lower Rock, Kankakee, and Bourbeuse are the only populations at high risk due to landscape factors under Scenario 1. Of the remaining Upper Mississippi River basin populations, eight populations are at moderate risk, and two are at low risk due to landscape factors. The overall risk associated with landscape factors remained at the same level from current conditions through the Scenario 1 projected future for all populations with two exceptions. The Kankakee and Bourbeuse populations both declined in condition from moderate risk under current conditions to high risk under

Scenario 1 due to increases in urban and agricultural (Bourbeuse only) landcover (Table G.6).

- **Hydrological Regime:** Twelve of the 13 Upper Mississippi River basin populations are at a moderate level of overall risk associated with hydrological regime factors and one population (Castle Rock) is at low risk. Overall, twelve of the 13 populations are expected to experience increased drought conditions under Scenario 1. The percent change in CDSI ranged widely across populations from a decrease in drought severity of -14.65 percent (Flambeau) to a 220.11 percent increase (Grant-Little Maquoketa), with an average of 77.80 percent change.
- **Connectivity:** Two populations continue to experience high risk under Scenario 1 due to connectivity factors (Bourbeuse and Meramec). An additional two populations (Buffalo-Whitewater and Upper Chippewa) increase from a moderate to a high level of risk due to a projected increase of 27.3 percent in unpaved road crossings under Scenario 1. The remaining populations are projected to maintain a similar level of overall low to moderate risk as a result of connectivity factors between current conditions and Scenario 1.
- **Invasive Species:** The neighbor hotspot analysis projects 12 of the 13 Upper Mississippi River basin populations will have a high risk associated with the presence of invasive species under Scenario 1. The remaining population, Flambeau, is projected to continue to experience a moderate level of risk. All populations are expected to maintain the same level of overall risk associated with the presence of invasive species from current conditions through projected future conditions under Scenario 1, except for the Upper Chippewa population. The neighbor hotspot analysis projects that this population will experience an increase from moderate to high risk associated with the presence of invasive species under Scenario 1.
- **Catastrophic Events:** Oil and natural gas supply are projected to increase in areas that already have infrastructure. All populations in the Upper Mississippi basin are at high risk for catastrophic events for oil and natural gas. Scenario 1 projects an increase in production and consumption and therefore increases the risk of an event for all populations. We project no change in risk for catastrophic events related to coal given all the populations within the Upper Mississippi basin are currently at a low risk.

Ohio River Basin Representation Unit

Based on the overall risk levels in the Ohio River basin, we project that seven populations will become extirpated under Scenario 1: Little Scioto-Tygarts, Silver-Little Kentucky, Lower Ohio, Raccoon-Symmes, Upper Ohio-Shade, Little Muskingum-Middle Island, and Muskingum (Table G.1, Table G.4, Figure 5.1). Of these seven populations, six are currently in low demographic condition and one is currently considered to be in functionally extirpated condition (Table G.4). Of the remaining populations, two populations are projected to be in low condition (Upper Green, Tippecanoe), both of which are currently in high condition. The remaining six populations are projected to be functionally extirpated, five of which are currently in moderate condition and one in low condition. None of the Ohio River basin populations are projected to be in high or moderate condition. We highlight the projected changes for populations within the Ohio River basin for Scenario 1 in the following paragraphs, Table G.1, and Tables G.5 – G.10.

- **Water Quality/Contaminants:** Under Scenario 1, the Middle Allegheny-Tionesta, Little Muskingum-Middle Island, Upper Ohio-Shade, Muskingum, Upper Kanawha, Raccoon-Symmes, Little Scioto-Tygarts, Ohio Brush-Whiteoat, Silver-Little Kentucky, Lower Ohio-Little Pigeon, and Lower Ohio populations are predicted to continue to experience high risk associated with water quality impairment. The remaining four populations are currently experiencing moderate risk associated with water quality impairment. We do not have the data to determine whether increases or decreases in the four chemicals would meet or exceed threshold levels, thereby affecting the overall risk category. Instead, we were able to project only whether the contaminant risk would be increasing or decreasing for a specific chemical. Under Scenario 1, we project concentrations for each of the four primary contaminants (ammonia, chloride, copper, and nitrate) will increase into the future for all 15 of the Ohio River basin populations, as indicated by the projected increase in urban and agricultural landcover.
- **Landscape:** Projected landscape changes in the Lower Ohio, Lower Ohio-Little Pigeon, Upper Green, Walhonding, and Tippecanoe populations increase the risk level of these populations from moderate to high. These changes are primarily a result of increased percent urban land cover in all five populations and decreased riparian buffer vegetation in the Upper Green, Tippecanoe, and Lower Ohio populations. The remaining populations within the Ohio River basin are projected to continue to experience a similar level of overall moderate risk associated with landscape factors under Scenario 1.
- **Hydrological Regime:** Eight of the 15 Ohio River basin populations are at a moderate level of risk for hydrological regime factors and seven populations are at low risk. Overall, the CDSI projects that all 15 populations will experience increased drought conditions under Scenario 1. The percent change in CDSI ranged widely across populations from an increase in severity of 54.70 percent (Tippecanoe) to 223.08 percent (Green River), with an average of increase of 117.12 percent change.
- **Connectivity:** Two populations (Upper Ohio-Shade and Muskingum) increase from a moderate to a high level of risk due to a projected increase of 27.3 percent in unpaved road crossings under Scenario 1. The remaining populations are projected to maintain a similar level of moderate to low overall risk as a result of connectivity factors between current conditions and Scenario 1.
- **Invasive Species:** The neighbor hotspot analysis projects seven of the 15 Ohio River basin populations will have a high risk associated with the presence of invasive species under Scenario 1. The remaining eight populations, are projected to continue to experience a moderate level of risk. All populations are expected to maintain the same level of overall risk associated with the presence of invasive species from current conditions through projected future conditions under Scenario 1, with the exception of

the Raccoon-Symmes, Tippecanoe, and Walhonding populations. The neighbor hotspot analysis projects risk for each of these three populations will increase from moderate to high associated with the presence of invasive species under Scenario 1 (Table G.9).

- **Catastrophic Events:** Oil and natural gas production and consumption are projected to increase in areas that already have infrastructure under Scenario 1. All populations in the Ohio River basin are currently at high risk for catastrophic events related to oil and natural gas; therefore, we project an increased risk of a catastrophic event in these populations. We project no changes in coal production under Scenario 1; therefore, there is not expected to be a change to any population's current risk of a catastrophic event related to coal, with six populations remaining at high risk and nine populations remaining at low risk (Table G.10).

Tennessee River Basin Representation Unit

Based on the overall risk levels in the Tennessee River basin, we project that four populations will become extirpated under Scenario 1: Lower Tennessee-Beech, Lower Duck, Wheeler Lake, and Holston (Table G.1, Table G.4, Figure 5.1). Of these three populations, two are currently in low demographic condition and two are currently considered functionally extirpated (Table G.4). Of the remaining populations, one is projected to decline in demographic condition from high to low (Upper Clinch, Tennessee, Virginia). The remaining three populations are projected to be functionally extirpated, two of which are currently in moderate condition and one of which is currently in low condition. None of the Tennessee River basin populations are projected to be in moderate or high condition. We highlight the projected changes for populations within the Tennessee River basin for Scenario 1 in the following paragraphs, Table G.1, and Tables G.5 – G.10.

- **Water Quality/Contaminants:** Under Scenario 1, the Holston, and Lower Tennesse populations are predicted to continue to experience high risk associated with water quality impairment. The remaining six populations are currently experiencing moderate risk associated with water quality impairment. We do not have the data to determine whether increases or decreases in the four contaminants would meet or exceed threshold levels, thereby affecting the overall risk category. Instead, we were able to project only whether the contaminant risk would be increasing or decreasing for a specific contaminant. Under Scenario 1, we project concentrations for each of the four primary contaminants (ammonia, chloride, copper, and nitrate) will increase into the future for all eight of the Tennessee River basin populations, as indicated by the projected increase in urban and agricultural landcover.
- **Landcover:** Projected landscape changes in the Lower Tennessee and Holston populations increase the risk level of these populations from moderate to high. These changes are primarily a result of a projected 20.81 percent increase in agricultural landcover within the Holston population and a combination of a project 218.10 percent increase in urban landcover and 52.53 percent reduction in vegetation cover within the

riparian buffer in the Lower Tennessee population. The remaining populations within the Tennessee River basin are projected to continue to experience a similar moderate level of overall risk associated with landscape factors under Scenario 1.

- **Hydrological Regime:** The CDSI projects that all eight of the Tennessee River basin populations will experience increased drought conditions under Scenario 1, all of which are currently at moderate risk. The percent change in CDSI ranged widely across populations from an increase in severity of 63.58 percent (Pickwick Lake) to 240.62 percent (Upper Clinch, Tennessee, Virginia), with an average of increase of 144.90 percent change.
- **Connectivity:** Three populations continue to experience high risk under Scenario 1 due to connectivity factors (Lower Tennessee-Beech, Lower Duck, and Holston). An additional two populations (Upper Clinch, Tennessee Virginia and Powell) increase from a moderate to a high level of risk due to a projected increase of 27.3 percent in unpaved road crossings under Scenario 1. The remaining three populations are projected to maintain a similar moderate level of overall risk as a result of connectivity factors between current conditions and Scenario 1.
- **Invasive Species:** The neighbor hotspot analysis projects five of the eight Tennessee River basin populations will have a high risk associated with the presence of invasive species under Scenario 1. The remaining three populations are projected to continue to experience a moderate level of risk. All populations are expected to maintain the same level of overall risk associated with the presence of invasive species from current conditions through projected future conditions under Scenario 1, except for the Lower Duck and Lower Tennessee populations. The neighbor hotspot analysis projects that these poulations will experience an increase from moderate to high risk associated with the presence of invasive species under Scenario 1.
- **Catastrophic Events:** Oil and natural gas production and consumption are projected to increase in areas that already have infrastructure under Scenario 1. All of the sheepnose populations within the Tennessee River basin are currently at high risk for catastrophic events associated with oil and natural gas related activities; therefore, we project an increased risk of a catastrophic event in these populations. We project no changes in coal production under Scenario 1; therefore, the current level of risk for a catastrophic event related to coal is not expected to change in any of the Tennessee River basin populations, with two popualtions currently experiencing high risk and the remaining populations at low risk (Table G.10).

Lower Mississippi River Basin Representation Unit

The Big Sunflower population is currently considered to be in low demographic condition and is projected to become extirpated under Scenario 1 due to the high levels of risk the population is projected to continue to experience. We highlight the projected changes for the Big Sunflow population under Scenario 1 in the following paragraphs, Table G.1, and Tables G.5 – G.10.

- **Water Quality/Contaminants:** Under Scenario 1, the Big Sunflower population is predicted to continue to experience high risk associated with water quality impairment. We do not have the data to determine whether increases or decreases in the four contaminants would meet or exceed threshold levels, thereby affecting the overall risk category. Instead, we were able to project only whether the contaminant risk would be increasing or decreasing for a specific contaminant. Copper seems to be the driver of the high risk for this population; however, concentrations of all four of the primary contaminants (ammonia, chloride, copper, and nitrate) are predicted to increase into the future as indicated by the projected increase in urban and agricultural landcover.
- **Landscape:** The Big Sunflower population is projected to maintain an overall moderate level of threat for landscape factors between current conditions and Scenario 1.
- **Hydrological Regime:** The Big Sunflower population is projected to have the CDSI increase by approximately 27.14% under Scenario 1, increasing the risk of drought to sheepnose. However, we cannot determine if this increase would move the risk factor into the high threshold.
- **Connectivity:** The Big Sunflower population is projected to maintain a similar level of low overall risk as a result of connectivity factors between current conditions and Scenario 1.
- **Invasive Species:** The neighbor hotspot analysis projects that the Big Sunflower population will continue to experience a moderate level of threat associated with the presence of invasive species.
- **Catastrophic Events:** Oil and natural gas supply are projected to increase only in areas that already have infrastructure. The Big Sunflower population is currently at high risk for catastrophic events for oil and natural gas. Therefore, we project an increased risk of a catastrophic event associated with the production and consumption of oil and natural gas under Scenario 1. However, we project risk for catastrophic events related to coal will remain low under Scenario 1.

Table G.1. Scenario 1 risk factor future projections for extant sheepnose populations rangewide.

Stream	HUC 8	HUC 8 ID	State(s)	Current Condition	Scenario 1 Projected Condition					
				Overall Risk	**Water Quality/ Contaminants**	**Landscape (2070)**	**Hydrological Regime (% change in CDSI)**	**Connectivity (2040 & 2050)**	**Invasive Species**	**Overall Risk**
Upper Mississippi River Basin Representation Unit										
Mississippi River	Buffalo-Whitewater	07040003	MN, WI	High	Low↑	Moderate	Moderate (52.68)	**High**$^-$	High	High
Mississippi River	La Crosse-Pine	07040006	MN, WI	High	Moderate↑	Moderate	Moderate (107.46)	Moderate	High	High
Mississippi River	Grant-Little Maquoketa	07060003	IA, WI	High	High↑	Moderate	Moderate (220.11)	Low	High	High
Mississippi River	Copperas-Duck	07080101	IA, IL	High	High↑	Moderate	Moderate (60.94)	Moderate	High	High
Chippewa River	Upper Chippewa	07050001	WI	Moderate	Low↑	Low	Moderate (8.28)	**High**$^-$	**High**$^-$	**High**$^-$
Chippewa River	Lower Chippewa	07050005	WI	High	Moderate↑	Moderate	Moderate (41.97)	Moderate	High	High
Flambeau River	Flambeau	07050002	WI	High	High↑	Low	Moderate (-14.65)	Moderate	Moderate	High
Wisconsin River	Castle Rock	07070003	WI	High	High↑	Moderate	Low (119.23)	Moderate	High	High
Wisconsin River	Lower Wisconsin	07070005	WI	High	Moderate↑	Moderate	Moderate (196.27)	Moderate	High	High
Rock River	Lower Rock	07090005	IL	High	High↑	High	Moderate (69.30)	Moderate	High	High
Kankakee River	Kankakee	07120001	IL	High	High↑	**High**$^-$	Moderate (31.98)	Moderate	High	High
Bourbeuse River	Bourbeuse	07140103	MO	High	Low↑	**High**$^-$	Moderate (71.50)	High	High	High
Meramec River	Meramec	07140102	MO	High	High↑	Moderate	Moderate (73.29)	High	High	High

Table G.1 (continued). Scenario 1 risk factor future projections for extant sheepnose populations rangewide.

