Butler
2003

Status assessment for the sheepnose, *Plethobasus cyphyus*, occurring in the Mississippi River system

Prepared by

Ohio River Valley Ecosystem Team
Mollusk Subgroup
Robert S. Butler, Subgroup Leader
U.S. Fish and Wildlife Service
160 Zillicoa Street
Asheville NC 28801

March 2003

Disclaimer

This document is a compilation of biological data and a description of past, present, and likely future threats to the sheepnose (*Plethobasus cyphyus*). It does not represent a decision by the U.S. Fish and Wildlife Service (Service) on whether this taxon should be designated as a candidate species for listing as threatened or endangered under the Federal Endangered Species Act. That decision will be made by the Service after reviewing this document; other relevant biological and threat data not included herein; and all relevant laws, regulations, and policies. The result of the decision will be posted on the Service's Region 3 Web site (refer to: http://midwest.fws.gov/eco_serv/endangrd/lists/concern.html). If designated as a candidate species, the taxon will subsequently be added to the Service's candidate species list that is periodically published in the Federal Register and posted on the World Wide Web (refer to: http://endangered.fws.gov/wildlife.html). Even if the taxon does not warrant candidate status it should benefit from the conservation recommendations that are contained in this document.

Common name: sheepnose

Scientific name: *Plethobasus cyphyus*

Controversial or unsettled taxonomic issues: The sheepnose is a member of the mussel family Unionidae and was originally described as *Obliquaria cyphya* Rafinesque, 1820. The type locality is the Falls of the Ohio (on the Ohio River in the vicinity of Louisville, Kentucky, and adjacent Indiana) (Parmalee and Bogan 1998). Parmalee and Bogan (1998) summarized the synonomy of the sheepnose. Over the years, the specific epithet of this species has been variably spelled *cyphya, scyphius, cyphius, cyphia, cyphyum,* and ultimately as *cyphyus.* The 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), where it remains today (Turgeon et al. 1998). The Service recognizes *Unio aesopus* and *U. compertus* as synonyms of *Plethobasus cyphyus*. Sheepnose is the common name for *Plethobasus cyphyus* as established by the Committee on Scientific and Vernacular Names of Mollusks of the Council of Systematic Malacologists, American Malacological Union (Turgeon et al. 1998). The Service also recognizes "bullhead" and "clear profit" as older common names for the sheepnose.

Physical description of the taxon: The following description of the sheepnose is generally summarized from Oesch (1984) and Parmalee and Bogan (1998). The 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 the 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 (1984). Key characters useful for distinguishing the sheepnose from other mussels include its shell color, the occurrence of central tubercles, and its outline.

Summary of biology and natural history: Adult freshwater mussels are filter-feeders, siphoning phytoplankton, diatoms, and other microorganisms from the water column (Fuller 1974). For their first several months juvenile mussels employ foot (pedal) feeding, and are thus suspension feeders that feed on algae and detritus (Yeager et al. 1994). Mussels tend to grow relatively rapidly for the first few years, then slow appreciably at sexual maturity, when energy is being diverted from growth to reproductive activities (Baird 2000).

As a group, mussels are extremely long-lived, living from a couple to several decades, and possibly up to 100 to 200 years in extreme instances (Mutvei et al. 1994). Thick-shelled, large river forms, such as the sheepnose, are thought to live longer than other species (Stansbery 1961). No quantitative longevity information on the sheepnose is available. Data on longevity gathered from qualitative estimation of external growth rings estimated one individual from the Meramec River, Missouri, to be 21-25 years old.

Most mussels, including the sheepnose, generally have separate sexes. Age at sexual maturity for the sheepnose is unknown, but in other species is estimated to occur after a few years. Males expel clouds of sperm into the water column are drawn in by females through their incurrent siphons. Fertilization takes place internally, and the resulting zygotes develop into specialized larvae termed glochidia within the gills. The sheepnose utilizes only the outer pair of gills as a marsupium for its glochidia. It is thought to be a short-term brooder, with most reproduction taking place in early summer (Parmalee and Bogan 1998), and glochidial release presumably occurring later in the summer. Hermaphroditism occurs in many mussel species (van der Schalie 1966), but is not known for the sheepnose. This reproductive mechanism, which is thought to be rare in dense populations, may be implemented when populations exhibit low densities and high dispersion levels. Females changing to hermaphrodites may be an adaptive response (Bauer 1987) assuring that a recruitment class may not be lost in small populations. If hermaphroditism does occur in the sheepnose, it may explain the occurrence of small, but persistent populations over long periods of time common in many parts of its range (see "Current and historical populations, and population trends" below).

Glochidia are released in the form of conglutinates, which are analogous to cold capsules (i.e., gelatinous containers with numerous glochidia within), and mimic fish food organisms. The conglutinates of the sheepnose are narrow and lanceolate in outline, solid and red in color, and discharged in unbroken form (Oesch 1984). Ortmann (1911) observed discharge of sheepnose conglutinates in late July (location unknown, but may be Pennsylvania as he named the nominal species *Pleurobema aesopus*, whose type locality is in that state). He described them as being pink and "lying behind the posterior end of the shell, which were greedily devoured by a number of minnows." A female specimen taking back to his lab expelled conglutinates out of the anal aperture. They therefore resemble small worms and infect fish gills. Conglutinates for many species typically contain not only glochidia, but embryos and undeveloped ova as well. This may explain the color differences described by Oesch (1984) and Ortmann (1911). Sheepnose glochidia are semicircular in outline, with the ventral margin obliquely rounded, hinge line long, and medium in size. The length (0.009 inches) is slightly greater than the height (0.008 inches) (Oesch 1984). Several score to a few hundred glochidia probably occur in each conglutinate. Fecundity is positively related to body size and inversely related to glochidia size (Bauer 1994). Total fecundity (including glochidia and ova) per female sheepnose is probably in the tens of thousands.

Glochidia must come into contact with a specific host fish(es) in order for their survival to be ensured. Without the proper host fish, the glochidia will perish. Little is known regarding host fishes of the sheepnose (Roberts and Bruenderman 2000). The sauger (*Stizostedion canadense*) is the only known natural host (Surber 1913, Wilson 1914), but others must be available (see Tippecanoe River account under "Current and historical populations, and population trends"). In many species of mussels, a few weeks are spent parisitizing the fishes' gill tissues. Newly-metamorphosed juveniles drop off to begin a free-living existence on the stream bottom. Unless they drop off in suitable habitat, they will die. Thus, the complex life history of the sheepnose and other mussels has many weak links that may prevent successful reproduction and/or recruitment of juveniles into existing populations (Neves 1993).

Habitat requirements: The following habitat requirements of the sheepnose are generally summarized from Oesch (1984) and Parmalee and Bogan (1998). The sheepnose is primarily a larger-stream species. It occurs primarily in shallow shoal habitats with moderate to swift currents over coarse sand and gravel (Oesch 1984). Habitats with sheepnose may also have mud, cobble, and boulders. Specimens in larger rivers may occur in deep runs (Parmalee and Bogan 1984). Strayer (1999a) demonstrated in field trials that mussels in streams occur chiefly in flow refuges, or relatively stable areas that displayed little movement of particles during flood events. Flow refuges conceivably allow relatively immobile mussels to remain in the same general location throughout their entire lives. He thought that features commonly used in the past to explain the spatial patchiness of mussels (e.g., water depth, current speed, sediment grain size) were poor predictors of where mussels actually occur in streams.

Historical and current range: The distributional history of the sheepnose presented in this section is detailed in tabular form in Appendix I and on a dot distribution drainage map in Figure 1. (Appendix II, Figure 1) Information in Appendix I is presented by major river drainage (i.e., upper Mississippi, lower Missouri, Ohio, Cumberland, Tennessee, lower Mississippi River systems), counties, and states of occurrence. In addition, the authority of each record is presented, the year of the record, and the shell condition (i.e., live/fresh dead [FD], relic). Fresh dead shells still have flesh attached to the shell, or at least retain a luster to their nacre, indicating relatively recent death. Relic shells in this report may originally have been reported as either weathered or subfossil. Fresh dead shells probably indicate the continued presence of the species at a site, while weathered (relic) shells only probably indicate that the population in question is extirpated (Watters and Dunn 1993-94). This information has been gathered from a large body of published and unpublished survey work conducted rangewide since the 1800s. More current, unpublished distribution and status information has been obtained from biologists with State Heritage Programs, agencies, academia, museums, and others.

Historical range: Historically, the sheepnose occurred throughout much of the Mississippi River system with the exception of the upper Missouri River system and most lowland tributaries in the lower Mississippi River system (Appendix I, Figure 1). This species is known from the Mississippi, Ohio, Cumberland, Tennessee, and Ohio main stems, and scores of tributary streams rangewide. The sheepnose was historically known from 77 streams (including 1 canal) in 15 states and 3 Service regions (3, 4, and 5). In the order presented in Appendix I, these include by stream system (with tributaries) the following: upper Mississippi River system (Mississippi River [Minnesota, St. Croix, Chippewa (Flambeau River), Wisconsin, Rock, Iowa, Des Moines, Illinois (Des Plaines, Kankakee, Fox, Mackinaw, Spoon, Sangamon [Salt Creek] Rivers; Quiver Creek; Illinois and Michigan Canal), Meramec (Bourbeuse, Big Rivers), Kaskaskia, Saline, Castor, Whitewater Rivers]); lower Missouri River system (Little Sioux, Little Blue, Gasconade [Osage Fork] Rivers); Ohio River system (Ohio River [Allegheny (Hemlock Creek), Monongahela, Beaver (Duck Creek), Muskingum (Tuscarawas, Walhonding [Mohican River], Otter Fork Licking Rivers), Kanawha, Scioto, Little Miami, Licking, Kentucky, Salt, Green (Barren River), Wabash (Mississinewa, Eel, Tippecanoe, Vermillion, Embarras, White [East, West Forks White River] Rivers) Rivers]); Cumberland River system (Cumberland River [Obey, Harpeth Rivers; Caney Fork]); Tennessee River system (Tennessee River [Holston (North Fork Holston River), French Broad (Little Pigeon River), Little Tennessee, Clinch (North Fork Clinch, Powell Rivers), Hiwassee, Duck Rivers]); and lower Mississippi River system (Hatchie, Black, Yazoo [Big Sunflower River], Big Black Rivers). The sheepnose historically occurred in Alabama, Illinois, Indiana, Iowa, Kentucky, Minnesota, Mississippi, Missouri, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and Wisconsin. These states comprise Service Regions 3 (Midwest), 4 (Southeast), and 5 (Northeast).

Current distribution: Populations of the sheepnose were generally considered extant if live or FD specimens have been collected since the mid-1980's unless subsequent sampling efforts indicated otherwise. Extant populations of the sheepnose are known from 26 streams in 14 states and all 3 regions (Appendix II, Figure 1). Region 3 has the most extant streams of occurrence with 14, while Region 4 has 9, and Region 5 has 5 (Appendix II). In the order presented in Appendix I, these include by stream system (with tributaries) the following: upper Mississippi River system (Mississippi River [St. Croix, Chippewa (Flambeau River), Wisconsin, Kankakee, Meramec (Bourbeuse River) Rivers]); lower Missouri River system (Osage Fork Gasconade River); Ohio River system (Ohio River [Allegheny, Muskingum (Walhonding River), Kanawha, Licking, Kentucky, Wabash, Tippecanoe, Eel, Green Rivers]); Cumberland River system (Cumberland River); Tennessee River system (Tennessee River [Holston, Clinch (Powell River) Rivers]); and lower Mississippi River system (Big Sunflower River). The 26 extant sheepnose populations occur in the following 14 states (with streams): Alabama (Tennessee River), Illinois (Mississippi, Kankakee, Ohio [*contra* Cummings and Mayer 1997], Wabash Rivers), Indiana (Ohio, Wabash, Tippecanoe, Eel Rivers), Iowa (Mississippi River), Kentucky (Ohio, Licking, Kentucky, Green, Cumberland Rivers), Minnesota (Mississippi, St. Croix Rivers), Mississippi (Big Sunflower River), Missouri (Mississippi, Meramec, Bourbeuse, Osage Fork Gasconade Rivers), Ohio (Ohio, Muskingum Rivers), Pennsylvania (Allegheny River), Tennessee (Tennessee, Holston, Clinch, Powell Rivers), Virginia (Clinch, Powell Rivers), West Virginia (Ohio, Kanawha Rivers), and Wisconsin (Mississippi, St. Croix, Chippewa, Flambeau, Wisconsin Rivers).

Current and historical populations, and population trends: *broken out by state and province, and for individual local populations, if possible. It is important to distinguish between current (say within the last 10 years) and historical trends; historical trends provide background and perspective, while current trends provide the evidence that listing is warranted or unwarranted. The "ideal" is to describe the current trend (and threats, see below) for each known population unit across the entire range; get as close to the ideal as the data allow.*

The sheepnose was last reported live several decades ago for many streams (e.g., Minnesota, Rock, Iowa, Illinois, Des Plaines, Fox, Mackinaw, Spoon, Castor, Little Sioux, Little Blue, Monongahela, Beaver, Scioto, Little Miami, Salt, Mississenewa, Vermilion, Embarras, White, Obey, Harpeth, North Fork Holston, French Broad, North Fork Clinch, Duck Rivers; Caney Fork) (Appendix I). The only sheepnose records known from some streams are archeological specimens (e.g., Little Pigeon, Big Black, Yazoo Rivers; Saline Creek). According to Parmalee and Bogan (1998) and Neves (1991), the sheepnose has been extirpated throughout much of its former range or reduced to isolated populations.

The sheepnose has been eliminated from two-thirds of the total number of streams from which it was historically known (26 streams currently compared to 77 streams historically). This species has also been eliminated from long reaches of former habitat in hundreds of miles of the Illinois, Cumberland, and other rivers, and from several reaches of the Mississippi and Tennessee Rivers.

During historical times, the sheepnose was fairly widespread in many Mississippi River system streams (see Appendix I), although rarely ever very common. Archaeological evidence on relative abundance indicates that it has been an uncommon or even rare species in many streams for centuries (Morrison 1942; Patch 1976; Parmalee et al. 1980, 1982; Parmalee and Bogan 1986; Parmalee and Hughes 1994), and relatively common in only a few (Bogan 1990).

Museum collections of this species, with few exceptions, are almost always small (K.S. Cummings, Illinois Natural History Survey [INHS]; G.T. Watters, Ohio State University Museum of Biological Diversity [OSUM], pers. comm., 2001), with the exception of 1960s collections from the Clinch and Powell Rivers, Tennessee and Virginia. Fair numbers were also commonly recorded historically from the upper Muskingum River system in Ohio and the lower Wabash River, Indiana and Ohio, based on museum lots. Schuster and Williams (1989) reported is as being "relatively uncommon" rangewide, while Cummings and Mayer (1992) considered it "rare throughout its range." The American Malacological Union considers the sheepnose to be threatened (Williams et al. 1993).

Although quantitative historical abundance data for the sheepnose is rare, generalized relative abundance was sometimes noted in the historical literature and can be gathered from museum lots. Following is a summary of what is known on the relative abundance and trends of sheepnose populations thought to be extant by stream system, as outlined in the "Current Distribution" above.

Upper Mississippi River system

The sheepnose was historically known from 26 streams in the Mississippi River system, or one-third of the total streams known over its entire range. Currently, only eight streams are thought to have extant sheepnose populations remaining. The percentage of stream population losses in the Mississippi River system (18 of 26, 69%) is slightly higher to that recorded rangewide (51 of 77, 66%).

Mississippi River main stem: Judging from the archeological record, the sheepnose was not uncommon at some sites on the Mississippi (Bogan 1990). Historical sites are known from numerous localities, including the entire length of the Wisconsin portion of the Mississippi River (D.J. Heath, Wisconsin Department of Natural Resources [WDNR], pers. comm., 2001). Paul Bartsch conducted sampling at 140 upper Mississippi River sites in 1907. Bartsch' findings were presented by M. Havlik, Malacological Consultants, at the second annual meeting of the Freshwater Mollusk Conservation Society in Pittsburgh, Pennsylvania, in March 2001. According to INHS museum records, Bartsch found the sheepnose at least at 12 sites (K.S. Cummings, INHS, pers. comm., 2001) from what are now Mississippi River Pools (MRP) 13-23. Lot sizes were consistently smaller than three specimens, generally with only one. Grier (1922) sampled portions of what are now parts of MRP 4-6. He found 37 species total, but the sheepnose occurred in relatively low numbers (<1.0% relative abundance). Collecting mussels primarily with a dredge, M.M. Ellis in 1930 and 1931 floated the upper Mississippi River from Lake Pepin downstream to near the mouth of the Missouri River. In reporting Ellis' findings, van der Schalie and van der Schalie (1950) described the sheepnose as being very rare, stating that it was simply "a matter of chance" to find one. They only reported 8 specimens in 4 river reaches, from a total of 254 sites sampled, with mussels found at 86 of them). It represented <0.1% relative abundance of the 38 species they reported.

Sampling efforts over the past 25 years show the sheepnose to be extremely rare. Havlik and Stansbery (1978) found this species only as relic shells from the Prairie du Chien, Wisconsin, area (MRP 8). Thiel (1981) failed to locate living sheepnose in the Wisconsin portion of the upper Mississippi River (between Mississippi River Lock and Dams 3-11) using brail and SCUBA, but found dead shells in MRP 5a and 9. Havlik and Marking (1981) quantitatively sampled 0.001% of the material from a 3,532,000 foot^3 spoil site dredged from MRP 10 at Prairie du Chien, Wisconsin. They found five sheepnose in their samples for a relative abundance of 0.08%. Whitney et al. (1996) reported the sheepnose from Sylvan Slough, in MRP 15. They recorded single live specimens in 1985 and 1987, and 10 specimens from 1994-95. Densities in the latter sampling period were 0.03/foot^2.