Stream	**HUC 8**	**HUC 8 ID**	**State(s)**	**Current Condition**	**Scenario 1 Projected Condition**					
				Overall Risk	**Water Quality/ Contaminants**	**Landscape (2070)**	**Hydrological Regime (% change in CDSI)**	**Connectivity (2040 & 2050)**	**Invasive Species**	**Overall Risk**
Ohio River Basin Representation Unit										
Ohio River	Lower Ohio	05140206	IL, KY	High	High↑	**High**$^{-}$	Moderate (76.68)	Moderate	High	High
Ohio River	Lower Ohio-Little Pigeon	05140201	IN, KY	High	High↑	**High**$^{-}$	Moderate (87.01)	Moderate	Moderate	High
Ohio River	Silver-Little Kentucky	05140101	IN, KY	High	High↑	Moderate	Moderate (78.74)	Moderate	Moderate	High
Ohio River	Ohio Brush-Whiteoak	05090201	KY, OH	High	High↑	Moderate	Moderate (63.53)	Moderate	Moderate	High
Ohio River	Little Scioto-Tygarts	05090103	KY, OH	High	High↑	Moderate	Moderate (86.24)	Moderate	Moderate	High
Ohio River	Raccoon-Symmes	05090101	OH, WV	High	High↑	Moderate	Low (122.26)	Moderate	**High**$^{-}$	High
Ohio River	Upper Ohio-Shade	05030202	OH, WV	High	High↑	Moderate	Low (116.81)	**High**$^{-}$	High	High
Ohio River	Little Muskingum-Middle Island	05030201	OH, WV	High	High↑	Moderate	Low (156.57)	Moderate	High	High
Allegheny River	Middle Allegheny-Tionesta	05010003	PA	High	High↑	Moderate	Low (171.83)	Moderate	Moderate	High
Green River	Upper Green	05110001	KY	Moderate	Moderate↑	**High**$^{-}$	Moderate (223.08)	Moderate	Moderate	**High**$^{-}$
Kanawha River	Upper Kanawha	05050006	WV	High	High↑	Moderate	Low (135.51)	Low	Moderate	High

Table G.1 (continued). Scenario 1 risk factor future projections for extant sheepnose populations rangewide.

				Current Condition	**Scenario 1 Projected Condition**					
Stream	**HUC 8**	**HUC 8 ID**	**State(s)**	**Overall Risk**	**Water Quality/ Contaminants**	**Landscape (2070)**	**Hydrological Regime (% change in CDSI)**	**Connectivity (2040 & 2050)**	**Invasive Species**	**Overall Risk**
Licking River	Licking	05100101	KY	Moderate	Moderate↑	Moderate	Moderate (111.91)	Moderate	Moderate	Moderate
Muskingum River	Muskingum	05040004	OH	High	High↑	Moderate	Low (123.66)	**High$^-$**	High	High
Walhonding River	Walhonding	05040003	OH	Moderate	Moderate↑	**High$^-$**	Low (148.24)	Moderate	**High$^-$**	**High$^-$**
Tippecanoe River	Tippecanoe	05120106	IN	Moderate	Moderate↑	**High$^-$**	Moderate (54.70)	Moderate	**High$^-$**	**High$^-$**
Tennessee River Basin Representation Unit										
Tennessee River	Lower Tennessee	06040006	KY	High	High↑	**High$^-$**	Moderate (152.05)	Moderate	**High$^-$**	High
Tennessee River	Lower Tennessee-Beech	06040001	TN	High	Moderate↑	Moderate	Moderate (95.86)	High	Moderate	High
Tennessee River	Pickwick Lake	06030005	AL	Moderate	Moderate↑	Moderate	Moderate (63.58)	Moderate	Moderate	Moderate
Tennessee River	Wheeler Lake	06030002	AL	Moderate	Moderate↑	Moderate	Moderate (98.09)	Moderate	Moderate	Moderate
Clinch River	Upper Clinch, Tennessee, Virginia	06010205	TN, VA	High	Moderate↑	Moderate	Moderate (240.62)	**High$^-$**	High	High
Duck River	Lower Duck	06040003	TN	High	Moderate↑	Moderate	Moderate (140.65)	High	**High$^-$**	High
Holston River	Holston	06010104	TN	High	High↑	**High$^-$**	Moderate (160.16)	High	High	High

Table G.1 (continued). Scenario 1 risk factor future projections for extant sheepnose populations rangewide.

Stream	**HUC 8**	**HUC 8 ID**	**State(s)**	**Current Condition**	**Scenario 1 Projected Condition**					
				Overall Risk	**Water Quality/ Contaminants**	**Landscape (2070)**	**Hydrological Regime (% change in CDSI)**	**Connectivity (2040 & 2050)**	**Invasive Species**	**Overall Risk**
Powell River	Powell	06010206	TN, VA	High	Moderate↑	Moderate	Moderate (208.21)	**High**$^{-}$	High	High
Lower Mississippi River Representation Unit										
Big Sunflower River	Big Sunflower	08030207	MS	High	High↑	Moderate	Moderate (27.14)	Low	Moderate	High

Bold text indicates a change from the current risk factor condition, (-) = Declining condition, (+) = Improving condition

↑ = Increased percentage of urban and/or agricultural landcover projected under Scenario 1, indicating an increased risk associated with primary contaminants (ammonia, chloride, copper, nitrate)

G.2 Scenario 2

Upper Mississippi River Basin Representation Unit

Based on the overall risk levels in the Upper Mississippi River basin, we project the same demographic conditions as predicted under Scenario 1, with one exception (Table G.2, Table G.4). The Upper Chippewa population was projected to become extirpated under Scenario 1, but is projected to persist in functionally extirpated demographic condition under Scenario 2. We highlight the projected changes for populations within the Upper Mississippi River basin for Scenario 2 in the following paragraphs, Table G.2, and Tables G.5 – G.10.

- **Water Quality/Contaminants:** Under Scenario 2, the Flambeau, Grant-Little Maquoketa, Castle Rock, Copperas-Duck, Lower Rock, Kankakee, and Meramec populations are predicted to continue to experience high risk associated with water quality impairment. The remaining six populations are currently experiencing low to moderate risk associated with water quality impairment. We do not have the data to determine whether increases or decreases in the four contaminants would meet or exceed threshold levels, thereby affecting the overall risk category. Instead, we were able to project only whether the contaminant risk would be increasing or decreasing for a specific chemical. Under Scenario 2, we project concentrations for each of the four primary contaminants (ammonia, chloride, copper, and nitrate) will increase into the future for all populations within the Upper Mississippi River basin, as indicated by the projected increase in urban and agricultural landcover.
- **Landscape:** The Lower Rock is the only population at high risk due to landscape factors under Scenario 2. The remaining twelve populations are projected to maintain similar current condition low to moderate levels of risk under Scenario 2.
- **Hydrological Regime:** Twelve of the 13 Upper Mississippi River basin populations are at a moderate level of overall risk associated with hydrological regime factors and one population (Castle Rock) is at low risk. Overall, eleven populations are expected to experience decreased drought conditions under Scenario 2, with the remaining two populations (Bourbeuse and Meramec) projected to experience increased drought conditions. The percent change in CDSI ranged widely across populations from a decrease in drought severity of -57.03 percent (Lower Rock) to a 55.19 percent increase (Meramec), with an average of -23.51 percent change.
- **Connectivity:** Two populations continue to experience high risk under Scenario 2 due to connectivity factors (Bourbeuse and Meramec). The remaining populations are projected to maintain a similar moderate to low level of overall risk as a result of connectivity factors between current conditions and Scenario 2.
- **Invasive Species:** The invasive species risks are projected to remain unchanged from the current conditions scores under Scenario 2, with 11 populations currently experiencing a high level of risk and two popualtions experiencing moderate risk.

- **Catastrophic Events:** Oil and natural gas supply as well as coal mining activities are projected to decrease in Scenario 2 leading to decrease in the frequency and intensity of potential catastrophic events. However, the infrastructure is still present. All populations in the Upper Mississippi River basin are at high risk for catastrophic events for oil and natural gas, with no change projected for Scenario 2 (Table G.10). All populations are at low risk of catastrophic event due to coal activity. We project no change in risk for catastrophic events related to coal because the Upper Mississippi River basin populations will remain at low risk.

Ohio River Basin Representation Unit

Based on the overall risk levels in the Ohio River basin, we project the same demographic condition as those under Scenario 1 with two exceptions (Table G.2, Table G.4). The Upper Green and Tippecanoe populations are projected to move from low condition under Scenario 1 to moderate demographic condition under Scenario 2. We highlight the projected changes for populations within the Ohio River basin for Scenario 2 in the following paragraphs, Table G.2, and Tables G.5 – G.10.

- **Water Quality/Contaminants:** Under Scenario 2, the Middle Allegheny-Tionesta, Little Muskingum-Middle Island, Upper Ohio-Shade, Muskingum, Upper Kanawha, Raccoon-Symmes, Little Scioto-Tygarts, Ohio Brush-Whiteoak, Silver-Little Kentucky, Lower Ohio-Little Pigeon, and Lower Ohio populations are predicted to continue to experience high risk associated with water quality impairment. The remaining four populations are currently experiencing moderate risk associated with water quality impairment. We do not have the data to determine whether increases or decreases in the four chemicals would meet or exceed threshold levels, thereby affecting the overall risk category. Instead, we were able to project only whether the contaminant risk would be increasing or decreasing for a specific chemical. Under Scenario 2, we project concentrations for each of the four primary contaminants (ammonia, chloride, copper, and nitrate) will increase into the future for all 15 of the Ohio River basin populations, as indicated by the projected increase in urban and agricultural landcover.
- **Landscape:** Projected landscape changes in the Lower Ohio-Little Pigeon and Walhonding populations increase the risk level of these populations from moderate to high. These changes are primarily a result of projected increase in percent urban land cover by 132.14 and 112.37 percent, respectively. The remaining populations within the Ohio River basin are projected to continue to experience a similar level of overall moderate risk associated with landscape factors under Scenario 2.
- **Hydrological Regime:** Eight of the 15 Ohio River basin populations are at a moderate level of risk for hydrological regime factors and seven populations are at low risk. Overall, the CDSI projects that 13 populations will experience increased drought conditions under Scenario 2, with the remaining two popultations, the Walhonding and Tippecanoe, experiencing decreased drought conditions. The percent change in CDSI

ranged widely across populations from a decrease in severity of -40.27 percent (Walhonding) to 100.09 percent (Little Muskingum-Middle Island), with an average of increase of 51.09 percent change.

- **Connectivity:** All 15 of the Ohio River basin populations are projected to maintain a similar level of moderate to low overall risk as a result of connectivity factors between current conditions and Scenario 2.
- **Invasive Species:** The invasive species risks are projected to remain unchanged from the current conditions scores under Scenario 2, with four populations experiencing high risk and 11 populations at moderate risk.
- **Catastrophic Events:** Oil and natural gas supply as well as coal mining activities are projected to decrease under Scenario 2, leading to a decrease in the frequency and intensity of potential catastrophic events. All populations in the Ohio basin are currently at high risk for a catastrophic event associated with oil and natural gas activities with decreased risk projected under Scenario 2; however, the infrastructure is still present. Most populations are at low risk of catastrophic event due to coal activity, with the exception of the Lower Ohio-Little Pigeon, Raccoon-Symmes, Little Muskingum-Middle Island, Middle Allegheny-Tionesta, Upper Kanawha, and Licking populations. Once again while coal activities will decrease, the infrastructure is still present, which is why the risk for some populations may continue to remain high despite a decrease in production/activity.

Tennessee River Basin Representation Unit

Based on the overall risk levels in the Tennessee River basin, we project the same projected demographic condition as Scenario 1 (Table G.2, Table G.4). We highlight the projected changes for populations within the Tennessee River basin for Scenario 2 in the following paragraphs, Table G.2, and Tables G.5 – G.10.

- **Water Quality/Contaminants:** Under Scenario 2, the Holston, and Lower Tennesse populations are predicted to continue to experience high risk associated with water quality impairment. The remaining six populations are currently experiencing moderate risk associated with water quality impairment. We do not have the data to determine whether increases or decreases in the four chemicals would meet or exceed threshold levels, thereby affecting the overall risk category. Instead, we were able to project only whether the contaminant risk would be increasing or decreasing for a specific chemical. Under Scenario 2, we project concentrations for each of the four primary contaminants (ammonia, chloride, copper, and nitrate) will increase into the future for all eight of the Tennessee River basin populations, as indicated by the projected increase in urban and agricultural landcover.
- **Landscape:** Under Scenario 2, the overall moderate risk conditions associated with landscape factors are projected to remain the same as current conditions for all eight populations within the Tennessee River basin.

- **Hydrological Regime:** All eight of the Tenneesee River basin populations currently experience a moderate level of risk associated with the hydrological regime. Overall, the CDSI projects that all eight populations will experience increased drought conditions under Scenario 2. However, the percent change in CDSI ranged widely across populations from an increase in severity of 84.96 percent (Wheeler Lake) to 133.11 percent (Lower Tennessee-Beech), with an average of increase of 110.03 percent change.
- **Connectivity:** Three populations continue to experience high risk under Scenario 2 due to connectivity factors (Lower Tennessee-Beech, Lower Duck, and Holston). The remaining five populations are projected to maintain a similar moderate level of overall risk as a result of connectivity factors between current conditions and Scenario 2.
- **Invasive Species:** The invasive species risks are projected to remain unchanged from the current conditions scores under Scenario 2, with three of the populations experiencing high risk conditions and the remaining populations at moderate risk.
- **Catastrophic Events:** Oil and natural gas supply as well as coal mining activities are projected to decrease in Scenario 2, leading to decrease in the frequency and intensity of potential catastrophic events. All of the Tennessee River basin populations are at high risk for catastrophic events for oil and natural gas. Once again while coal activities will decrease, the infrastructure is still present, which is why for some of the populations the risk remains high despite a decrease in production/activity.