Today, the sheepnose is thought to be extant in five pools, and in very low numbers. My records include MRP 3 (downstream of St. Croix River, Minnesota and Wisconsin; last seen live/FD in 2000-01, D.E. Kelner, Minnesota Department of Natural Resources [MDNR], pers. comm., 2002), MRP 7 (Trempeleau to Onalaska, Wisconsin and Minnesota; 2001, M. Davis, MDNR, pers. comm., 2002), MRP 15 (Quad Cities area, Illinois and Iowa; 1998, INHS museum number 22893), MRP 20 (downstream of Keokuk, Iowa, area, Illinois and Missouri; 1986, INHS 15659), MRP 22 (Quincy, Illinois and Hannibal, Missouri area; 1987, INHS 14795). The 2001 MRP 7 record was for a live juvenile 1.3 inches long and estimated to be three years old. Interestingly, it had five zebra mussels attached to its shell (M. Davis, MDNR, pers. comm., 2002). In the upper Mississippi River, the sheepnose is an example of a rare species becoming rarer. Despite the discovery of juvenile recruitment in MRP 7, the sheepnose population levels in the upper Mississippi River appear to be very small and of questionable long-term viability given the threats outlined below.

The sheepnose and other mussel populations in the upper Mississippi River are seriously threatened by zebra mussels (see "Factor E. Other natural or manmade factors affecting its continued existence" below). Even if some level of sheepnose recruitment was documented, the status of this species in the Mississippi is highly jeopardized, with imminent extirpation a distinct possibility. Other threats include channel maintenance dredging and sedimentation from tributary systems. The sedimentation load of the Chippewa River is particularly evident below its confluence (Thiel 1981). Sediment accumulations above lock and dams generally preclude the occurrence of sheepnose.

St. Croix River: The furthest upstream extant population of the sheepnose is in St. Croix River, Minnesota and Wisconsin. The sheepnose was once distributed over the lower 54 miles of the St. Croix (D.J. Heath, WDNR, pers. comm., 2002). The sheepnose was reported in 1988 from a mussel relocation effort for a new bridge crossing at the mouth of the St. Croix (Heath 1989). He recorded three live specimens from five sampling sites, but at extremely low overall densities (0.0001/foot^2). Three live individuals were also found in recent years in the same river reach, while it was absent in the other 15 river reaches sampled (Hornbach 2001). Relative abundance for the sheepnose of the 31 species he recorded in that reach was 0.0004%, but much lower when all live mussels (n = 46,140) throughout the study area were considered. Currently, the population is thought to be very small, comprised of very old individuals, and restricted to the lowermost main stem (below RM 1) in Washington County, Minnesota, and Pierce County, Wisconsin (D.J. Heath, WDNR, pers. comm., 2002). The viability status of the sheepnose population in the St. Croix is highly doubtful.

The long-term health of St. Croix mussel populations may be in jeopardy. Hornbach et al. (2001) determined that juvenile mussel density had suffered a statistically significant decline at 3 of 4 sites that they had sampled in the 1990s and again in 2000 in the lower St. Croix. Zebra mussels threaten the sheepnose and other mussel populations in the lower river (to RM 24; D.J. Heath, WDNR, pers. comm., 2002). A 2000 survey at 20 sites on the lowermost 24 miles of the St. Croix River estimated that nearly 1% of the unionids were infested with zebra mussels (Kelner and Davis 2002). The proximity of the St. Croix to the expanding Minneapolis/St. Paul metropolitan area may also pose various anthropogenic threats to the sheepnose.

Chippewa River: The Chippewa River is located in western Wisconsin. The sheepnose is known from the Chippewa in two long reaches: the Lake Holcombe to upstream of Bruce river reach in the upper Chippewa (Balding and Balding 1996) and the lower Chippewa from Eau Claire downstream to the Red Cedar River confluence (Balding 1992; T. Balding in litt., 2001). Balding and Balding (1996) reported 50 live specimens sampled from 1989-1994, but more recent collections have expanded sites of occurrence to 20 of 67 stations (30%) in the middle and upper portions of the Chippewa (T. Balding in litt., 2001). Relative abundance in this reach is 0.8%. Balding (1992) found 12 live specimens from 13.5% of the 37 sites in the lower river he sampled, and 31 dead shells of unstated condition. Additional survey work has extended the number of stations where it was found live to 10 of 45, or 22% (T. Balding in litt., 2001). Relative abundance of the sheepnose in the lower river is 0.56%.

Some evidence for recent recruitment was discovered in both reaches studied in the Chippewa. The smallest live specimen in the upper river was 1.4 inches, while the smallest live specimen in the lower river was 1.7 inches. Two bridge replacement mussel relocation projects Balding conducted yielded 15 (1.8% relative abundance) and 50 (0.17%) sheepnose, respectively. The sheepnose population in the Chippewa appears to be "stable" based on this data (T. Balding in litt., 2001). Sampling during the summer of 2002 in the lower river below the dam at Eau Claire revealed juvenile sheepnose approximately 5-7 years old (D.J. Heath, WDNR, pers. comm., 2002).

Numerous small dams on the Chippewa River have impacted sheepnose habitat. The proximity of the Chippewa population of sheepnose to the Mississippi River makes the ultimate threat of zebra mussel invasion a real possibility. Thiel (1981) noted a tremendous sediment bed load transported down the Chippewa into the Mississippi River. Municipal pollutants associated with Eau Claire and agricultural runoff may also be a localized threat to the sheepnose in the system.

Flambeau River: A tributary of the Chippewa, the sheepnose population in the Flambeau is relatively small (T. Balding in litt., 2001). He reported 6 specimens (0.33% relative abundance) from 2 of 14 sites from Thornapple Dam to the mouth, a distance of approximately 8 river miles. Thesis work on the Flambeau (Kelner 1995) resulted in the collection of 15 live sheepnose in 1994, including relatively young individuals (D.E. Kelner, MDNR, pers. comm., 2002). They, too, were limited in distribution to the lower eight miles of river, and represented 1.1% relative abundance. Balding and Kelner considered this population to be relatively healthy, viable, and stable. The Flambeau and upper Chippewa probably represent a single sheepnose metapopulation (D.J. Heath, WDNR, pers. comm., 2002). Although not as high a possibility as in its parent river, there is the potential threat of zebra mussels in the Flambeau. Sedimentation is also a threat to this species.

Wisconsin River: The Wisconsin River is a major upper Mississippi River tributary draining much of central Wisconsin. Records for the sheepnose are available throughout nearly the entire length of the Wisconsin River, a distance of approximately 200 miles (D.J. Heath, WDNR, pers. comm., 2002). Archeological material and modern records over the past century are known. In July 2002, ~20 live specimens were found in a dense mussel bed near Port Andrew (B. Seitman, MDNR, pers. comm., 2002). Many juveniles of other species were found in the bed, although recently recruited sheepnose specimens were not among them. Currently, the sheepnose is primarily confined to the lower river from RM 82 downstream, and has been found in roughly half of the 26 known mussel beds (D.J. Heath, WDNR, pers. comm., 2002). It is all but absent in the 10 miles below the dam at Prairie du Sac. A single live individual has been found in recent years at RM 130.1 downstream of Killborn Dam. Survey work conducted over the past 15 years indicates that overall mussel populations in the Wisconsin River have declined (D.J. Heath, WDNR, pers. comm., 2002).

The sheepnose population is probably recruiting in the river, but apparently only in the lower river (below RM 82). Recruitment levels are fairly low despite the presence of gravid females with viable glochidia (D.J. Heath, WDNR, pers. comm., 2002). Threats include excessive sedimentation, agricultural runoff, excessive nutrients, dam discharges, and potentially the zebra mussel.

Kankakee River: The sheepnose once occurred along the lower two-thirds of the Kankakee River, an upper Illinois River tributary, in Indiana and Illinois. This species has disappeared from the upper channelized portion of the Kankakee in Indiana, but persists in a localized portion of central Kankakee County, Illinois. Records since 1986 place the sheepnose from the vicinity of the Iroquois River confluence (Aroma Park) downstream to Kankakee, a distance of approximately six river miles (K.S. Cummings, INHS, pers. comm., 2001). Several live specimens have been sampled since 1996 from Aroma Park. The Kankakee population of sheepnose is very localized, small, and of questionable viability. Gravel mining in the watershed has been documented (Fuller 1974), and may still pose a threat to the sheepnose population. Sedimentation and urban runoff may also be threats to the sheepnose in the Kankakee.

Meramec River: The Meramec River flows into the Mississippi River downstream of St. Louis in east-central Missouri. It harbors one of the best sheepnose populations remaining rangewide.

Buchanan (1980) reported this species as being "generally distributed" in the downstream 140 miles of the Meramec from late 1970s sampling. Similar to all other streams where it occurs, the sheepnose exists in relatively low relative abundance. In the late 1970s, Buchanan (1980) found the sheepnose to represent 0.4% of the Meramec River mussel fauna. During Buchanan's (1980) study, 39 live individuals from 18 sites, FD individuals from 7 more sites, and relic shells only from 6 sites were recorded (Roberts and Bruenderman 2000). The maximum number of live specimens (13) in the late 1970s was recorded from Meramec River mile (RM) 39.8. Live or FD individuals were found on the Meramec from RM 4.5 to 145.7.