Lower Mississippi River Basin Representation Unit

Based on the overall risk levels in the Lower Mississippi River basin, we project the same projected demographic condition as Scenario 1 (Table G.2, Table G.4). We highlight the projected changes for Big Sunflower population within the Lower Mississippi basin for Scenario 2 in the following paragraphs, Table G.2, and Tables G.5 – G.10.

- **Water Quality/Contaminants:** Under Scenario 2, the Big Sunflower population is predicted to continue to experience high risk associated with water quality impairment. We do not have the data to determine whether increases or decreases in the four contaminants would meet or exceed threshold levels, thereby affecting the overall risk category. Instead, we were able to project only whether the contaminant risk would be increasing or decreasing for a specific contaminat. Copper seems to be the driver of the high risk for this population; however, concentrations of all four of the primary contaminants (ammonia, chloride, copper, and nitrate) are predicted to increase into the future as indicated by the projected increase in urban and agricultural landcover.
- **Landscape:** The Big Sunflower population is projected to maintain an overall moderate level of threat for landscape factors between current conditions and Scenario 2.
- **Hydrological Regime:** The Big Sunflower population is projected to have the CDSI increase by approximately 71.77 percent under Scenario 2, increasing the risk of drought to sheepnose. However, we cannot determine if this increase would move the risk factor into the high threshold.

- **Connectivity:** The Big Sunflower population is projected to maintain a similar level of low overall risk as a result of connectivity factors between current conditions and Scenario 2.
- **Invasive Species:** The invasive species risks are projected to remain unchanged from a moderate risk under Scenario 2.
- **Catastrophic Events:** Oil and natural gas supply as well as coal mining activities are projected to decrease in Scenario 2 leading to decrease in the frequency and intensity of potential catastrophic events. However, the infrastructure is still present; therefore, the Big Sunflower population is at high risk for catastrophic events for oil and natural gas. We project no change in risk for catastrophic events related to coal because the Big Sunflower population remains at low risk (Table G.10).

Table G.2. Scenario 2 risk factor future projections for extant sheepnose populations rangewide.

Stream	HUC 8	HUC 8 ID	State(s)	Current Condition	Scenario 2 Projected Condition					
				Overall Risk	Water Quality/ Contaminants	Landscape (2070)	Hydrological Regime (% change in CDSI)	Connectivity (2040 & 2050)	Invasive Species	Overall Risk
Upper Mississippi River Basin Representation Unit										
Mississippi River	Buffalo-Whitewater	07040003	MN, WI	High	Low↑	Moderate	Moderate (-46.54)	Moderate	High	High
Mississippi River	La Crosse-Pine	07040006	MN, WI	High	Moderate↑	Moderate	Moderate (-41.66)	Moderate	High	High
Mississippi River	Grant-Little Maquoketa	07060003	IA, WI	High	High↑	Moderate	Moderate (-14.41)	Low	High	High
Mississippi River	Copperas-Duck	07080101	IA, IL	High	High↑	Moderate	Moderate (-39.83)	Moderate	High	High
Chippewa River	Upper Chippewa	07050001	WI	Moderate	Low↑	Low	Moderate (-19.35)	Moderate	Moderate	Moderate
Chippewa River	Lower Chippewa	07050005	WI	High	Moderate↑	Moderate	Moderate (-49.85)	Moderate	High	High
Flambeau River	Flambeau	07050002	WI	High	High↑	Low	Moderate (-9.80)	Moderate	Moderate	High
Wisconsin River	Castle Rock	07070003	WI	High	High↑	Moderate	Low (-56.69)	Moderate	High	High
Wisconsin River	Lower Wisconsin	07070005	WI	High	Moderate↑	Moderate	Moderate (-43.42)	Moderate	High	High
Rock River	Lower Rock	07090005	IL	High	High↑	High	Moderate (-57.03)	Moderate	High	High
Kankakee River	Kankakee	07120001	IL	High	High↑	Moderate	Moderate (-32.15)	Moderate	High	High
Bourbeuse River	Bourbeuse	07140103	MO	High	Low↑	Moderate	Moderate (49.95)	High	High	High
Meramec River	Meramec	07140102	MO	High	High↑	Moderate	Moderate (55.19)	High	High	High

Table G.2 (continued). Scenario 2 risk factor future projections for extant sheepnose populations rangewide.

Stream	HUC 8	HUC 8 ID	State(s)	Current Condition	Scenario 2 Projected Condition					
				Overall Risk	**Water Quality/ Contaminants**	**Landscape (2070)**	**Hydrological Regime (% change in CDSI)**	**Connectivity (2040 & 2050)**	**Invasive Species**	**Overall Risk**
Ohio River Basin Representation Unit										
Ohio River	Lower Ohio	05140206	IL, KY	High	High↑	Moderate	Moderate (86.55)	Moderate	High	High
Ohio River	Lower Ohio-Little Pigeon	05140201	IN, KY	High	High↑	**High**$^{-}$	Moderate (42.76)	Moderate	Moderate	High
Ohio River	Silver-Little Kentucky	05140101	IN, KY	High	High↑	Moderate	Moderate (32.87)	Moderate	Moderate	High
Ohio River	Ohio Brush-Whiteoak	05090201	KY, OH	High	High↑	Moderate	Moderate (48.44)	Moderate	Moderate	High
Ohio River	Little Scioto-Tygarts	05090103	KY, OH	High	High↑	Moderate	Moderate (70.82)	Moderate	Moderate	High
Ohio River	Raccoon-Symmes	05090101	OH, WV	High	High↑	Moderate	Low (75.65)	Moderate	Moderate	High
Ohio River	Upper Ohio-Shade	05030202	OH, WV	High	High↑	Moderate	Low (83.73)	Moderate	High	High
Ohio River	Little Muskingum-Middle Island	05030201	OH, WV	High	High↑	Moderate	Low (100.09)	Moderate	High	High
Allegheny River	Middle Allegheny-Tionesta	05010003	PA	High	High↑	Moderate	Low (17.47)	Moderate	Moderate	High
Green River	Upper Green	05110001	KY	Moderate	Moderate↑	Moderate	Moderate (97.82)	Moderate	Moderate	Moderate

Table G.2 (continued). Scenario 2 risk factor future projections for extant sheepnose populations rangewide.

Stream	**HUC 8**	**HUC 8 ID**	**State(s)**	**Current Condition**	**Scenario 2 Projected Condition**					
				Overall Risk	**Water Quality/ Contaminants**	**Landscape (2070)**	**Hydrological Regime (% change in CDSI)**	**Connectivity (2040 & 2050)**	**Invasive Species**	**Overall Risk**
Kanawha River	Upper Kanawha	05050006	WV	High	High↑	Moderate	Low (58.84)	Low	Moderate	High
Licking River	Licking	05100101	KY	Moderate	Moderate↑	Moderate	Moderate (70.68)	Moderate	Moderate	Moderate
Muskingum River	Muskingum	05040004	OH	High	High↑	Moderate	Low (30.68)	Moderate	High	High
Walhonding River	Walhonding	05040003	OH	Moderate	Moderate↑	**High**$^-$	Low (-40.27)	Moderate	Moderate	**High**$^-$
Tippecanoe River	Tippecanoe	05120106	IN	Moderate	Moderate↑	Moderate	Moderate (-9.76)	Moderate	Moderate	Moderate
Tennessee River Basin Representation Unit										
Tennessee River	Lower Tennessee	06040006	KY	High	High↑	Moderate	Moderate (128.82)	Moderate	Moderate	High
Tennessee River	Lower Tennessee-Beech	06040001	TN	High	Moderate↑	Moderate	Moderate (133.11)	High	Moderate	High
Tennessee River	Pickwick Lake	06030005	AL	Moderate	Moderate↑	Moderate	Moderate (98.49)	Moderate	Moderate	Moderate
Tennessee River	Wheeler Lake	06030002	AL	Moderate	Moderate↑	Moderate	Moderate (84.96)	Moderate	Moderate	Moderate
Clinch River	Upper Clinch, Tennessee, Virginia	06010205	TN, VA	High	Moderate↑	Moderate	Moderate (89.22)	Moderate	High	High
Duck River	Lower Duck	06040003	TN	High	Moderate↑	Moderate	Moderate (128.22)	High	Moderate	High

Table G.2 (continued). Scenario 2 risk factor future projections for extant sheepnose populations rangewide.

Stream	**HUC 8**	**HUC 8 ID**	**State(s)**	**Current Condition**	**Scenario 2 Projected Condition**					
				Overall Risk	**Water Quality/ Contaminants**	**Landscape (2070)**	**Hydrological Regime (% change in CDSI)**	**Connectivity (2040 & 2050)**	**Invasive Species**	**Overall Risk**
Holston River	Holston	06010104	TN	High	High↑	Moderate	Moderate (113.48)	High	High	High
Powell River	Powell	06010206	TN, VA	High	Moderate↑	Moderate	Moderate (103.96)	Moderate	High	High
Lower Mississippi River Representation Unit										
Big Sunflower River	Big Sunflower	08030207	MS	High	High↑	Moderate	Moderate (71.77)	Low	Moderate	High

Bold text indicates a change from the current risk factor condition, (-) = Declining condition, (+) = Improving condition
↑ = Increased percentage of urban and/or agricultural landcover projected under Scenario 2, indicating an increased risk associated with primary contaminants (ammonia, chloride, copper, nitrate)

G.3 Summary of Scenarios 1 and 2

Table G.3. Summary of projected demographic condition for sheepnose extant populations given Scenario 1 and Scenario 2 risk levels across the species' range.

Demographic Condition	**Upper Mississippi River Basin**		**Ohio River Basin**		**Tennessee River Basin**		**Lower Mississippi River Basin**	
	HUC8 Count							
	Current Condition	**Projected (2040-2070)**	**Current Condition**	**Projected (2040-2070)**	**Current Condition**	**Projected (2040-2070)**	**Current Condition**	**Projected (2040-2070)**
High	3	0	2	0	1	0	0	0
Moderate	2	0	5	0/2*	2	0	0	0
Low	5	3	7	2/0*	3	1	1	0
Functionally Extirpated	3	2/3*	1	6	2	3	0	0
Extirpated	--	8/7*	--	7	--	4	--	1
Total	13	5/6*	15	8	8	4	1	0

* Scenario 1 / Scenario 2

Table G.4. Summary of current demographic and risk population conditions with future risk factors for Scenarios 1 and 2 and the predicted demographic population conditions for sheepnose.

Stream	HUC 8	HUC 8 ID	State(s)	Current Condition		Scenario 1		Scenario 2	
				Overall Risk Factor	**Demographic Condition***	**Overall Risk Factor**	**Predicted Demographic Condition***	**Overall Risk Factor**	**Predicted Demographic Condition***
Upper Mississippi River Basin Representation Unit									
Mississippi River	Buffalo-Whitewater	07040003	MN, WI	High	Low	High	Extirpated	High	Extirpated
Mississippi River	La Crosse-Pine	07040006	MN, WI	High	Fx	High	Extirpated	High	Extirpated
Mississippi River	Grant-Little Maquoketa	07060003	IA, WI	High	Fx	High	Extirpated	High	Extirpated
Mississippi River	Copperas-Duck	07080101	IA, IL	High	Moderate	High	Fx	High	Fx
Chippewa River	Upper Chippewa	07050001	WI	Moderate	Low	High	Extirpated	Moderate	Fx
Chippewa River	Lower Chippewa	07050005	WI	High	High	High	Low	High	Low
Flambeau River	Flambeau	07050002	WI	High	Low	High	Extirpated	High	Extirpated
Wisconsin River	Castle Rock	07070003	WI	High	Low	High	Extirpated	High	Extirpated
Wisconsin River	Lower Wisconsin	07070005	WI	High	Low	High	Extirpated	High	Extirpated
Rock River	Lower Rock	07090005	IL	High	Fx	High	Extirpated	High	Extirpated
Kankakee River	Kankakee	07120001	IL	High	High	High	Low	High	Low
Bourbeuse River	Bourbeuse	07140103	MO	High	Moderate	High	Fx	High	Fx
Meramec River	Meramec	07140102	MO	High	High	High	Low	High	Low
Ohio River Basin Representation Unit									
Ohio River	Lower Ohio	05140206	IL, KY	High	Low	High	Extirpated	High	Extirpated
Ohio River	Lower Ohio-Little Pigeon	05140201	IN, KY	High	Moderate	High	Fx	High	Fx
Ohio River	Silver-Little Kentucky	05140101	IN, KY	High	Low	High	Extirpated	High	Extirpated
Ohio River	Ohio Brush-Whiteoak	05090201	KY, OH	High	Moderate	High	Fx	High	Fx
Ohio River	Little Scioto-Tygarts	05090103	KY, OH	High	Low	High	Extirpated	High	Extirpated

Table G.4 (continued). Summary of current demographic and risk population conditions with future risk factors for Scenarios 1 and 2 and the predicted demographic population conditions for sheepnose.

Stream	**HUC 8**	**HUC 8 ID**	**State(s)**	**Current Condition**		**Scenario 1**		**Scenario 2**	
				Overall Risk Factor	**Demographic Condition***	**Overall Risk Factor**	**Predicted Demographic Condition***	**Overall Risk Factor**	**Predicted Demographic Condition***
Ohio River	Raccoon-Symmes	05090101	OH, WV	High	Low	High	Extirpated	High	Extirpated
Ohio River	Upper Ohio-Shade	05030202	OH, WV	High	Low	High	Extirpated	High	Extirpated
Ohio River	Little Muskingum-Middle Island	05030201	OH, WV	High	Low	High	Extirpated	High	Extirpated
Allegheny River	Middle Allegheny-Tionesta	05010003	PA	High	Moderate	High	Fx	High	Fx
Green River	Upper Green	05110001	KY	Moderate	High	High	Low	Moderate	Moderate
Kanawha River	Upper Kanawha	05050006	WV	High	Moderate	High	Fx	High	Fx
Licking River	Licking	05100101	KY	Moderate	Low	Moderate	Fx	Moderate	Fx
Muskingum River	Muskingum	05040004	OH	High	Fx	High	Extirpated	High	Extirpated
Walhonding River	Walhonding	05040003	OH	Moderate	Moderate	High	Fx	High	Fx
Tippecanoe River	Tippecanoe	05120106	IN	Moderate	High	High	Low	Moderate	Moderate
Tennessee River Basin Representation Unit									
Tennessee River	Lower Tennessee	06040006	KY	High	Moderate	High	Fx	High	Fx
Tennessee River	Lower Tennessee-Beech	06040001	TN	High	Low	High	Extirpated	High	Extirpated
Tennessee River	Pickwick Lake	06030005	AL	Moderate	Low	Moderate	Fx	Moderate	Fx
Tennessee River	Wheeler Lake	06030002	AL	Moderate	Fx	Moderate	Extirpated	Moderate	Extirpated
Clinch River	Upper Clinch, Tennessee, Virginia	06010205	TN, VA	High	High	High	Low	High	Low
Duck River	Lower Duck	06040003	TN	High	Fx	High	Extirpated	High	Extirpated
Holston River	Holston	06010104	TN	High	Low	High	Extirpated	High	Extirpated

Table G.4 (continued). Summary of current demographic and risk population conditions with future risk factors for Scenarios 1 and 2 and the predicted demographic population conditions for sheepnose.

Stream	HUC 8	HUC 8 ID	State(s)	Current Condition		Scenario 1		Scenario 2	
				Overall Risk Factor	Demographic Condition*	Overall Risk Factor	Predicted Demographic Condition*	Overall Risk Factor	Predicted Demographic Condition*
Powell River	Powell	06010206	TN, VA	High	Moderate	High	Fx	High	Fx
Lower Mississippi River Basin Representation Unit									
Big Sunflower River	Big Sunflower	08030207	MS	High	Low	High	Extirpated	High	Extirpated

*Fx = Functionally Extirpated (refer to Section 4.2.1)

Table G.5. Water Quality/ Contaminants Risk Factors - Metrics Summary

HUC2 Name	**HUC8 Name**	**HUC8 ID**	**Current Condition**											
			Individual Contaminant Risk Category										**Overall Score**	**Overall Risk**
			Ammonia	**Chloride**	**Copper**	**Nitrate**	**Aluminum**	**Cadmium**	**Lead**	**Potassium**	**Sulfate**	**Zinc**		
Ohio River	Middle Allegheny-Tionesta	5010003	Low	Low	High	Low	Low	Low	Moderate	Low	Low	Moderate	3	High
	Little Muskingum-Middle Island	5030201	Low	Low	Moderate	High	Moderate	Moderate	High	High	Low	Moderate	3	High
	Upper Ohio-Shade	5030202	Low	High	Moderate	High	Moderate	Moderate	Moderate	High	Low	Moderate	3	High
	Walhonding	5040003	Moderate	Moderate	Moderate	--	Moderate	Moderate	Moderate	Moderate	Low	Moderate	2	Moderate
	Muskingum	5040004	Low	Low	High	--	High	High	High	Moderate	Low	High	3	High
	Upper Kanawha	5050006	High	Low	Low	--	Low	Low	Low	--	--	Low	3	High
	Raccoon-Symmes	5090101	Low	Low	Moderate	High	Moderate	Low	Low	Low	Low	Low	3	High
	Little Scioto-Tygarts	5090103	Low	Low	High	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Moderate	3	High
	Ohio Brush-Whiteoak	5090201	Low	Low	Moderate	High	Moderate	Moderate	Moderate	Moderate	Low	Moderate	3	High
	Licking	5100101	Moderate	Low	Moderate	Low	Low	Low	Low	Moderate	Low	Low	2	Moderate
	Upper Green	5110001	Low	Low	Moderate	Low	Low	Moderate	Low	Moderate	Low	Low	2	Moderate
	Tippecanoe	5120106	Low	Low	Moderate	Low	Low	Low	Low	High	Low	Moderate	2	Moderate
	Silver-Little Kentucky	5140101	Moderate	Low	High	High	Low	Low	Low	Low	Low	Moderate	3	High
	Lower Ohio-Little Pigeon	5140201	Low	Low	Moderate	High	Low	Moderate	Moderate	Moderate	Low	Moderate	3	High
	Lower Ohio	5140206	Low	Low	High	Moderate	Low	High	High	High	Low	High	3	High
Tennessee River	Holston	6010104	Low	Low	High	Low	Low	High	Moderate	--	Low	Low	3	High
	Upper Clinch, Tennessee, Virginia	6010205	Low	Low	Moderate	Low	Low	Moderate	Moderate	Low	Low	Moderate	2	Moderate
	Powell	6010206	Low	Low	Moderate	Low	Low	Moderate	Moderate	Low	Low	Low	2	Moderate
	Wheeler Lake	6030002	Low	Moderate	Moderate	--	Low	Low	Low	--	Low	Low	2	Moderate
	Pickwick Lake	6030005	Low	Low	Moderate	Low	Low	Low	Low	Low	Low	Low	2	Moderate
	Lower Tennessee-Beech	6040001	Low	Low	Moderate	Low	Low	Moderate	High	Low	Low	High	2	Moderate
	Lower Duck	6040003	Low	Low	Moderate	Low	Low	Moderate	Moderate	Low	Low	Low	2	Moderate
	Lower Tennessee	6040006	Low	Low	High	Low	Low	High	High	Low	Low	High	3	High
Upper Mississippi River	Buffalo-Whitewater	7040003	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	1	Low
	La Crosse-Pine	7040006	Low	Moderate	Low	Low	Low	Low	Low	Low	Low	Low	2	Moderate
	Upper Chippewa	7050001	Low	Low	--	--	--	--	--	--	--	Low	1	Low
	Flambeau	7050002	Low	Low	High	--	--	Low	Low	Low	Low	Low	3	High
	Lower Chippewa	7050005	Low	Moderate	Low	Low	Low	Low	Low	Low	Low	Low	2	Moderate
	Grant-Little Maquoketa	7060003	High	High	High	High	Low	Low	Low	High	Low	Low	3	High
	Castle Rock	7070003	Moderate	High	High	Low	--	Low	Low	Low	Low	Low	3	High
	Lower Wisconsin	7070005	Moderate	Moderate	--	Low	--	--	--	Low	Low	Low	2	Moderate
	Copperas-Duck	7080101	Low	High	High	Moderate	Low	High	High	High	Low	High	3	High
	Lower Rock	7090005	Low	Moderate	Moderate	High	Low	Low	Low	High	Low	Moderate	3	High
	Kankakee	7120001	Low	Moderate	High	Low	Low	Low	Low	High	Low	Moderate	3	High
	Meramec	7140102	Low	High	Moderate	Moderate	Low	Low	Low	Low	Low	Low	3	High
	Bourbeuse	7140103	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	1	Low
Lower Mississippi River	Big Sunflower	8030207	Low	Low	High	Moderate	Low	Low	Low	Low	Low	Low	3	High

Table G.5 (continued). Water Quality/ Contaminants Risk Factors - Metrics Summary

HUC2 Name	**HUC8 Name**	**HUC8 ID**	**Scenario 1**									
			Percent Change Urban Development Land Cover	**Urban Land Cover Trend**	**Percent Change Agricultural Land Cover**	**Ag Land Cover Trend**	**Trends of Primary Contaminants (Ag and/or Urban Land Cover)****					**Number of Primary Contaminants with Increasing Trends***
							Ammonia	**Chloride**	**Copper**	**Nitrate**	**Metals**	
							Urban and Ag	**Urban and Ag**	**Urban**	**Urban and Ag**	**Urban**	
Ohio River	Middle Allegheny-Tionesta	5010003	73.56	Increasing	116.85	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Little Muskingum-Middle Island	5030201	7.11	Increasing	27.94	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Upper Ohio-Shade	5030202	23.87	Increasing	21.19	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Walhonding	5040003	163.06	Increasing	21.36	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Muskingum	5040004	34.13	Increasing	33.16	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Upper Kanawha	5050006	242.4	Increasing	51.34	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Raccoon-Symmes	5090101	62.01	Increasing	19.17	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Little Scioto-Tygarts	5090103	97.82	Increasing	48.41	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Ohio Brush-Whiteoak	5090201	82.91	Increasing	17.46	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Licking	5100101	84.89	Increasing	49.31	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Upper Green	5110001	87.52	Increasing	31.63	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Tippecanoe	5120106	74.87	Increasing	2.83	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Silver-Little Kentucky	5140101	44.74	Increasing	7.55	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Ohio-Little Pigeon	5140201	90.11	Increasing	10.12	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Ohio	5140206	120.79	Increasing	5.46	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
Tennessee River	Holston	6010104	40.03	Increasing	20.81	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Upper Clinch, Tennessee, Virginia	6010205	38.50	Increasing	29.65	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Powell	6010206	29.70	Increasing	25.39	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Wheeler Lake	6030002	99.41	Increasing	8.03	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Pickwick Lake	6030005	118.74	Increasing	20.55	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Tennessee-Beech	6040001	3.54	Increasing	60.82	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Duck	6040003	168.79	Increasing	65.35	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Tennessee	6040006	218.10	Increasing	14.21	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
Upper Mississippi River	Buffalo-Whitewater	7040003	64.37	Increasing	8.47	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	La Crosse-Pine	7040006	97.11	Increasing	6.93	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Upper Chippewa	7050001	0.00	Increasing	35.51	Increasing	Increasing	Increasing	Decreasing	Increasing	Increasing	3
	Flambeau	7050002	34.42	Increasing	15.91	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Chippewa	7050005	119.48	Increasing	5.81	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Grant-Little Maquoketa	7060003	100.53	Increasing	5.80	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Castle Rock	7070003	166.90	Increasing	13.60	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Wisconsin	7070005	47.63	Increasing	15.65	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Copperas-Duck	7080101	36.17	Increasing	-5.03	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Rock	7090005	89.15	Increasing	-7.62	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Kankakee	7120001	140.64	Increasing	-1.49	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Meramec	7140102	36.78	Increasing	70.15	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Bourbeuse	7140103	72.18	Increasing	31.95	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4

Table G.5 (continued). Water Quality/ Contaminants Risk Factors - Metrics Summary

HUC2 Name	HUC8 Name	HUC8 ID	Scenario 1									
			Percent Change Urban Development Land Cover	**Urban Land Cover Trend**	**Percent Change Agricultural Land Cover**	**Ag Land Cover Trend**	**Trends of Primary Contaminants (Ag and/or Urban Land Cover)****					**Number of Primary Contaminants with Increasing Trends***
							Ammonia	**Chloride**	**Copper**	**Nitrate**	**Metals**	
							Urban and Ag	**Urban and Ag**	**Urban**	**Urban and Ag**	**Urban**	
Lower Mississippi River	Big Sunflower	8030207	82.26	Increasing	1.71	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4

HUC2 Name	HUC8 Name	HUC8 ID	Scenario 2									
			Percent Change Urban Development Land Cover	**Urban Land Cover Trend**	**Percent Change Agricultural Landcover**	**Ag Land Cover Trend**	**Trends of Primary Contaminants by Source (Ag and/or Urban Land Cover)****					**Number of Primary Contaminants with Increasing Trends***
							Ammonia	**Chloride**	**Copper**	**Nitrate**	**Metals**	
							Urban and Ag	**Urban and Ag**	**Urban**	**Urban and Ag**	**Urban**	
Ohio River	Middle Allegheny-Tionesta	5010003	21.74	Increasing	-31.2	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Little Muskingum-Middle Island	5030201	3.21	Increasing	-13.46	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Upper Ohio-Shade	5030202	7.1	Increasing	-7.42	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Walhonding	5040003	112.37	Increasing	-14.25	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Muskingum	5040004	14.18	Increasing	-10.21	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Upper Kanawha	5050006	94.5	Increasing	-47.07	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Raccoon-Symmes	5090101	23.72	Increasing	-8.97	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Little Scioto-Tygarts	5090103	31.14	Increasing	-14.62	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Ohio Brush-Whiteoak	5090201	44.85	Increasing	-7.02	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Licking	5100101	73.28	Increasing	-17.69	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Upper Green	5110001	113.63	Increasing	-16.4	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Tippecanoe	5120106	54.01	Increasing	-1.95	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Silver-Little Kentucky	5140101	31.20	Increasing	-8.46	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Ohio-Little Pigeon	5140201	132.14	Increasing	-4.70	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Ohio	5140206	142.52	Increasing	-6.02	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
Tennessee River	Holston	6010104	23.53	Increasing	-13.88	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Upper Clinch, Tennessee, Virginia	6010205	9.69	Increasing	-22.50	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Powell	6010206	2.13	Increasing	-18.91	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Wheeler Lake	6030002	97.51	Increasing	-12.08	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Pickwick Lake	6030005	107.70	Increasing	-15.60	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Tennessee-Beech	6040001	0.34	Increasing	-45.60	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Duck	6040003	166.97	Increasing	-23.36	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Tennessee	6040006	226.29	Increasing	-23.79	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4

Table G.5 (continued). Water Quality/ Contaminants Risk Factors - Metrics Summary

HUC2 Name	HUC8 Name	HUC8 ID	Scenario 2									
			Percent Change Urban Development Land Cover	Urban Land Cover Trend	Percent Change Agricultural Landcover	Ag Land Cover Trend	Trends of Primary Contaminants by Source (Ag and/or Urban Land Cover)**					Number of Primary Contaminants with Increasing Trends*
							Ammonia	Chloride	Copper	Nitrate	Metals	
							Urban and Ag	Urban and Ag	Urban	Urban and Ag	Urban	
Upper Mississippi River	Buffalo-Whitewater	7040003	17.54	Increasing	-8.72	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	La Crosse-Pine	7040006	63.70	Increasing	-12.06	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Upper Chippewa	7050001	0.01	Increasing	-14.00	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Flambeau	7050002	11.16	Increasing	-12.50	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Chippewa	7050005	99.25	Increasing	-8.41	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Grant-Little Maquoketa	7060003	77.40	Increasing	-5.34	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Castle Rock	7070003	114.64	Increasing	-11.68	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Wisconsin	7070005	22.89	Increasing	-9.44	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Copperas-Duck	7080101	19.19	Increasing	-0.47	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Lower Rock	7090005	33.36	Increasing	1.38	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Kankakee	7120001	64.54	Increasing	0.01	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Meramec	7140102	25.88	Increasing	-12.11	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
	Bourbeuse	7140103	47.12	Increasing	-5.12	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4
Lower Mississippi River	Big Sunflower	8030207	67.99	Increasing	-4.50	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	4

Primary Contaminants = Ammonia, Chloride, Copper, Nitrate

*Trend projected based on percent change for agriculture and/or urban development in FORE-SCE land cover change model SRES A2.