During 1997, Roberts and Bruenderman (2000) using similar sampling methods resurveyed the Meramec River system and collected 32 sheepnose live from 9 sites, with an additional 3 sites yielding relic shells only. Sheepnose relative abundance was 0.4%, which had not changed since the study by Buchanan (1980). The maximum number of live specimens (10) in 1997 was recorded from RM 48.8. The Meramec River reach that yielded live or FD individuals in 1997 stretched from RM 25.6 to 91.3 (Roberts and Bruenderman 2000).

When sites that yielded evidence of the sheepnose during both surveys are compared (n = 8), there is no discernable population trend data (25 live specimens found in each survey). However, the number of sites that yielded live specimens decreased from eight to five, with relic shells only located at the other three sites in 1997. Thus, between the late 1970s and 1997 sites producing live or FD sheepnose decreased from 25 to 9, although total numbers of live sheepnose was similar. Even catch-per-unit-effort (0.2/person hour) was identical over both surveys. The river reach harboring live or FD specimens shrank by over half from 140 to 65 river miles.

The sheepnose population appears to be recruiting, as 6 of 25 live sheepnose deemed to be juveniles (less than 6 years old as estimated qualitatively by external growth ring counts) were sampled in 1997 (Roberts and Bruenderman 2000), demonstrating some level of viability (S.A. Bruenderman, Missouri Department of Conservation [MDC], pers. comm., 2002). Baird (2000) thought that conditions for recruitment in another species, the spectaclecase (*Cumberlandia monodonta*), in the Meramec have apparently declined in the past 20-30 years, but that causes were undetermined. The trend data from the late 1970s to 1997 clearly indicate that the sheepnose has declined in total range within the Meramec River, if not in total population size (Roberts and Bruenderman 2000). The extent of the population in the lower end appears to be shrinking upriver. Factors potentially contributing to this reduction in range may include forces associated with its proximity to the burgeoning St. Louis metropolitan area (e.g., accelerated runoff, channel scouring). Despite these problems, the continuing importance of the Meramec sheepnose population cannot be over stressed. An expanded site associated with a railroad crossing in St. Louis County on the river above Castlewood State Park yielded 43 live specimens over 3 days of sampling in July 2002, including at least 1 gravid female (A. Roberts, Service, pers. comm., 2002). Collectively, these data reinforce the level of importance of the Meramec population for the sheepnose rangewide.

Detailed information on threats to the mussel communities of the Meramec River system were presented by Roberts and Bruenderman (2000). They pointed to habitat loss from channel and bank degradation as the most evident reason for mussel declines in the system. Also noted was "extensive" instream gravel mining and an increasing loss of riparian vegetation in the watershed, while they documented the loss of suitable stable habitat and mussel beds at many sites in the system where mussels occurred in the late 1970s. Their 1999 record for a zebra mussel in the lower main stem is particularly noteworthy. Recreational and commercial boating in the Meramec could enable zebra mussels to spread upstream into sheepnose habitat. The potential spread of zebra mussels up the Meramec system warrants very close monitoring.

Bourbeuse River: The Bourbeuse River is a northern tributary of the Meramec River joining it at RM 68. The Bourbeuse sheepnose population is "generally distributed" in the downstream 90 miles of the river (Buchanan 1980), but exceedingly rare. In the late 1970s, Buchanan (1980) found the sheepnose to represent 0.1% of the Bourbeuse River mussel fauna, with 10 live specimens sampled from 7 sites. Based on data collected by Buchanan (1980) and additional survey work in 1980, live or FD individuals stretched on the Bourbeuse from RM 6.5 to 90.0.

Data from a resurvey of the Bourbeuse collected in 1997 yielded 9 live sheepnose from 4 sites (Roberts and Bruenderman 2000). Fresh dead shells were located at an additional site. Sheepnose relative abundance was 0.4%. Live or FD individuals occurred on the Bourbeuse from RM 1.4 to 66.3. A decrease in the number of extant sites (7 to 4) and length of river reach (83 to 65 miles) supporting the sheepnose population has occurred over the 20-year period. Although these data may not be statistically significant, they are comparable to the trend in declining sheepnose distribution in the parent Meramec River (see account above). Recruitment is taking place in the Bourbeuse (two of eight specimens were estimated at six-years old; Roberts and Bruenderman 2000), and the sheepnose population appears to be viable.

Gravel mining is common in the Bourbeuse (see "Meramec River" account above). Roberts and Bruenderman (2000) thought that nutrient over-enrichment was also a particular problem in the Bourbeuse. They noted a low-head dam at RM 11.6. Row crops along the Bourbeuse are commonly tilled to the stream's edge, while cattle have easy access to the river at many sites. Runoff from agricultural fields (e.g., soybeans) may also be an impact to the sheepnose in the Bourbeuse, as mussel populations are sometimes depauperate near areas with row crops (S.A. Bruenderman, MDC, pers. comm., 2002).

Lower Missouri River system

Osage Fork Gasconade River: The Osage Fork is a southwestern headwater tributary of the Gasconade River. A single live specimen, qualitatively aged at 10+ years, was located in 1999 at RM 21.1 (Bruenderman et al. 2001). No other record is available for the Osage Fork, and none for the main stem Gasconade for over 20 years. Based on a dearth of available information, the viability of the Osage Fork population is highly doubtful, and threatened by a substantial sedimentation bedload in the system.

Ohio River system

The sheepnose was historically known from 28 streams in the Ohio River system. Currently, only 11 streams are thought to have extant sheepnose populations in the system. The percentage of stream population losses in the Ohio River system (17 of 28, 61%) is a few percentage points less than that recorded rangewide (51 of 77, 66%).

Ohio River main stem: The Ohio River is the largest eastern tributary of the Mississippi, with its confluence marking the divide between the upper and lower portions of the latter system. Historically, the sheepnose was documented from the entire length of the Ohio River, and was first collected there in the early 1800s (its type locality). Notes on its status in the Ohio run the gamut of relative abundance. Ortmann (1909) sampled it "sparingly" from the Ohio River in Pennsylvania. Sampling mostly by brail along the length of the northern border of Kentucky, a distance of 664 river miles, Williams (1969) collected 41 specimens. Most of these (29) were found in the upper portions of river he sampled (from RM 317-538), but extended downstream to RM 871. Relative abundance was 0.7% for the entire reach sampled.

Schuster and Williams (1989) resampled by brail in 1982 the reach of the Ohio River investigated by Williams (1969). The sheepnose comprised 0.3% relative abundance of the mussel population, with a total of 21 specimens collected from 5 pools (from RM 776.1 upstream to RM 341.0). Puzzlingly, Cicerello et al. (1991) stated that it was "generally distributed and common" in the Kentucky portion of the Ohio. By the early 1980s, Taylor and Spurlock (1982) considered the sheepnose to be extirpated from the upper Ohio River adjacent West Virginia. However, primarily using brail, Zeto et al. (1987) collected the sheepnose from two of seven upper Ohio sites they sampled in Ohio and West Virginia, one site each in the Greenup (total of two sites collected) and Belleville (five sites collected) Pools. Seven specimens were found at Ohio RM 289 (relative abundance of 1.85%) and one specimen (0.09%) from RM 179.0-179.9.

Ecological Specialists, Inc. (2000) reported a synopsis of sheepnose collections over the previous few decades in upper Ohio River pools. They reported on the number of live sheepnose collectively found from Belleville downstream to Meldahl between 1969 and 1999. The number of live specimens for each pool, followed by relative abundance, is as follows: Belleville (22, 0.2%), Racine (2, <0.01%), Byrd (0), Greenup (64, 0.4%), Greenup and Meldahl lumped (17, 2.0%), Meldahl (10, 0.1%), and total (115, 0.2%). The youngest sheepnose qualitatively aged in four pools was 11 years (Greenup), 9 (Racine), 8 (Belleville), and 5 (Meldahl), but recruitment was not necessarily documented in recent years.

Actual population status during the last couple of decades appear to be somewhere between the extremes stated by Taylor and Spurlock (1982) and Cicerello et al. (1991), but probably much closer to the status stated in the former than in the latter publication. Currently, the sheepnose is generally distributed, but rare, in most pools, but is apparently absent from the Pennsylvania portion of the system. The population in the Ohio is probably viable, but continues to show a declining status trend, similar to that in the Mississippi River (see account above).

Navigational improvements on the Ohio River began in 1830 (Cicerello et al. 1991), leading to the construction of 53 locks and dams by the 1960s. Since that time, several "high level" locks and dams were constructed and replaced all but the two lowermost older and smaller structures (Schuster and Williams 1989). Today, 18 (16 high and 2 low) locks and dams impound nearly the entire 981 mile length of river (all but the lowermost portion near the Mississippi River confluence). Threats, such as the chemical spill that caused the major mussel kill outlined below under "The present or threatened destruction, modification, or curtailment of its habitat or range; Chemical Contaminants," maintenance dredging, and the zebra mussel invasion are making the sheepnose increasingly imperiled in the Ohio River. Although the zebra mussel population appears to have already peaked and crashed in the Ohio (P.A. Morrison, Service, pers. comm., 2001), much damage to existing mussel beds was realized. They persist in the river, and may continue to impact native mussels such as the sheepnose over time.