**Trend projected based on percent change for agriculture and/or urban development in FORE-SCE land cover change model SRES B1.

Table G.6. Landscape Risk Factors - Metrics Summary

HUC2 Name	HUC8 Name	HUC8 ID	Current Condition																
			Impervious Surface			Urban Land Cover			Agricultural Land Cover			Riparian Buffer Vegetation			Canopy Cover			Overall Risk Score	Overall Risk Category
			Mean Value	Risk Score	Risk Category	Percent Cover	Risk Score	Risk Category	Percent Cover	Risk Score	Risk Category	Percent Cover	Risk Score	Risk Category	Mean Value	Risk Score	Risk Category		
Ohio River	Middle Allegheny-Tionesta	5010003	0.54	1	Low	5.20	2	Moderate	10.25	1	Low	79.34	1	Low	42.99	3	High	2	Moderate
	Little Muskingum-Middle Island	5030201	0.81	1	Low	6.09	2	Moderate	9.79	1	Low	45.20	3	High	19.70	3	High	2	Moderate
	Upper Ohio-Shade	5030202	1.54	1	Low	8.00	2	Moderate	18.78	1	Low	42.08	3	High	17.61	3	High	2	Moderate
	Walhonding	5040003	1.53	1	Low	8.16	2	Moderate	50.87	3	High	46.96	3	High	25.64	3	High	2	Moderate
	Muskingum	5040004	1.20	1	Low	7.14	2	Moderate	29.53	2	Moderate	49.47	3	High	30.92	3	High	2	Moderate
	Upper Kanawha	5050006	2.04	1	Low	6.28	2	Moderate	0.72	1	Low	36.07	3	High	23.12	3	High	2	Moderate
	Raccoon-Symmes	5090101	1.47	1	Low	7.25	2	Moderate	17.77	1	Low	31.55	3	High	13.89	3	High	2	Moderate
	Little Scioto-Tygarts	5090103	2.64	1	Low	10.01	3	High	15.48	1	Low	28.98	3	High	12.47	3	High	2	Moderate
	Ohio Brush-Whiteoak	5090201	1.17	1	Low	6.41	2	Moderate	32.86	2	Moderate	55.61	2	Moderate	17.18	3	High	2	Moderate
	Licking	5100101	1.25	1	Low	6.41	2	Moderate	29.17	2	Moderate	67.04	2	Moderate	43.05	3	High	2	Moderate
	Upper Green	5110001	0.68	1	Low	5.98	2	Moderate	41.71	3	High	70.32	2	Moderate	44.90	3	High	2	Moderate
	Tippecanoe	5120106	1.39	1	Low	6.95	2	Moderate	80.52	3	High	56.83	2	Moderate	30.16	3	High	2	Moderate
	Silver-Little Kentucky	5140101	6.12	1	Low	20.05	3	High	30.06	2	Moderate	54.83	2	Moderate	13.41	3	High	2	Moderate
	Lower Ohio-Little Pigeon	5140201	1.21	1	Low	7.19	2	Moderate	43.45	3	High	40.52	3	High	10.40	3	High	2	Moderate
	Lower Ohio	5140206	1.71	1	Low	8.60	2	Moderate	53.70	3	High	61.99	2	Moderate	11.51	3	High	2	Moderate
Tennessee River	Holston	6010104	2.70	1	Low	13.18	3	High	34.07	2	Moderate	45.57	3	High	20.13	3	High	2	Moderate
	Upper Clinch, Tennessee, Virginia	6010205	1.45	1	Low	7.37	2	Moderate	18.38	1	Low	69.55	2	Moderate	41.12	3	High	2	Moderate
	Powell	6010206	1.43	1	Low	7.79	2	Moderate	14.56	1	Low	79.02	1	Low	48.24	3	High	2	Moderate
	Wheeler Lake	6030002	3.08	1	Low	12.82	3	High	41.18	3	High	68.67	2	Moderate	16.16	3	High	2	Moderate
	Pickwick Lake	6030005	1.56	1	Low	8.08	2	Moderate	36.21	2	Moderate	79.82	1	Low	11.17	3	High	2	Moderate
	Lower Tennessee-Beech	6040001	0.63	1	Low	5.12	2	Moderate	20.60	1	Low	52.89	2	Moderate	23.51	3	High	2	Moderate
	Lower Duck	6040003	1.09	1	Low	7.13	2	Moderate	23.82	1	Low	59.36	2	Moderate	37.51	3	High	2	Moderate
	Lower Tennessee	6040006	1.73	1	Low	9.72	2	Moderate	48.52	3	High	58.02	2	Moderate	21.65	3	High	2	Moderate
Upper Mississippi River	Buffalo-Whitewater	7040003	1.09	1	Low	5.43	2	Moderate	48.75	3	High	82.34	1	Low	16.53	3	High	2	Moderate
	La Crosse-Pine	7040006	3.29	1	Low	10.54	3	High	32.47	2	Moderate	77.93	1	Low	16.10	3	High	2	Moderate
	Upper Chippewa	7050001	0.24	1	Low	3.07	1	Low	7.51	1	Low	86.05	1	Low	40.59	3	High	1	Low
	Flambeau	7050002	0.35	1	Low	3.77	1	Low	2.81	1	Low	93.69	1	Low	53.24	2	Moderate	1	Low
	Lower Chippewa	7050005	1.18	1	Low	5.95	2	Moderate	46.73	3	High	77.73	1	Low	31.61	3	High	2	Moderate
	Grant-Little Maquoketa	7060003	1.10	1	Low	5.46	2	Moderate	67.03	3	High	91.23	1	Low	15.22	3	High	2	Moderate
	Castle Rock	7070003	1.38	1	Low	6.86	2	Moderate	34.52	2	Moderate	82.20	1	Low	24.28	3	High	2	Moderate
	Lower Wisconsin	7070005	0.83	1	Low	4.98	1	Low	44.48	3	High	88.44	1	Low	36.18	3	High	2	Moderate
	Copperas-Duck	7080101	5.64	1	Low	16.74	3	High	61.13	3	High	73.28	2	Moderate	16.33	3	High	2	Moderate
	Lower Rock	7090005	3.98	1	Low	12.24	3	High	77.24	3	High	45.69	3	High	18.50	3	High	3	High
	Kankakee	7120001	2.63	1	Low	9.40	2	Moderate	75.69	3	High	60.53	2	Moderate	24.36	3	High	2	Moderate
	Meramec	7140102	2.10	1	Low	8.80	2	Moderate	18.05	1	Low	66.77	2	Moderate	34.77	3	High	2	Moderate
	Bourbeuse	7140103	1.35	1	Low	6.87	2	Moderate	35.57	2	Moderate	65.07	2	Moderate	34.74	3	High	2	Moderate
Lower Mississippi River	Big Sunflower	8030207	0.65	1	Low	4.79	1	Low	79.83	3	High	40.05	3	High	25.89	3	High	2	Moderate

Table G.6 (continued). Landscape Risk Factors - Metrics Summary

HUC2 Name	HUC8 Name	HUC8 ID	Scenario 1*																			
			Impervious Surface			Urban Land Cover				Agricultural Land Cover				Riparian Buffer Vegetation				Canopy Cover			Overall Risk Score	Overall Risk Category
			Percent Cover	Risk Score	Risk Category	Percent Cover	Percent Cover	Risk Score	Risk Category	Percent Cover	Percent Change	Risk Score	Risk Category	Percent Cover	Percent Change	Risk Score	Risk Category	Percent Cover	Risk Score	Risk Category		
Ohio River	Middle Allegheny-Tionesta	5010003	0.94	1	Low	9.02	73.56	2	Moderate	22.22	116.85	1	Low	63.74	-19.67	2	Moderate	34.53	3	High	2	Moderate
	Little Muskingum-Middle Island	5030201	0.87	1	Low	6.52	7.11	2	Moderate	12.53	27.94	1	Low	41.85	-7.40	3	High	18.24	3	High	2	Moderate
	Upper Ohio-Shade	5030202	1.91	1	Low	9.91	23.87	2	Moderate	22.76	21.19	1	Low	37.50	-10.89	3	High	15.70	3	High	2	Moderate
	Walhonding	5040003	4.03	1	Low	21.47	163.06	3	High	61.73	21.36	3	High	27.17	-42.13	3	High	14.84	3	High	3	High
	Muskingum	5040004	1.61	1	Low	9.58	34.13	2	Moderate	39.32	33.16	2	Moderate	35.26	-28.72	3	High	22.04	3	High	2	Moderate
	Upper Kanawha	5050006	7.00	1	Low	21.52	242.40	3	High	1.09	51.34	1	Low	29.74	-17.53	3	High	19.07	3	High	2	Moderate
	Raccoon-Symmes	5090101	2.38	1	Low	11.75	62.01	3	High	21.17	19.17	1	Low	28.53	-9.55	3	High	12.57	3	High	2	Moderate
	Little Scioto-Tygarts	5090103	5.22	1	Low	19.81	97.82	3	High	22.98	48.41	1	Low	24.73	-14.68	3	High	10.64	3	High	2	Moderate
	Ohio Brush-Whiteoak	5090201	2.14	1	Low	11.73	82.91	3	High	38.60	17.46	2	Moderate	46.20	-16.93	3	High	14.28	3	High	2	Moderate
	Licking	5100101	2.30	1	Low	11.85	84.89	3	High	43.56	49.31	3	High	52.63	-21.49	2	Moderate	33.80	3	High	2	Moderate
	Upper Green	5110001	1.27	1	Low	11.21	87.52	3	High	54.90	31.63	3	High	48.90	-30.46	3	High	31.22	3	High	3	High
	Tippecanoe	5120106	2.43	1	Low	12.15	74.87	3	High	82.79	2.83	3	High	37.71	-33.64	3	High	20.01	3	High	3	High
	Silver-Little Kentucky	5140101	8.86	1	Low	29.02	44.74	3	High	32.33	7.55	2	Moderate	39.80	-27.41	3	High	9.73	3	High	2	Moderate
	Lower Ohio-Little Pigeon	5140201	2.29	1	Low	13.66	90.11	3	High	47.85	10.12	3	High	31.26	-22.84	3	High	8.03	3	High	3	High
	Lower Ohio	5140206	3.78	1	Low	19.00	120.79	3	High	56.64	5.46	3	High	47.35	-23.62	3	High	8.79	3	High	3	High
Tennessee River	Holston	6010104	3.78	1	Low	18.46	40.03	3	High	41.16	20.81	3	High	37.90	-16.82	3	High	16.74	3	High	3	High
	Upper Clinch, Tennessee, Virginia	6010205	2.01	1	Low	10.20	38.50	3	High	23.83	29.65	1	Low	62.62	-9.96	2	Moderate	37.02	3	High	2	Moderate
	Powell	6010206	1.86	1	Low	10.10	29.70	3	High	18.25	25.39	1	Low	71.29	-9.78	2	Moderate	43.52	3	High	2	Moderate
	Wheeler Lake	6030002	6.15	1	Low	25.57	99.41	3	High	44.48	8.03	3	High	54.60	-20.49	2	Moderate	12.85	3	High	2	Moderate
	Pickwick Lake	6030005	3.42	1	Low	17.68	118.74	3	High	43.65	20.55	3	High	64.88	-18.72	2	Moderate	9.08	3	High	2	Moderate
	Lower Tennessee-Beech	6040001	0.66	1	Low	5.30	3.54	2	Moderate	33.13	60.82	2	Moderate	42.86	-18.97	3	High	19.05	3	High	2	Moderate
	Lower Duck	6040003	2.94	1	Low	19.15	168.79	3	High	39.38	65.35	2	Moderate	39.99	-32.64	3	High	25.27	3	High	2	Moderate
	Lower Tennessee	6040006	5.50	1	Low	30.93	218.10	3	High	55.42	14.21	3	High	27.54	-52.53	3	High	10.28	3	High	3	High
Upper Mississippi River	Buffalo-Whitewater	7040003	1.80	1	Low	8.93	64.37	2	Moderate	52.88	8.47	3	High	70.11	-14.85	2	Moderate	14.07	3	High	2	Moderate
	La Crosse-Pine	7040006	6.49	1	Low	20.77	97.11	3	High	34.72	6.93	2	Moderate	65.61	-15.81	2	Moderate	13.55	3	High	2	Moderate
	Upper Chippewa	7050001	0.24	1	Low	3.07	0.00	1	Low	10.18	35.51	1	Low	77.89	-9.48	1	Low	36.74	3	High	1	Low
	Flambeau	7050002	0.47	1	Low	5.07	34.42	2	Moderate	3.25	15.91	1	Low	89.82	-4.12	1	Low	51.05	2	Moderate	1	Low
	Lower Chippewa	7050005	2.58	1	Low	13.07	119.48	3	High	49.45	5.81	3	High	61.04	-21.47	2	Moderate	24.83	3	High	2	Moderate
	Grant-Little Maquoketa	7060003	2.21	1	Low	10.95	100.53	3	High	70.92	5.80	3	High	71.12	-22.05	2	Moderate	11.86	3	High	2	Moderate
	Castle Rock	7070003	3.69	1	Low	18.32	166.90	3	High	39.22	13.60	2	Moderate	66.29	-19.36	2	Moderate	19.58	3	High	2	Moderate
	Lower Wisconsin	7070005	1.22	1	Low	7.36	47.63	2	Moderate	51.44	15.65	3	High	70.84	-19.90	2	Moderate	28.98	3	High	2	Moderate
	Copperas-Duck	7080101	7.68	1	Low	22.80	36.17	3	High	58.06	-5.03	3	High	67.53	-7.86	2	Moderate	15.05	3	High	2	Moderate
	Lower Rock	7090005	7.52	1	Low	23.16	89.15	3	High	71.35	-7.62	3	High	38.59	-15.54	3	High	15.63	3	High	3	High
	Kankakee	7120001	6.32	1	Low	22.63	140.64	3	High	74.56	-1.49	3	High	44.41	-26.63	3	High	17.88	3	High	3	High
	Meramec	7140102	2.87	1	Low	12.04	36.78	3	High	30.71	70.15	2	Moderate	51.44	-22.96	2	Moderate	26.79	3	High	2	Moderate
	Bourbeuse	7140103	2.32	1	Low	11.83	72.18	3	High	46.94	31.95	3	High	49.67	-23.66	3	High	26.52	3	High	3	High
Lower Mississippi River	Big Sunflower	8030207	1.19	1	Low	8.72	82.26	2	Moderate	81.20	1.71	3	High	34.20	-14.60	3	High	22.11	3	High	2	Moderate