Allegheny River: The Allegheny River drains northwestern Pennsylvania and joins the Monongahela River at Pittsburgh to form the Ohio River. Historically, Ortmann (1909) considered the sheepnose to occur "more abundantly " in the Allegheny in Armstrong County than it did in the Ohio in Pennsylvania, where he sampled it "sparingly." A population of the sheepnose remains in the Allegheny River in Forest and Vanango Counties, Pennsylvania (T. Proch, Pennsylvania Department of Environmental Protection [PDEP], pers. comm., 2001; G. Zimmerman, EnviroScience, Inc., pers. comm., 2002). Zimmerman reported several live and FD specimens, including juveniles, near Oil City in 2002. This evidence supports the presence of a viable population of the sheepnose in the Allegheny.

Nine locks and dams were constructed on the lower Allegheny River from Armstrong County to Pittsburgh that disrupted historical riverine habitat for the sheepnose. Current threats to the sheepnose in the Allegheny River include sedimentation, bridge replacement projects, and silvicultural activities (T. Proch, PDEP, pers. comm., 2002). Oil and gas extraction is accelerating in the watershed (R.M. Anderson, Service, pers. comm., 2002). Pollutants from these activities include brines and organics. Zebra mussels are dense in Chautauqua Lake, New York (S.A. Ahlstedt, U.S. Geological Survey [USGS], pers. comm., 2002), in the headwaters of the system. There is a distinct possibility that they will move down into the Allegheny main stem. A large distillery in Warren is a potential source for pollutants in the Allegheny.

Muskingum River: A major northern tributary of the Ohio River, the Muskingum River is the largest drainage basin in Ohio and drains the east central portion of the state. The sheepnose has a long collection history in the Muskingum River, which is one of the best sampled rivers in the country for mussels (Watters and Dunn 1994-94). Records span most of the mainstem and its headwater rivers, and represent one of the larger sheepnose populations known historically (G.T. Watters, OSUM, pers. comm., 2001). Surveys of the Muskingum main stem were conducted from 1967-70 (Bates 1970), 1979-81 (Stansbery and King 1983), and 1992-93 (Watters and Dunn 1993-94). Since 1967, the sheepnose has been considered rare in the Muskingum (Watters and Dunn 1993-94). Densities at sites where the sheepnose still occurs are similar to densities recorded in the previous two surveys.

During 1992-93, only 6 specimens of the sheepnose were collected. Relative abundance was a mere 0.05%. These were sampled in three of the six beds that they located and mapped in the lower reaches of the river, with all sheepnose being found below RM 12. These beds are relatively near the Muskingum's confluence with the Ohio, where an extant population occurs (see "Ohio River" account above). Watters and Dunn (1993-94) thought the lower Muskingum was "probably" the only stream reach where the sheepnose remains in Ohio.

Watters and Dunn (1993-94) surmised that mussel population survival in the lower Muskingum River was "precarious." The relatively short reach of stream where mussels still exist could possibly be severely damaged or eliminated entirely from a single catastrophic chemical spill or similar event. A recent spill, although "minor and well contained" occurred on the lower Muskingum (Watters and Dunn 1993-94). They concluded that the sheepnose population in the Muskingum was recruiting, indicating some level of viability. Five specimens were qualitatively aged in 1992 at 8 (1 specimen), 10 (1), 13 (1) and 14 (2) years of age. Its small size and limited river reach currently inhabited is obviously cause for ongoing concern.

Eleven locks and dams were once constructed on the Muskingum from Zanesville, Ohio, downstream (R. Sanders, Ohio Department of Natural Resources, pers. comm., 2002). While some of these have been breached and one is entirely gone, mussel beds were generally located in proximal reaches below existing locks and dams. During their study, Watters and Dunn (1993-94) located few mussels outside of beds. However, they found ample evidence that mussel populations were once more generally distributed in other portions of the lower Muskingum. Some or all of the locks and dams may eventually be removed (Watters and Dunn 1993-94). If removed, they thought that the release of silt and detritus that have built up behind them for decades could be "disastrous" for mussels downstream, as most beds are located just below the structures. Channel maintenance dredging is also a major concern. A large amount of spoil was dumped directly on a mussel bed that included the sheepnose in the late 1990s (G.T. Watters, OSUM, pers. comm., 2002). Thousands of mussels were killed as the result of this single event. They also noted that the lower ends of two mussel beds coincided with the mouths of two streams, Wolf and Bear Creeks. This lead them to surmise that pollutants, such as sediment loads or agricultural runoff, in their watersheds may adversely impact mussels in the main stem Muskingum below their respective confluences.

Walhonding River: The Walhonding River is a tributary of the upper Muskingum River system, in central Ohio, forming the latter river at its confluence with the Tuscarawas River at Coschocton. In the 1960s and through the mid-1970s, the sheepnose was not uncommon in the Walhonding based on OSUM records. However, by the late 1970s, the species had become increasingly rare in the river (again based on museum records). During 1991-93, Hoggarth (1995-96) discovered five live specimens at an undisclosed number of sites; seven relic specimens were also reported. Relative abundance was <0.1%. A small sheepnose population is thought to remain in the Walhonding currently, but its status is unknown. The Walhonding population is isolated from the population in the Muskingum by several locks and dams.

A major impoundment has severely curtailed available habitat and the sheepnose population in the Walhonding River. The construction of Mohawk Dam on the mainstem Walhonding ~30 RMs above its mouth destroyed many miles of potential habitat. Fourteen OSUM collections were made in the reach of river now flooded behind Mohawk Dam. Between 1961 and 1977, an additional 14 primarily small OSUM collections of the sheepnose were made from the lower Mohican River, a Walhonding tributary that is now flooded by the reservoir. Current threats to the sheepnose in this system are thought to be similar to those non-navigation channel impacts included under the Muskingum River account above (e.g., sedimentation, agricultural runoff) in addition to flow releases from Mohawk Dam..

Kanawha River: The Kanawha River is a major southern tributary of the Ohio River draining much of West Virginia. The population of the sheepnose is found in a short reach of stream in Fayette County, south central West Virginia. It appears to be limited to a five-mile stretch of stream immediately below Kanawha Falls (J.L. Clayton, West Virginia Division of Natural Resources [WVDNR], pers. comm., 2001). The first reported record in the Kanawha was collected in 1970 (1 FD, OSUM 1970:0048). Subsequent collections in the 1980s and 1990s have confirmed the continued existence of a small population (J.L. Clayton, WVDNR, pers. comm., 2001). The sheepnose population in the Kanawha is thought to be viable (W.A. Tolin, Service, pers. comm., 2002). Threats to the sheepnose include sedimentation, mine runoff, and developmental activities in the narrow band of bottomlands along the deeply entrenched New River (the portion of the Kanawha River above the Falls). Chemical spills are a distinct possibility with the railroad and highway rights-of-ways that lie immediately parallel to the river (W.A. Tolin, Service, pers. comm., 2002).

Licking River: The sheepnose is known from the lower half of the Licking River, a southern tributary of the Ohio River in northeastern Kentucky, where it has been collected sporadically over the past few decades. Currently, the species is "very uncommon" in the Licking (R.R. Cicerello, Kentucky State Nature Preserves Commission [KSNPC], pers. comm., 2001), and was collected in 1998. There has been no documented evidence of recent recruitment. Therefore, the viability of the population is very questionable. Threats include sedimentation, agricultural runoff, and nutrient enrichment.

Kentucky River: The Kentucky River is a major southern Ohio River tributary draining much of central and southeastern Kentucky. Unlike several other streams in Kentucky, the mussel fauna of the Kentucky River main stem has been poorly sampled. Danglade (1922) generated the first list of Kentucky River mussels, but failed to report the sheepnose. It was not discovered in the system until 1996, when R.R. Cicerello (KSNPC, pers. comm., 2001) reported a FD specimen from the middle portion of the main stem in the Palisades region. Similar to nearly all other extant populations, the sheepnose would appear to be rare in the Kentucky River.

Construction of Kentucky River Locks and Dams 1 to 5 began in 1836-42 (S.L. Butler, father, pers. comm., 2002). By the time of Danglade's (1922) study, the entire length of the mainstem (259 river miles) was pooled behind 14 locks and dams, with habitat that he characterized as "for the most part, a soft mud bottom." He also mentioned that the narrow bottomlands were "extensively cultivated." The fact that the main stem has been impounded and its free-flowing habitats disrupted for over a century makes the possibility of a significant population occurring in the Kentucky River minimal. The viability of this population is questionable at best (R.R. Cicerello, KSNPC, pers. comm., 2002), and threatened currently by a large infestation of the zebra mussel.