Table G.6 (continued). Landscape Risk Factors - Metrics Summary

HUC2 Name	HUC8 Name	HUC8 ID	Scenario 2**																				
			Impervous Surface			Urban Land Cover				Agricultural Land Cover				Riparian Buffer Vegetation				Canopy Cover			Overall Risk Score	Overall Risk Category
			Percent Cover	Risk Score	Risk Category	Percent Cover	Percent Change	Risk Score	Risk Category	Percent Cover	Percent Change	Risk Score	Risk Category	Percent Cover	Percent Change	Risk Score	Risk Category	Percent Cover	Risk Score	Risk Category		
Ohio River	Middle Allegheny-Tionesta	5010003	0.66	1	Low	6.33	21.74	2	Moderate	7.05	-31.20	1	Low	78.73	-0.77	1	Low	42.66	3	High	2	Moderate
	Little Muskingum-Middle Island	5030201	0.84	1	Low	6.28	3.21	2	Moderate	8.48	-13.46	1	Low	45.67	1.04	3	High	19.91	3	High	2	Moderate
	Upper Ohio-Shade	5030202	1.65	1	Low	8.57	7.10	2	Moderate	17.39	-7.42	1	Low	41.91	-0.41	3	High	17.54	3	High	2	Moderate
	Walhonding	5040003	3.26	1	Low	17.33	112.37	3	High	43.61	-14.25	3	High	48.75	3.83	3	High	26.63	3	High	3	High
	Muskingum	5040004	1.37	1	Low	8.15	14.18	2	Moderate	26.51	-10.21	2	Moderate	48.30	-2.36	3	High	30.19	3	High	2	Moderate
	Upper Kanawha	5050006	3.97	1	Low	12.22	94.50	3	High	0.39	-46.07	1	Low	34.96	-3.08	3	High	22.41	3	High	2	Moderate
	Raccoon-Symmes	5090101	1.82	1	Low	8.97	23.72	2	Moderate	16.17	-8.97	1	Low	31.84	0.92	3	High	14.02	3	High	2	Moderate
	Little Scioto-Tygarts	5090103	3.46	1	Low	13.13	31.14	3	High	13.22	-14.62	1	Low	28.61	-1.27	3	High	12.31	3	High	2	Moderate
	Ohio Brush-Whiteoak	5090201	1.69	1	Low	9.29	44.85	2	Moderate	30.55	-7.02	2	Moderate	54.78	-1.49	2	Moderate	16.93	3	High	2	Moderate
	Licking	5100101	2.16	1	Low	11.10	73.28	3	High	24.01	-17.69	1	Low	65.41	-2.43	2	Moderate	42.00	3	High	2	Moderate
	Upper Green	5110001	1.45	1	Low	12.77	113.63	3	High	34.87	-16.40	2	Moderate	69.98	-0.48	2	Moderate	44.68	3	High	2	Moderate
	Tippecanoe	5120106	2.14	1	Low	10.70	54.01	3	High	78.95	-1.95	3	High	55.57	-2.21	2	Moderate	29.50	3	High	2	Moderate
	Silver-Little Kentucky	5140101	8.03	1	Low	26.30	31.20	3	High	27.52	-8.46	2	Moderate	51.67	-5.76	2	Moderate	12.64	3	High	2	Moderate
	Lower Ohio-Little Pigeon	5140201	2.80	1	Low	16.68	132.14	3	High	41.41	-4.70	3	High	38.25	-5.59	3	High	9.82	3	High	3	High
	Lower Ohio	5140206	4.15	1	Low	20.87	142.52	3	High	50.47	-6.02	3	High	58.18	-6.14	2	Moderate	10.80	3	High	2	Moderate
Tennessee River	Holston	6010104	3.33	1	Low	16.28	23.53	3	High	29.34	-13.88	2	Moderate	45.38	-0.40	3	High	20.05	3	High	2	Moderate
	Upper Clinch, Tennessee, Virginia	6010205	1.59	1	Low	8.08	9.69	2	Moderate	14.25	-22.50	1	Low	70.71	1.67	2	Moderate	41.80	3	High	2	Moderate
	Powell	6010206	1.46	1	Low	7.96	2.13	2	Moderate	11.80	-18.91	1	Low	80.73	2.17	1	Low	49.29	3	High	2	Moderate
	Wheeler Lake	6030002	6.09	1	Low	25.32	97.51	3	High	36.20	-12.08	2	Moderate	67.11	-2.27	2	Moderate	15.80	3	High	2	Moderate
	Pickwick Lake	6030005	3.25	1	Low	16.79	107.70	3	High	30.56	-15.60	2	Moderate	79.53	-0.37	1	Low	11.13	3	High	2	Moderate
	Lower Tennessee-Beech	6040001	0.63	1	Low	5.13	0.34	2	Moderate	11.20	-45.60	1	Low	55.80	5.49	2	Moderate	24.80	3	High	2	Moderate
	Lower Duck	6040003	2.92	1	Low	19.02	166.97	3	High	18.25	-23.36	1	Low	57.55	-3.06	2	Moderate	36.37	3	High	2	Moderate
	Lower Tennessee	6040006	5.64	1	Low	31.73	226.29	3	High	36.98	-23.79	2	Moderate	58.28	0.45	2	Moderate	21.74	3	High	2	Moderate
Upper Mississippi River	Buffalo-Whitewater	7040003	1.28	1	Low	6.39	17.54	2	Moderate	44.50	-8.72	3	High	89.97	9.27	1	Low	18.06	3	High	2	Moderate
	La Crosse-Pine	7040006	5.39	1	Low	17.25	63.70	3	High	28.55	-12.06	2	Moderate	79.57	2.10	1	Low	16.44	3	High	2	Moderate
	Upper Chippewa	7050001	0.24	1	Low	3.07	0.01	1	Low	6.46	-14.00	1	Low	86.67	0.72	1	Low	40.88	3	High	1	Low
	Flambeau	7050002	0.39	1	Low	4.19	11.16	1	Low	2.46	-12.50	1	Low	94.45	0.82	1	Low	53.68	2	Moderate	1	Low
	Lower Chippewa	7050005	2.35	1	Low	11.86	99.25	3	High	42.80	-8.41	3	High	79.86	2.74	1	Low	32.48	3	High	2	Moderate
	Grant-Little Maquoketa	7060003	1.95	1	Low	9.69	77.40	2	Moderate	63.44	-5.34	3	High	94.50	3.58	1	Low	15.76	3	High	2	Moderate
	Castle Rock	7070003	2.97	1	Low	14.73	114.64	3	High	30.49	-11.68	2	Moderate	83.54	1.62	1	Low	24.67	3	High	2	Moderate
	Lower Wisconsin	7070005	1.01	1	Low	6.12	22.89	2	Moderate	40.28	-9.44	3	High	92.11	4.16	1	Low	37.69	3	High	2	Moderate
	Copperas-Duck	7080101	6.72	1	Low	19.95	19.19	3	High	60.84	-0.47	3	High	73.61	0.45	2	Moderate	16.40	3	High	2	Moderate
	Lower Rock	7090005	5.30	1	Low	16.33	33.36	3	High	78.30	1.38	3	High	45.82	0.28	3	High	18.56	3	High	3	High
	Kankakee	7120001	4.32	1	Low	15.47	64.54	3	High	75.70	0.01	3	High	54.68	-9.65	2	Moderate	22.01	3	High	2	Moderate
	Meramec	7140102	2.64	1	Low	11.08	25.88	3	High	15.86	-12.11	1	Low	62.50	-6.40	2	Moderate	32.55	3	High	2	Moderate
	Bourbeuse	7140103	1.99	1	Low	10.11	47.12	3	High	33.75	-5.12	2	Moderate	61.33	-5.75	2	Moderate	32.74	3	High	2	Moderate
Lower Mississippi River	Big Sunflower	8030207	1.09	1	Low	8.04	67.99	2	Moderate	76.24	-4.50	3	High	46.69	16.60	3	High	30.19	3	High	2	Moderate

*Percent change as modeled in FORE-SCE land cover change model SRES A2.
**Percent change as modeled in FORE-SCE land cover change model SRES B1.

Table G.7. Hydrological Regime Risk Factors – Metrics Summary

HUC2 Name	HUC8 Name	HUC8 ID	Current Condition						Scenario 1*			Scenario 2**		
			Number of Events	**Min Cumulative Weeks**	**Max Cumulative Weeks**	**Mean Cumulative Weeks**	**Risk Score**	**Risk Category**	**% Change WW 1980-2009 vs 2040-2069**	**Risk Score (WW Scenario 1 CDSI Change 2040-2069)**	**Overall Risk Category**	**% Change HD 1980-2009 vs 2040-2069**	**Risk Score (HD, Scenario 2 CDSI Change 2040-2069)**	**Overall Risk Category**
Ohio River	Middle Allegheny-Tionesta	5010003	none	none	none	none	1	Low	171.83	1	Low	17.47	1	Low
	Little Muskingum-Middle Island	5030201	none	none	none	none	1	Low	156.57	1	Low	100.09	1	Low
	Upper Ohio-Shade	5030202	none	none	none	none	1	Low	116.81	1	Low	83.73	1	Low
	Walhonding	5040003	none	none	none	none	1	Low	148.24	1	Low	-40.27	1	Low
	Muskingum	5040004	none	none	none	none	1	Low	123.66	1	Low	30.68	1	Low
	Upper Kanawha	5050006	none	none	none	none	1	Low	135.51	1	Low	58.84	1	Low
	Raccoon-Symmes	5090101	1	2	2	2	1	Low	122.26	1	Low	75.65	1	Low
	Little Scioto-Tygarts	5090103	1	9	9	9	2	Moderate	86.24	2	Moderate	70.82	2	Moderate
	Ohio Brush-Whiteoak	5090201	1	9	9	9	2	Moderate	63.53	2	Moderate	48.44	2	Moderate
	Licking	5100101	2	1	13	7	2	Moderate	111.91	2	Moderate	70.68	2	Moderate
	Upper Green	5110001	3	2	9	6.33	2	Moderate	223.08	2	Moderate	97.82	2	Moderate
	Tippecanoe	5120106	1	6	6	6	2	Moderate	54.70	2	Moderate	-9.76	2	Moderate
	Silver-Little Kentucky	5140101	2	6	7	6.5	2	Moderate	78.74	2	Moderate	32.87	2	Moderate
	Lower Ohio-Little Pigeon	5140201	3	3	10	6.33	2	Moderate	87.01	2	Moderate	42.76	2	Moderate
	Lower Ohio	5140206	2	8	16	12	2	Moderate	76.68	2	Moderate	86.55	2	Moderate
Tennessee River	Holston	6010104	6	1	38	10	2	Moderate	160.16	2	Moderate	113.48	2	Moderate
	Upper Clinch, Tennessee, Virginia	6010205	4	1	36	13.75	2	Moderate	240.62	2	Moderate	89.22	2	Moderate
	Powell	6010206	3	2	33	17	2	Moderate	208.21	2	Moderate	103.96	2	Moderate
	Wheeler Lake	6030002	5	1	58	21	2	Moderate	98.09	2	Moderate	84.96	2	Moderate
	Pickwick Lake	6030005	4	1	43	16	2	Moderate	63.58	2	Moderate	98.49	2	Moderate
	Lower Tennessee-Beech	6040001	3	2	22	11	2	Moderate	95.86	2	Moderate	133.11	2	Moderate
	Lower Duck	6040003	4	1	22	7.25	2	Moderate	140.65	2	Moderate	128.22	2	Moderate
	Lower Tennessee	6040006	2	9	16	12.5	2	Moderate	152.05	2	Moderate	128.82	2	Moderate
Upper Mississippi River	Buffalo-Whitewater	7040003	1	17	17	17	2	Moderate	52.68	2	Moderate	-46.54	2	Moderate
	La Crosse-Pine	7040006	2	4	16	10	2	Moderate	107.46	2	Moderate	-41.66	2	Moderate
	Upper Chippewa	7050001	3	2	6	3.33	2	Moderate	8.28	2	Moderate	-19.35	2	Moderate
	Flambeau	7050002	4	1	6	3	2	Moderate	-14.65	2	Moderate	-9.80	2	Moderate
	Lower Chippewa	7050005	1	15	15	15	2	Moderate	41.97	2	Moderate	-49.85	2	Moderate
	Grant-Little Maquoketa	7060003	1	14	14	14	2	Moderate	220.11	2	Moderate	-14.41	2	Moderate
	Castle Rock	7070003	2	1	2	1.5	1	Low	119.23	1	Low	-56.69	1	Low
	Lower Wisconsin	7070005	1	4	4	4	2	Moderate	196.27	2	Moderate	-43.42	2	Moderate
	Copperas-Duck	7080101	2	13	27	20	2	Moderate	60.94	2	Moderate	-39.83	2	Moderate
	Lower Rock	7090005	3	7	21	15	2	Moderate	69.30	2	Moderate	-57.03	2	Moderate
	Kankakee	7120001	2	3	6	4.5	2	Moderate	31.98	2	Moderate	-32.15	2	Moderate
	Meramec	7140102	2	1	6	3.5	2	Moderate	73.29	2	Moderate	55.19	2	Moderate
	Bourbeuse	7140103	2	1	6	3.5	2	Moderate	71.50	2	Moderate	49.95	2	Moderate