Green River: The Green River is a lower Ohio River tributary in west central Kentucky. The Green historically had the most diverse mussel fauna known from a single site exclusive of the Tennessee River. The sheepnose was first reported in the Green River, Kentucky, by Price (1900), and has been collected sporadically since. Ortmann (1926) and Clench and van der Schalie (1944) failed to find it at the seven stations they collected on the Green. Stansbery (1965) documented its occurrence in the mid-1960s at Munfordville, Hart County, where he reported an astonishing 47 species collected over a series of several years in the early 1960s. Williams (1969) brailed 11 specimens from the upper Green, 10 from upstream of Mammoth Cave National Park (MCNP), and 1 from downstream of MCNP to Lock and Dam 4, for a relative abundance of 0.3%. Cicerello and Hannan (1990) reported 19 live specimens from MCNP during 1987-89, including 2 juveniles, from 14 sampling sites. Additional sampling in the Green from 1988-96 located live specimens from nine sites from the eastern portion of MCNP upstream to very near the eastern border of Hart County (Cicerello 1999). From 1996-98, he reported four live and one FD specimens at four quantitative sites, where the sheepnose accounted for 0.05% of overall mussel relative abundance.

Currently, a generally small population remains in the upper Green River from the vicinity of MCNP upstream into Hart County. Although reported downstream of MCNP in 1993 by Gordon and Sherman (1995), a concerted effort (~15 person hours [PH] per site) at several sites in this general river reach in 2001 failed to reveal a single sheepnose shell. Summer 2002 sampling in Hart County located nine juveniles 1.1-1.5 inches in length in muskrat middens (J.B. Layzer, USGS, pers. comm., 2002). Similar sized juveniles have also been reported by R.R. Cicerello (KSNPC, pers. comm., 2002) from above MCNP through Hart County to very near the Green County line. The Green River therefore harbors a sheepnose population considered to be currently viable.

Threats to this population primarily include agricultural runoff, sedimentation, and fluctuating flow releases from Green River Dam. Although riparian zones throughout much of the main stem are fairly intact, tributaries in the upper part of the system are active contributors of sedimentation and associated runoff into the river. Activities outlined under "Past, current, and anticipated conservation activities undertaken for the benefit of the species or its habitat" will help mitigate impacts from these factors.

Wabash River: The Wabash River is one of the largest sub-basins within the Ohio River system, with a watershed encompassing much of Indiana, west-central Ohio, and southeastern Illinois. Call (1900) considered the sheepnose to be common in deeper portions of the Wabash River.

Material housed in major museums verify its relative abundance in historical times, particularly in the lower main stem (K.S. Cummings, INHS; G.T. Watters, OSUM, pers. comm., 2001). However, by the 1940s, the sheepnose was thought to be rare everywhere in Indiana (Goodrich and van der Schalie 1944). Cummings et al. (1987) thought the sheepnose was extirpated from the lower Wabash, as no surveys since 1966 had verified its continued existence there. The following year (1988), a FD specimen was found in the middle Wabash in Tippecanoe County (INHS 6640), while a single live specimen was found in the lower Wabash in northern Knox County (INHS 6271; Cummings and Mayer 1992). These are the last verified records for the sheepnose in the main stem Wabash. The sheepnose population in the Wabash is very tenuous. Recruitment has not been documented in recent years, making the viability if its population doubtful (B.E. Fisher, Indiana Department of Natural Resources [IDNR], pers. comm., 2001).

Eel River: The Eel River is a tributary of the upper Wabash River in north-central Indiana. A few records for the sheepnose are extant from this system. Relic shells were reported in a 1986 survey, and museum records of unknown date and shell condition are also known. The only recent record for live material was from the lower main stem in Cass County in 1997. Two specimens were found, including one fairly small individual (B.E. Fisher, IDNR, pers. comm., 2001). Based on this limited information, the current status of the population in the Eel is largely unknown, but there would appear to be some level of recruitment in the population (B.E. Fisher, IDNR, pers. comm., 2001). Several mill dams are on the Eel, some in various states of disrepair.

Tippecanoe River: Another Wabash River tributary, the Tippecanoe River drains the central portion of northern Indiana. Cummings and Berlocher (1990) surveyed the Tippecanoe in 1987, and summarized mussel information known from the system. The sheepnose was first reported from the Tippecanoe circa 1900. Goodrich and van der Schalie (1944) considered it rare in Indiana by mid-century, including, presumably, in the Tippecanoe. Sampling in 1987 produced only 10 live specimens from 6 sites, primarily in the middle reaches of the river. Relative abundance was low (0.7%). One site was below Freeman Reservoir (*contra* Cummings and Berlocher 1990; K.S. Cummings, INHS, pers. comm., 2001).

Survey work conducted during 1991-92 indicated very high diversity in the Tippecanoe River (Ecological Specialists, Inc. 1993). Collectively, 48 mussel species were found live or FD at 30 sites. They reported the sheepnose from 12 sites, but only 4 live individuals were found at 3 sites, with FD specimens at an additional 4 sites. Interestingly, two of the four live specimens were qualitatively estimated to be 3 and 6 years of age, indicating recent recruitment into the population. The fact that sauger apparently do not occur in the system (Ecological Specialists, Inc. 1993) indicates that another species of fish acts as its host. Furthermore, the oldest individual was estimated at 13 years. Its continued occurrence in most of the river reaches sampled during the surveys of 1987 and 1991-92 was verified in 1995 (B.E. Fisher, IDNR, pers. comm., 2001). In addition, he reported it from at least two sites below Freeman Reservoir, and extended its currently known range upstream into Marshall County. Records since 1991 confirm its existence from at least 14 sites. The sheepnose is now known from highly disjunct localities in the lower two-thirds of the river, a distance of about 45 river miles. Viability has been documented with the occurrence of juveniles recruiting into the population in the 1990s (Ecological Specialists, Inc. 1993; R.M. Anderson, Service; B.E. Fisher, IDNR, pers. comm., 2001) despite apparently very low overall numbers.

Sheepnose threats in the Tippecanoe River were noted by Cummings and Berlocher (1990) and Ecological Specialists, Inc. (1993). They include evidence of nutrient enrichment manifest in abundance of filamentous algae in some reaches. Turbidity increases in downstream areas indicated that streambank and other sources of erosion were more prevalent than they were upstream. Unrestricted cattle access in some riparian areas is a sedimentation and nutrification concern. The extent of suitable habitat in the lower river has been compromised by two major reservoirs, Shafer and Freeman. Mussel populations in general below the impoundments were highly localized in deeper pools and comprised primarily of species indicative of slow water and soft substrate habitats generally associated with impoundments. This indicated to them that riffle habitats may be impacted by tailwater conditions, such as temporary exposure during low flow releases. The zebra mussel is known from some of the glacial lakes in the headwaters of the system (B.E. Fisher, IDNR, pers. comm., 2001). The extent that this alien invader species has moved downstream in the main stem Tippecanoe is not known. However, if it spreads downstream, significant impacts to the sheepnose and other native species may soon be realized. Close monitoring of its distribution in the watershed is highly advised.

Cumberland River system

Cumberland River main stem: Historical sheepnose records in the Cumberland River are known from throughout the mainstem downstream of Cumberland Falls and three of its tributaries. Wilson and Clark (1914) reported it from 14 main stem sites from what is now Cumberland Reservoir, Kentucky, downstream to Stewart County, Tennessee. This represents a distance of nearly 500 miles. They stated that they didn't see "many examples" of the sheepnose, but that it was "common enough to be well known among the clammers." In a 1947-49 survey of the Kentucky portion of the upper Cumberland River, Neel and Allen (1964) considered it "a rare species" while reporting it live from two of the six main stem sites sampled. It was last documented in the Tennessee portion of the river during a 1976 survey (Tennessee Valley Authority 1976).

The only recent record for the Cumberland is from the extreme lower end of the river near its confluence with the Ohio River below Barkley Dam in 1987 (R.R. Cicerello, KSNPC, pers., comm., 2002). The status of this population is unknown, but it could be considered a part of the lower Ohio River sheepnose metapopulation. Threats include the zebra mussel and channel maintenance activities.

Tennessee River system

The sheepnose was originally known from the Tennessee River and nine of its tributary streams. Historically, Ortmann (1925) considered the sheepnose to occur "sparingly" in the lower

Tennessee River, and to be "rare" in the upper part of the system (Ortmann 1918). It appears to be absent from tributaries downstream of the Hiwassee. The population in the upper tributaries was described as a distinct species, *Unio compertus* Frierson, 1911 (in Parmalee and Bogan 1998).

Hundreds of miles of large river habitat on the Tennessee main stem have been converted under nine reservoirs, with additional dams constructed in tributaries historically harboring this species (e.g., Clinch, Holston, Elk Rivers) (Tennessee Valley Authority 1971). Watters (2000) summarizes the tremendous loss of mussel species from various reaches of the Tennessee. Despite this fact, the Tennessee River system continues to represent one of the last strongholds of the sheepnose rangewide. Today, at least one of four extant stream populations appears to be viable, while the status of remaining populations in other parts of the system are unknown. However, its status could easily be subject to change given its diminutive population size in the Tennessee River system.

Tennessee River main stem: The sheepnose was historically distributed throughout the Tennessee River main stem. The species persists in the tailwaters of Guntersville, Wilson, Pickwick Landing, and Kentucky Dams. Gooch et al. (1979) considered the sheepnose to be "relatively uncommon" in the Guntersville Dam tailwaters, northern Alabama. Two FD specimens were recently reported there in 1999, where the population appears to be "very rare" (Garner and McGregor 2001).

The 53-mile stretch of river in northwestern Alabama collectively referred to as the Muscle Shoals historically harbored 69 species of mussels, making it among the most diverse mussel faunas ever known (Garner and McGregor 2001). At an archeological site near the lower end of the Muscle Shoals, Morrison (1942) found the sheepnose to be very rare. However, the construction of three dams (i.e., Wilson in 1925, Wheeler in 1930, Pickwick Landing in 1940) inundated most of the historical habitat, leaving small habitat remnants (Garner and McGregor 2001). The species has been found in low numbers by most investigators in the past 80 years from relic habitat in the Wilson Dam tailwaters, a several mile reach adjacent to, and downstream from, Florence. Based on recent collections, Garner and McGregor (2001) reported it as generally being "rare" in the Wilson tailwaters. They reported a 5-year old specimen in 1998, providing some evidence of recent recruitment.

The species is found only occasionally in the lower Tennessee River below Pickwick Landing Dam in southeastern Tennessee. Sheepnose were unreported in some previous surveys from this reach (e.g., van der Schalie 1939, Bates and Dennis 1981). Scruggs (1960) recorded a relative abundance of 0.2%, while Yokley (1972) considered it to be "very rare" in the lower Tennessee River below Pickwick Landing Dam in southwestern Tennessee (relative abundance of 0.1%). He reported only 2 specimens that were each qualitatively estimated to be 20+ years old. The sheepnose is still found occasionally in this tailwater, but only one specimen taken from a commercial harvester in 1996 from RM 141.5, Perry County, has been reported in recent years (D.W. Hubbs, Tennessee Wildlife Resources Agency [TWRA] pers. comm., 2001). During 1967-68, Williams (1969) reported brailing three sheepnose (relative abundance of 0.04%) from the lowermost Tennessee below Kentucky Dam, Kentucky. A FD specimen was found there in 1999 (R.R. Cicerello, KSNPC, pers., comm., 2001). Sheepnose populations in the Tennessee River continue to persist as small, remnant populations, but their long-term viability is uncertain (J.T. Garner, Alabama Department of Natural Resources [ADNR]; D.W. Hubbs, TWRA, pers. comm., 2002). Beginning in 2002, zebra mussel densities in the Tennessee River below Wilson Dam have become large enough to be measured quantitatively (G.T. Garner, ADNR, pers. comm., 2002), thus posing a significant threat to the sheepnose population. Other threats include gravel mining and navigational channel maintenance activities.

Holston River: The Holston River, is a major tributary of the Tennessee River, forming the latter at its confluence with the French Broad River at Knoxville, eastern Tennessee. The Holston River once supported one of the most diverse unionid mussel faunas in North America (Ortmann 1918). A total of 71 native mussel species have been identified from the main stem Holston River (P.W. Parmalee, University of Tennessee; S.A. Ahlstedt, USGS, unpublished data). Since the early 20th century, various perturbations to water and habitat quality have decimated this exceptional mussel fauna. Seven major dams impound or regulate a large proportion of the Holston River system, including the entire length of the main stem Holston. The lowermost dam in the system is Cherokee Dam, located at Holston RM 52.3 in Jefferson and Grainger Counties, Tennessee. Mussel resources in the main stem Holston River are now almost exclusively restricted to relic populations in a 25-mile reach downstream from Cherokee Dam.

Böpple and Coker (1912) first reported the sheepnose in the Holston in 1909 during their exploratory of mussel populations suitable for commercial harvest. Ahlstedt (1991a) records from 1981 indicated a sizable population downstream of Cherokee Dam at RM 52.3. He reported 43 live sheepnose from 4 of seven sites sampled, but none from sites within six miles of the dam. Sampling time averaged 6 PH/site. Overall relative abundance was 14.1%, making it the third most abundant among the 13 species found.

Sampling in July 2002 produced some astonishing results (S.J. Fraley, North Carolina Wildlife Resources Commission [NCWRC], pers. comm., 2002). Live sheepnose were found at 16 of the 20 sites sampled below Cherokee Dam. This reach extended from Nance Ferry to Monday Island (RM 14.6), Jefferson and Knox Counties. A total of 206 specimens were found, for an average of 12.9/site (range 1-41). Sampling time averaged 4 PH/site. Unlike anywhere else in its current range, the sheepnose represented the second most abundant species at the site behind the mucket (*Actinonaias ligamentina*). The sheepnose had an overall relative abundance of 18.2% among the 18 species reported live from this reach of the Holston in 2002.

Unfortunately, this is far from being the best population remaining. Only large, very old individuals were found. Sauger are common in this river reach (S.J. Fraley, NCWRC, pers. comm., 2002), but no evidence of recent recruitment was evident for this or any other species collected. Although individuals appeared to be fit, their shells were highly corroded, but showed obvious evidence of active shell growth in recent years. Eroded shells may be the result of decades of hydropower peaking flows that were thought to have scoured vegetation from bedrock ledges in the proximal reach below the dam (Ahlstedt 1991a). He also noted luxuriant growths of aquatic vegetation in 1981, and thought that drought conditions in 1981 coupled with "a history of pollution problems" have decimated mussel populations in the lower Holston. The residual effects of the tailwaters of Cherokee Dam may be having a lasting impact on the fauna (S.J. Fraley, NCWRC, pers. comm., 2002). The Holston sheepnose population is obviously slowly dying out. Zinc mining in the watershed (S.J. Fraley, NCWRC, pers. comm., 2002) may also have taken its toll on the species.

Clinch River: The Clinch River, southwestern Virginia and northeastern Tennessee, is one of the largest and most significant tributaries of the upper Tennessee River system. Based on archeological evidence, the sheepnose was "extremely rare" in the lower Clinch River (Parmalee and Bogan 1986). Ortmann (1918) considered it to be "rare" in the upper Tennessee River system, in general. Despite these assertions, the Clinch has perennially supported possibly the best sheepnose population rangewide. The largest lots of museum material available for the sheepnose have been from the Clinch and its tributary, the Powell (G.T. Watters, OSUM, pers. comm., 2001). This material dates from the 1960s and is primarily thought to represent muskrat midden material. Clinch River museum lots include 82 FD, OSUM:1969:0318; 70 FD, OSUM:1963:0094; 39 FD, OSUM:1963:0108; and 36 FD, OSUM:1967:0164.

Currently, the sheepnose population in the Clinch occurs in approximately 60 miles of river from northern Scott County, Virginia, into Hancock County, Tennessee. Ahlstedt (1991b) considered it to be "relatively common" in 1978-83 sampling throughout the free-flowing length of the Clinch River. However, he collected only 61 specimens from 29 sites. Were it not for the occurrence of 25 specimens from a single site in Tennessee (RM 184.5), his numbers would have been much less. Overall relative abundance was not calculated, but was very low, except at the site where 25 specimens were located (2.4%). Ahlstedt and Tuberville (1997) conducted quantitative sampling in the Clinch between 1979 and 1994 and found it at low densities of 0.009-0.018/foot^2). Despite low densities, the upper Clinch population of sheepnose is considered viable. Young juveniles are occasionally found, indicating the sheepnose is recruiting at least on the Tennessee side of the stream (S.A. Ahlstedt, USGS, pers. comm., 2002).

Despite the relatively healthy nature of many mussel populations in the system, the Clinch is not without its threats. Ahlstedt and Tuberville (1997) outlined major threats to the Clinch and Powell Rivers. Some coal mining activities take place in the headwaters, resulting in coal fines in river sediments. Known mussel toxicants, such as polycyclic aromatic hydrocarbons, heavy metals, and other chemicals from coal mining and other activities are known to contaminate sediments in the Clinch and Powell Rivers (Robison et al. 1996, Ahlstedt and Tuberville 1997; S.A. Ahlstedt, USGS, pers. comm., 2002). Agricultural runoff is a problem throughout much of the river, and has been implicated in the catastrophic decline of mussels in a tributary, Copper Creek (Fraley and Ahlstedt 2000).

Powell River: The sheepnose was first reported from the Powell, the Clinch River's largest tributary, by Ortmann (1918), when it was still a metapopulation of the larger Clinch River (i.e., before Norris Dam). The largest sheepnose collection known rangewide was collected in the Powell River, and included 6 live and 141 FD specimens (OSUM:1967:0145), the latter presumably from muskrat middens at a site in Claiborne County, Tennessee. Unfortunately, it is now considered very rare in the Powell. Sampling at 78 Powell sites in 1979, Ahlstedt (1991a) reported 45 live specimens from 17 sites (average 2.6/site). Ahlstedt and Tuberville (1997) conducted quantitative sampling in the Powell between 1979 and 1994 and found it at densities of 0.009-0.037/foot^2). The already very low density data tended to be declining over time. Recruitment is very low, and population viability is now questionable (S.A. Ahlstedt, USGS, pers. comm., 2002).