Table G.7 (continued). Hydrological Regime Risk Factors – Metrics Summary

HUC2 Name	HUC8 Name	HUC8 ID	Current Condition						Scenario 1*			Scenario 2**		
			Number of Events	Min Cumulative Weeks	Max Cumulative Weeks	Mean Cumulative Weeks	Risk Score	Risk Category	% Change WW 1980-2009 vs 2040-2069	Risk Score (WW Scenario 1 CDSI Change 2040-2069)	Overall Risk Category	% Change HD 1980-2009 vs 2040-2069	Risk Score (HD, Scenario 2 CDSI Change 2040-2069)	Overall Risk Category
Lower Mississippi River	Big Sunflower	8030207	8	1	13	4.63	2	Moderate	27.14	2	Moderate	71.77	2	Moderate

*Warm Wet projections of the Cumulative Severe Drought Index (CDSI) developed by the U.S. Forest Service

**Hot Dry projections of the Cumulative Severe Drought Index (CDSI) developed by the U.S. Forest Service

Table G.8. Connectivity Risk Factors – Metrics Summary

HUC2 Name	**HUC8 Name**	**HUC8 ID**	**Current Condition**								
			Adjusted Dams	**Adjusted Dam Risk Score**	**Adjusted Dam Risk Category**	**Unpaved Roads Stream Crossing Count**	**Unpaved Road Stream Crossings per KM**	**Unpaved Road Stream Crossing Risk Score**	**Unpaved Road Stream Crossing Risk Category**	**Overall Risk Score**	**Overall Risk Category**
Ohio River	Middle Allegheny-Tionesta	5010003	13	2	Moderate	0	0.00	1	Low	2	Moderate
	Little Muskingum-Middle Island	5030201	16	2	Moderate	754	0.23	2	Moderate	2	Moderate
	Upper Ohio-Shade	5030202	33	3	High	455	0.18	1	Low	2	Moderate
	Walhonding	5040003	21	2	Moderate	210	0.16	1	Low	2	Moderate
	Muskingum	5040004	47	3	High	350	0.17	1	Low	2	Moderate
	Upper Kanawha	5050006	6	1	Low	130	0.13	1	Low	1	Low
	Raccoon-Symmes	5090101	17	2	Moderate	375	0.17	1	Low	2	Moderate
	Little Scioto-Tygarts	5090103	14	2	Moderate	413	0.23	2	Moderate	2	Moderate
	Ohio Brush-Whiteoak	5090201	23	2	Moderate	320	0.09	1	Low	2	Moderate
	Licking	5100101	29	2	Moderate	661	0.12	1	Low	2	Moderate
	Upper Green	5110001	29	2	Moderate	127	0.03	1	Low	2	Moderate
	Tippecanoe	5120106	42	3	High	9	0.00	1	Low	2	Moderate
	Silver-Little Kentucky	5140101	29	2	Moderate	18	0.01	1	Low	2	Moderate
	Lower Ohio-Little Pigeon	5140201	23	2	Moderate	14	0.01	1	Low	2	Moderate
	Lower Ohio	5140206	11	2	Moderate	46	0.05	1	Low	2	Moderate
Tennessee River	Holston	6010104	14	2	Moderate	1540	1.09	3	High	3	High
	Upper Clinch, Tennessee, Virginia	6010205	15	2	Moderate	1141	0.36	2	Moderate	2	Moderate
	Powell	6010206	11	2	Moderate	512	0.36	2	Moderate	2	Moderate
	Wheeler Lake	6030002	25	2	Moderate	261	0.07	1	Low	2	Moderate
	Pickwick Lake	6030005	23	2	Moderate	853	0.25	2	Moderate	2	Moderate
	Lower Tennessee-Beech	6040001	35	3	High	1761	0.54	3	High	3	High
	Lower Duck	6040003	31	3	High	2216	0.87	3	High	3	High
	Lower Tennessee	6040006	17	2	Moderate	44	0.04	1	Low	2	Moderate
Upper Mississippi River	Buffalo-Whitewater	7040003	40	3	High	230	0.19	1	Low	2	Moderate
	La Crosse-Pine	7040006	19	2	Moderate	16	0.03	1	Low	2	Moderate
	Upper Chippewa	7050001	33	3	High	330	0.17	1	Low	2	Moderate
	Flambeau	7050002	18	2	Moderate	88	0.08	1	Low	2	Moderate
	Lower Chippewa	7050005	39	3	High	208	0.11	1	Low	2	Moderate
	Grant-Little Maquoketa	7060003	8	1	Low	69	0.06	1	Low	1	Low
	Castle Rock	7070003	93	3	High	282	0.11	1	Low	2	Moderate
	Lower Wisconsin	7070005	42	3	High	162	0.08	1	Low	2	Moderate
	Copperas-Duck	7080101	30	2	Moderate	110	0.11	1	Low	2	Moderate
	Lower Rock	7090005	27	2	Moderate	140	0.08	1	Low	2	Moderate
	Kankakee	7120001	23	2	Moderate	45	0.01	1	Low	2	Moderate
	Meramec	7140102	106	3	High	546	0.24	2	Moderate	3	High
	Bourbeuse	7140103	33	3	High	432	0.44	3	High	3	High
Lower Mississippi River	Big Sunflower	8030207	7	1	Low	0	0.00	1	Low	1	Low

Table G.8 (continued). Connectivity Risk Factors – Metrics Summary

Table G.8 (continued). Connectivity Risk Factors – Metrics Summary

HUC2 Name	HUC8 Name	HUC8 ID	Scenario 1								
			Number of Dams*	**Adjusted Dam Risk Score**	**Adjusted Dam Risk Category**	**Percent Change Unpaved Road Crossing Density^**	**Unpaved Road Crossing Density**	**Unpaved Road Density Risk Score**	**Unpaved Road Density Risk Category**	**Overall Risk Score**	**Overall Risk Category**
Ohio River	Middle Allegheny-Tionesta	5010003	13	2	Moderate	27.35	0.00	1	Low	2	Moderate
	Little Muskingum-Middle Island	5030201	16	2	Moderate	27.35	0.29	2	Moderate	2	Moderate
	Upper Ohio-Shade	5030202	33	3	High	27.35	0.22	2	Moderate	3	High
	Walhonding	5040003	21	2	Moderate	27.35	0.20	1	Low	2	Moderate
	Muskingum	5040004	47	3	High	27.35	0.22	2	Moderate	3	High
	Upper Kanawha	5050006	6	1	Low	27.35	0.17	1	Low	1	Low
	Raccoon-Symmes	5090101	17	2	Moderate	27.35	0.22	2	Moderate	2	Moderate
	Little Scioto-Tygarts	5090103	14	2	Moderate	27.35	0.29	2	Moderate	2	Moderate
	Ohio Brush-Whiteoak	5090201	23	2	Moderate	27.35	0.12	1	Low	2	Moderate
	Licking	5100101	29	2	Moderate	27.35	0.16	1	Low	2	Moderate
	Upper Green	5110001	29	2	Moderate	27.35	0.04	1	Low	2	Moderate
	Tippecanoe	5120106	42	3	High	27.35	0.00	1	Low	2	Moderate
	Silver-Little Kentucky	5140101	29	2	Moderate	27.35	0.01	1	Low	2	Moderate
	Lower Ohio-Little Pigeon	5140201	23	2	Moderate	27.35	0.01	1	Low	2	Moderate
	Lower Ohio	5140206	11	2	Moderate	27.35	0.06	1	Low	2	Moderate
Tennessee River	Holston	6010104	14	2	Moderate	27.35	1.39	3	High	3	High
	Upper Clinch, Tennessee, Virginia	6010205	15	2	Moderate	27.35	0.46	3	High	3	High
	Powell	6010206	11	2	Moderate	27.35	0.46	3	High	3	High
	Wheeler Lake	6030002	25	2	Moderate	27.35	0.09	1	Low	2	Moderate
	Pickwick Lake	6030005	23	2	Moderate	27.35	0.32	2	Moderate	2	Moderate
	Lower Tennessee-Beech	6040001	35	3	High	27.35	0.69	3	High	3	High
	Lower Duck	6040003	31	3	High	27.35	1.11	3	High	3	High
	Lower Tennessee	6040006	17	2	Moderate	27.35	0.05	1	Low	2	Moderate
Upper Mississippi River	Buffalo-Whitewater	7040003	40	3	High	27.35	0.25	2	Moderate	3	High
	La Crosse-Pine	7040006	19	2	Moderate	27.35	0.04	1	Low	2	Moderate
	Upper Chippewa	7050001	33	3	High	27.35	0.21	2	Moderate	3	High
	Flambeau	7050002	18	2	Moderate	27.35	0.10	1	Low	2	Moderate
	Lower Chippewa	7050005	39	3	High	27.35	0.14	1	Low	2	Moderate
	Grant-Little Maquoketa	7060003	8	1	Low	27.35	0.08	1	Low	1	Low
	Castle Rock	7070003	93	3	High	27.35	0.14	1	Low	2	Moderate
	Lower Wisconsin	7070005	42	3	High	27.35	0.10	1	Low	2	Moderate
	Copperas-Duck	7080101	30	2	Moderate	27.35	0.14	1	Low	2	Moderate
	Lower Rock	7090005	27	2	Moderate	27.35	0.10	1	Low	2	Moderate
	Kankakee	7120001	23	2	Moderate	27.35	0.02	1	Low	2	Moderate
	Meramec	7140102	106	3	High	27.35	0.30	2	Moderate	3	High
	Bourbeuse	7140103	33	3	High	27.35	0.56	3	High	3	High
Lower Mississippi River	Big Sunflower	8030207	7	1	Low	27.35	0.00	1	Low	1	Low

Table G.8 (continued). Connectivity Risk Factors – Metrics Summary

HUC2 Name	HUC8 Name	HUC8 ID	Scenario 2									
			Number Dams Removed Post 2012	**Projected Future Number of Dams****	**Dam Risk Score**	**Dam Risk Category**	**Percent Change Unpaved Road Crossing Density^^**	**Unpaved Road Crossing Density**	**Unpaved Road Density Risk Score**	**Unpaved Road Density Risk Category**	**Overall Risk Score**	**Overall Risk Category**
Ohio River	Middle Allegheny-Tionesta	5010003	1	12	2	Moderate	3.2	0.00	1	Low	2	Moderate
	Little Muskingum-Middle Island	5030201	0	16	2	Moderate	3.2	0.23	2	Moderate	2	Moderate
	Upper Ohio-Shade	5030202	0	33	3	High	3.2	0.18	1	Low	2	Moderate
	Walhonding	5040003	1	20	2	Moderate	3.2	0.16	1	Low	2	Moderate
	Muskingum	5040004	2	45	3	High	3.2	0.18	1	Low	2	Moderate
	Upper Kanawha	5050006	0	6	1	Low	3.2	0.14	1	Low	1	Moderate
	Raccoon-Symmes	5090101	1	16	2	Moderate	3.2	0.17	1	Low	2	Moderate
	Little Scioto-Tygarts	5090103	0	14	2	Moderate	3.2	0.24	2	Moderate	2	Moderate
	Ohio Brush-Whiteoak	5090201	0	23	2	Moderate	3.2	0.10	1	Low	2	Moderate
	Licking	5100101	0	29	2	Moderate	3.2	0.13	1	Low	2	Moderate
	Upper Green	5110001	1	28	2	Moderate	3.2	0.03	1	Low	2	Moderate
	Tippecanoe	5120106	1	41	3	High	3.2	0.00	1	Low	2	Low
	Silver-Little Kentucky	5140101	0	29	2	Moderate	3.2	0.01	1	Low	2	Moderate
	Lower Ohio-Little Pigeon	5140201	0	23	2	Moderate	3.2	0.01	1	Low	2	Moderate
	Lower Ohio	5140206	0	11	2	Moderate	3.2	0.05	1	Low	2	Moderate
Tennessee River	Holston	6010104	0	14	2	Moderate	3.2	1.13	3	High	3	Moderate
	Upper Clinch, Tennessee, Virginia	6010205	0	15	2	Moderate	3.2	0.37	2	Moderate	2	Moderate
	Powell	6010206	0	11	2	Moderate	3.2	0.37	2	Moderate	2	Moderate
	Wheeler Lake	6030002	0	25	2	Moderate	3.2	0.07	1	Low	2	Moderate
	Pickwick Lake	6030005	0	23	2	Moderate	3.2	0.26	2	Moderate	2	Moderate
	Lower Tennessee-Beech	6040001	0	35	3	High	3.2	0.56	3	High	3	High
	Lower Duck	6040003	0	31	3	High	3.2	0.90	3	High	3	Moderate
	Lower Tennessee	6040006	0	17	2	Moderate	3.2	0.04	1	Low	2	Moderate
Upper Mississippi River	Buffalo-Whitewater	7040003	0	40	3	High	3.2	0.20	1	Low	2	Moderate
	La Crosse-Pine	7040006	0	19	2	Moderate	3.2	0.03	1	Low	2	Moderate
	Upper Chippewa	7050001	1	32	3	High	3.2	0.17	1	Low	2	High
	Flambeau	7050002	0	18	2	Moderate	3.2	0.08	1	Low	2	High
	Lower Chippewa	7050005	0	39	3	High	3.2	0.11	1	Low	1	Moderate
	Grant-Little Maquoketa	7060003	0	8	1	Low	3.2	0.06	1	Low	1	Low
	Castle Rock	7070003	1	92	3	High	3.2	0.12	1	Low	2	Moderate
	Lower Wisconsin	7070005	0	42	3	High	3.2	0.08	1	Low	2	Low
	Copperas-Duck	7080101	0	30	2	Moderate	3.2	0.12	1	Low	2	Moderate
	Lower Rock	7090005	0	27	2	Moderate	3.2	0.08	1	Low	2	Moderate
	Kankakee	7120001	0	23	2	Moderate	3.2	0.01	1	Low	2	Moderate
	Meramec	7140102	0	106	3	High	3.2	0.25	2	Moderate	3	High
	Bourbeuse	7140103	0	33	3	High	3.2	0.45	3	High	3	High

Table G.8 (continued). Connectivity Risk Factors – Metrics Summary

HUC2 Name	**HUC8 Name**	**HUC8 ID**	**Scenario 2**									
			Number Dams Removed Post 2012	**Projected Future Number of Dams****	**Dam Risk Score**	**Dam Risk Category**	**Percent Change Unpaved Road Crossing Density^^**	**Unpaved Road Crossing Density**	**Unpaved Road Density Risk Score**	**Unpaved Road Density Risk Category**	**Overall Risk Score**	**Overall Risk Category**
Lower Mississippi River	Big Sunflower	8030207	0	7	1	Low	3.2	0.00	1	Low	1	Low

*No change from Current Condition

**Dam removal based on 2000-2020 trends

^Increase density by 27.3% (GRIP Scenario SSP5)

^^Increase density by 3.2% (GRIP Scenario SSP3)

Table G.9. Invasive Species Risk Factors – Metrics Summary

HUC2 Name	HUC8 Name	HUC8 ID	Current Condition								Scenario 1			Scenario 2	
			Hotspot Analysis[n]												
			Direct Competition	Reduction of Reproductive Potential	Disturbance	Direct Harm/ Predation	Total # Hotspots	Incidences[i] (Y/N)	Risk Score	Risk Category^	Future Risk Projection	Future Risk Score	Future Risk Category^	Risk Score	Risk Category
			# Hotspots/ Coldspots	# Hotspots/ Coldspots	# Hotspots/ Coldspots	# Hotspots/ Coldspots									
Ohio River	Middle Allegheny-Tionesta	5010003	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Little Muskingum-Middle Island	5030201	1/0	0/0	0/0	0/0	1	Y	3	High	Increases	3	High	3	High
	Upper Ohio-Shade	5030202	11/0	0/0	0/0	0/0	11	Y	3	High	Increases	3	High	3	High
	Walhonding	5040003	0/0	0/0	0/0	0/0	0	Y	2	Moderate	Increases	3	High	2	Moderate
	Muskingum	5040004	6/0	0/0	0/0	0/0	6	Y	3	High	Increases	3	High	3	High
	Upper Kanawha	5050006	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Raccoon-Symmes	5090101	0/0	0/0	0/0	0/0	0	Y	2	Moderate	Increases	3	High	2	Moderate
	Little Scioto-Tygarts	5090103	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Ohio Brush-Whiteoak	5090201	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Licking	5100101	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Upper Green	5110001	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Tippecanoe	5120106	0/0	0/0	0/0	0/0	0	Y	2	Moderate	Increases	3	High	2	Moderate
	Silver-Little Kentucky	5140101	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Lower Ohio-Little Pigeon	5140201	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Lower Ohio	5140206	6/0	0/0	0/0	0/0	6	Y	3	High	Increases	3	High	3	High
Tennessee River	Holston	6010104	2/0	0/0	0/0	0/0	2	Y	3	High	Increases	3	High	3	High
	Upper Clinch, Tennessee, Virginia	6010205	18/0	0/0	0/0	0/0	18	Y	3	High	Increases	3	High	3	High
	Powell	6010206	5/0	0/0	0/0	0/0	5	Y	3	High	Increases	3	High	3	High
	Wheeler Lake	6030002	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Pickwick Lake	6030005	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Lower Tennessee-Beech	6040001	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Lower Duck	6040003	0/0	0/0	0/0	0/0	0	Y	2	Moderate	Increases	3	High	2	Moderate
	Lower Tennessee	6040006	0/0	0/0	0/0	0/0	0	Y	2	Moderate	Increases	3	High	2	Moderate
Upper Mississippi River	Buffalo-Whitewater	7040003	3/0	8/0	8/0	7/0	26	Y	3	High	Increases	3	High	3	High
	La Crosse-Pine	7040006	0/0	4/0	4/0	4/0	12	Y	3	High	Increases	3	High	3	High
	Upper Chippewa	7050001	0/0	0/0	0/0	0/0	0	Y	2	Moderate	Increases	3	High	2	Moderate
	Flambeau	7050002	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate
	Lower Chippewa	7050005	0/0	17/0	17/0	11/0	45	Y	3	High	Increases	3	High	3	High
	Grant-Little Maquoketa	7060003	0/0	1/0	13/0	0/0	14	Y	3	High	Increases	3	High	3	High
	Castle Rock	7070003	0/0	8/0	9/0	0/0	17	Y	3	High	Increases	3	High	3	High
	Lower Wisconsin	7070005	0/0	18/0	33/0	0/0	51	Y	3	High	Increases	3	High	3	High
	Copperas-Duck	7080101	6/0	0/0	0/0	0/0	6	Y	3	High	Increases	3	High	3	High
	Lower Rock	7090005	6/0	0/0	0/0	0/0	6	Y	3	High	Increases	3	High	3	High
	Kankakee	7120001	4/0	0/0	0/0	0/0	4	Y	3	High	Increases	3	High	3	High
	Meramec	7140102	12/0	0/0	0/0	0/0	12	Y	3	High	Increases	3	High	3	High
	Bourbeuse	7140103	5/0	0/0	0/0	0/0	5	Y	3	High	Increases	3	High	3	High

Table G.9 (continued). Invasive Species Risk Factors – Metrics Summary

HUC2 Name	HUC8 Name	HUC8 ID	Current Condition								Scenario 1			Scenario 2	
			Hotspot Analysis[n]												
			Direct Competition	Reduction of Reproductive Potential	Disturbance	Direct Harm/ Predation	Total # Hotspots	Incidences[i] (Y/N)	Risk Score	Risk Category^	Future Risk Projection	Future Risk Score	Future Risk Category^	Risk Score	Risk Category
Lower Mississippi River	Big Sunflower	8030207	0/0	0/0	0/0	0/0	0	Y	2	Moderate	No change	2	Moderate	2	Moderate

*Neighbor hotspot analysis

**No changes from current condition

^Based on December 20, 2021 data

^^Based on December 16, 2021 data

[n] = number of hotspots and coldspots reported are an additive combination of 90, 95, and 99 percent GI bin results

[i] = one or more invasive species occurrence within HUC8 was reported

Table G.10. Catastrophic Events Risk Summary

HUC2 Name	HUC8 Name	HUC8 ID	Current Condition										Scenario 1		Scenario 2	
			Coal			Oil and Natural Gas							Coal*	Oil and Natural Gas^	Coal**	Oil and Natural Gas^^
			Coal Mines		Coal Overall Risk	All Pipe Crossings		Liquid Pipe Crossings		Oil and Natural Gas Wells		Oil and Natural Gas Overall Risk				
			Count	Present in HUC8 (Y/N)		Count	Present in HUC8 (Y/N)	Count	Present in HUC8 (Y/N)	Count	Present in HUC8 (Y/N)		Projected Overall Risk Trajectory	Projected Overall Risk Trajectory	Projected Overall Risk Trajectory	Projected Overall Risk Trajectory
Ohio River	Middle Allegheny-Tionesta	5010003	1	Y	High	127	Y	0	N	7996	Y	High	No Change	Increase	Decrease	Decrease
	Little Muskingum-Middle Island	5030201	2	Y	High	580	Y	92	Y	10264	Y	High	No Change	Increase	Decrease	Decrease
	Upper Ohio-Shade	5030202	0	N	Low	143	Y	0	N	3410	Y	High	No Change	Increase	No Change	Decrease
	Walhonding	5040003	0	N	Low	116	Y	20	Y	6669	Y	High	No Change	Increase	No Change	Decrease
	Muskingum	5040004	0	N	Low	270	Y	34	Y	11334	Y	High	No Change	Increase	No Change	Decrease
	Upper Kanawha	5050006	18	Y	High	26	Y	0	N	0	N	High	No Change	Increase	Decrease	Decrease
	Raccoon-Symmes	5090101	4	Y	High	231	Y	19	Y	1025	Y	High	No Change	Increase	Decrease	Decrease
	Little Scioto-Tygarts	5090103	0	N	Low	303	Y	17	Y	246	Y	High	No Change	Increase	No Change	Decrease
	Ohio Brush-Whiteoak	5090201	0	N	Low	216	Y	0	N	3	Y	High	No Change	Increase	No Change	Decrease
	Licking	5100101	5	Y	High	550	Y	33	Y	0	N	High	No Change	Increase	Decrease	Decrease
	Upper Green	5110001	0	N	Low	395	Y	29	Y	0	N	High	No Change	Increase	No Change	Decrease
	Tippecanoe	5120106	0	N	Low	120	Y	35	Y	115	Y	High	No Change	Increase	No Change	Decrease
	Silver-Little Kentucky	5140101	0	N	Low	99	Y	14	Y	20	Y	High	No Change	Increase	No Change	Decrease
	Lower Ohio-Little Pigeon	5140201	3	Y	High	132	Y	24	Y	545	Y	High	No Change	Increase	Decrease	Decrease
	Lower Ohio	5140206	0	N	Low	71	Y	53	Y	0	N	High	No Change	Increase	No Change	Decrease
Tennessee River	Holston	6010104	0	N	Low	49	Y	2	Y	0	N	High	No Change	Increase	No Change	Decrease
	Upper Clinch, Tennessee, Virginia	6010205	11	Y	High	12	Y	0	N	0	N	High	No Change	Increase	Decrease	Decrease
	Powell	6010206	9	Y	High	1	Y	0	N	0	N	High	No Change	Increase	Decrease	Decrease
	Wheeler Lake	6030002	0	N	Low	80	Y	5	Y	0	N	High	No Change	Increase	No Change	Decrease
	Pickwick Lake	6030005	0	N	Low	238	Y	0	N	0	N	High	No Change	Increase	No Change	Decrease
	Lower Tennessee-Beech	6040001	0	N	Low	252	Y	13	Y	0	N	High	No Change	Increase	No Change	Decrease
	Lower Duck	6040003	0	N	Low	300	Y	22	Y	0	N	High	No Change	Increase	No Change	Decrease
	Lower Tennessee	6040006	0	N	Low	95	Y	6	Y	0	N	High	No Change	Increase	No Change	Decrease
Upper Mississippi River	Buffalo-Whitewater	7040003	0	N	Low	18	Y	1	Y	0	N	High	No Change	Increase	No Change	Decrease
	La Crosse-Pine	7040006	0	N	Low	19	Y	0	N	0	N	High	No Change	Increase	No Change	Decrease
	Upper Chippewa	7050001	0	N	Low	73	Y	55	Y	0	N	High	No Change	Increase	No Change	Decrease
	Flambeau	7050002	0	N	Low	7	Y	4	Y	0	N	High	No Change	Increase	No Change	Decrease
	Lower Chippewa	7050005	0	N	Low	76	Y	61	Y	0	N	High	No Change	Increase	No Change	Decrease
	Grant-Little Maquoketa	7060003	0	N	Low	17	Y	1	Y	0	N	High	No Change	Increase	No Change	Decrease
	Castle Rock	7070003	0	N	Low	157	Y	97	Y	0	N	High	No Change	Increase	No Change	Decrease
	Lower Wisconsin	7070005	0	N	Low	41	Y	8	Y	0	N	High	No Change	Increase	No Change	Decrease
	Copperas-Duck	7080101	0	N	Low	100	Y	30	Y	0	N	High	No Change	Increase	No Change	Decrease
	Lower Rock	7090005	0	N	Low	132	Y	56	Y	0	N	High	No Change	Increase	No Change	Decrease
	Kankakee	7120001	0	N	Low	452	Y	223	Y	12	Y	High	No Change	Increase	No Change	Decrease
	Meramec	7140102	0	N	Low	44	Y	26	Y	0	N	High	No Change	Increase	No Change	Decrease
	Bourbeuse	7140103	0	N	Low	63	Y	28	Y	0	N	High	No Change	Increase	No Change	Decrease

Table G.10 (continued). Catastrophic Events Risk Summary

HUC2 Name	HUC8 Name	HUC8 ID	Current Condition										Scenario 1		Scenario 2	
			Coal			Oil and Natural Gas							Coal*	Oil and Natural Gas^	Coal**	Oil and Natural Gas^^
			Coal Mines		Coal Overall Risk	All Pipe Crossings		Liquid Pipe Crossings		Oil and Natural Gas Wells		Oil and Natural Gas Overall Risk				
			Count	Present in HUC8 (Y/N)		Count	Present in HUC8 (Y/N)	Count	Present in HUC8 (Y/N)	Count	Present in HUC8 (Y/N)		Projected Overall Risk Trajectory	Projected Overall Risk Trajectory	Projected Overall Risk Trajectory	Projected Overall Risk Trajectory
Lower Mississippi River	Big Sunflower	8030207	0	N	Low	350	Y	49	Y	0	N	High	No Change	Increase	No Change	Decrease

*We assume no change in risk from current conditions.

**We assume a reduction in risk from current conditions.

^ High Oil and Gas Supply Scenario: The U.S. Energy Information Administration (EIA) projects increased crude oil production; we assume production and supply will increase where infrastructure is already present, increasing the risk of a catastrophic event.

^^Low Oil and Gas Supply Scenario: Production and consumption decrease and the risk of a catastrophic event decreases.