The Powell River mussel population has been slowly dwindling for decades (S.A. Ahlstedt, USGS, pers. comm., 2002) due to the toll taken by various anthropogenic activities (see "The present or threatened destruction, modification, or curtailment of its habitat or range"). Coal mining activities in the headwaters is much more of a threat here than in the Clinch. Agricultural runoff is of secondary importance. Coal slurry pond spills in the 1990s have been implicated in fish kills in the system (L.M. Koch, Service, pers. comm., 1998). Fines from coal processing activities are commonly found in river sediments (Kitchel et al. 1981). Several species, including some federally listed and other globally imperiled species, have become increasingly rare or extirpated in recent years. Nearly the entire mussel fauna in the Powell is currently highly jeopardized.

Lower Mississippi River system

The sheepnose was apparently never widely distributed in the lower Mississippi River system. The only verified records are for Hatchie River in Tennessee and the Delta region in Mississippi. Records for the Yazoo and Big Black Rivers are from archeological sites.

Big Sunflower River: The Big Sunflower River, Mississippi, sheepnose population is the only one remaining in the lower Mississippi system. Once "abundant," judging from museum and archeological records, the sheepnose is now considered to be not common (R.L. Jones, Mississippi Museum of Natural Science [MMNS], pers. comm., 2001). It is believed to be currently limited to a 12-15 mile reach upstream of Indianola, Sunflower County. Although no evidence of recent recruitment was noted in recent sampling efforts, variably-sized individuals indicate some, possibly very low, level of recruitment in the population.

Its long-term survival, along with some of the densest populations of mussels in North America, is imminently threatened by a Corps "flood control" project (R.L. Jones, MMNS, pers. comm., 2001). Dredging for this project is planned to take place upstream to Indianola, but head-cutting may ultimately destabilize the substrate where the sheepnose now exists. Given this threat, in addition to impacts from agricultural runoff and sedimentation in the Big Sunflower, the sheepnose population "will likely be gone in 10 years" (R.L. Jones, MMNS, pers. comm., 2001).

Summary of Extant Populations: The sheepnose has experienced a significant reduction in range and most of its populations are disjunct, isolated, and appear to be declining rangewide. The extirpation of this species from over 50 streams within its' historical range indicates that substantial population losses have occurred. In the vast majority of streams with extant populations, the sheepnose appears to be uncommon at best. Small population size and/or restricted stream reaches of current occurrence are a real threat to the sheepnose due to the negative aspects of genetics of small, geographically isolated populations. Several extant populations are thought to exhibit some level of population viability (e.g., Chippewa, Flambeau, Wisconsin, Meramec, Bourbeuse, Muskingum, Green, Tippecanoe, Clinch Rivers). However, given this compilation of current distribution, abundance, and trend information, the sheepnose appears to exhibit a relatively high level of imperilment.

Summary of status and threats:

A. The present or threatened destruction, modification, or curtailment of its habitat or range.

The decline of the sheepnose in the Mississippi River system and other mussel species in the eastern United States is primarily the result of habitat loss and degradation (Neves 1991). These losses have been well documented since the mid-19th century (Higgins 1858). Chief among the causes of decline are impoundments, channelization, chemical contaminants, mining, and sedimentation (Williams et al. 1993; Neves 1991, 1993; Neves et al. 1997; Watters 2000). Bourgeoning human populations will invariably increase the likelihood that many if not all of the factors in this section will continue to impact extant sheepnose populations.

Impoundments

Impoundments result in the dramatic modification of riffle and shoal habitats and the resulting loss of mussel resources, especially in larger rivers. Neves et al. (1997) and Watters (2000) reviewed the specific effects of impoundments on freshwater mollusks. Dams interrupt most of a river's ecological processes by modifying flood pulses; controlling impounded water elevations; altering water flow, sediments, nutrients, and energy inputs and outputs; increasing depth; decreasing habitat heterogeneity; decreasing stability due to subsequent sedimentation; blocking host fish passage; and isolating mussel populations from fish hosts. Even small low-head dams can have some of these effects on mussels. The reproductive process of riverine mussels is generally disrupted by impoundments making the sheepnose unable to successfully reproduce and recruit under reservoir conditions. Some recruitment, however, is thought to be occurring in large rivers with locks and dams (e.g., Ohio, Muskingum).

In addition, dams can also seriously alter downstream water quality and riverine habitat, and negatively impact tailwater mussel populations (Allan and Flecker 1993, Neves et al. 1997, Watters 2000). These changes include thermal alterations immediately below dams; changes in channel characteristics, habitat availability, and flow regime; daily discharge fluctuations; increased sediment loads from bank sloughing; and altered host fish communities. Coldwater releases from large non-navigational dams and scouring of the river bed from highly fluctuating, turbulent tailwater flows have also been implicated in the demise of mussel faunas (Layzer et al.

1993, Vaughn and Taylor 1999). There is no evidence that the sheepnose may persist in hypolimnetic tailwater conditions.

Population losses due to impoundments have probably contributed more to the decline and imperilment of the sheepnose and other Mississippi River system mussels than has any other single factor. Large river habitat throughout nearly all of the range of the sheepnose has been impounded leaving generally short, isolated patches of vestigial habitat generally in the vicinity below dams. The majority of the Tennessee and Cumberland River main stems and many of their largest tributaries, which were once strongholds for the sheepnose (Ortmann 1918, 1925), are now impounded. For example, over 2,300 river miles (about 20 percent) of the Tennessee River and its tributaries with drainage areas of 25 square miles or greater were impounded by TVA by 1971 (Tennessee Valley Authority 1971). A total of 36 major dams are located in the Tennessee River system.

Approximately 90 percent of the 562-mile length of the Cumberland River downstream of Cumberland Falls is either impounded (three locks and dams and Wolf Creek Dam) or otherwise impacted by cold tailwater releases. Other major Corps impoundments on Cumberland River tributaries (e.g., Obey River, Caney Fork) have inundated over 100 miles of additional potential riverine habitat for the sheepnose. Coldwater releases from Wolf Creek, Dale Hollow (Obey River), and Center Hill (Caney Fork) Dams continue to adversely impact otherwise riverine habitat in the Cumberland River system for the sheepnose. One-third of the streams that the sheepnose was historically known from occur in the Tennessee and Cumberland River systems. Watters (2000) summarizes the tremendous loss of mussel species from various portions of the Tennessee and Cumberland River systems. The sheepnose has been all but eliminated from the Cumberland River system, and is now limited to a few highly isolated stream reaches in the Tennessee River system (see accounts under "Current and historical populations, and population trends" above). This scenario is all to familiar in many other parts of its range, and include numerous navigational locks and dams (e.g., upper Mississippi, Ohio, Allegheny, Muskingum, Kentucky, Green, Barren Rivers), some high-wall dams (e.g., Wisconsin, Kaskaskia, Walhonding, Tippecanoe Rivers), and many low-head dams (e.g., St. Croix, Chippewa, Flambeau, Wisconsin, Kankakee, Bourbeuse Rivers), that have contributed to the loss of sheepnose habitat. Sediment accumulations behind dams of all sizes generally preclude the occurrence of the sheepnose. The construction of high level dams in the Ohio River has therefore further reduced the extent of suitable habitat for the sheepnose and other riverine mussels.

Channelization

Dredging and channelization activities have profoundly altered riverine habitats nationwide. Hartfield (1993), Neves et al. (1997), and Watters (2000) reviewed the specific effects of channelization on freshwater mollusks. Channelization impacts a stream's physical (e.g., accelerated erosion, reduced depth, decreased habitat diversity, geomorphic instability, riparian canopy loss) and biological (e.g., decreased fish and mussel diversity, changed species composition and abundance, decreased biomass, and reduced growth rates) characteristics

(Hartfield 1993, Hubbard et al. 1993). Channel construction for navigation has been shown to increase flood heights (Belt 1975). This is partially attributed to a decrease in stream length and increase in gradient (Hubbard et al. 1993). Flood event may thus be exacerbated, conveying into streams large quantities of sediment, potentially with adsorbed contaminants. Channel maintenance may result in profound impacts downstream (Stansbery 1970), such as increases in turbidity and sedimentation that may smother benthic organisms.

Channel maintenance operations for barge navigation has impacted habitat for the sheepnose in many large rivers rangewide. The entire length of the upper Kankakee River in Indiana was channelized decades ago. The sheepnose is considered extirpated from the upper Kankakee, and now restricted to an un-channelized portion of the river in Illinois. Periodic maintenance may continue to adversely affect this species in the upper Mississippi, Ohio, Muskingum, and Tennessee Rivers. A huge amount of dredge spoil was dumped on a sheepnose bed in the Muskingum River in the 1990s (G.T. Watters, OSUM, pers. comm., 2001). In the Tennessee River, a plan to deepen the navigation channel has been proposed (D.W. Hubbs, TWRA, pers. comm., 2002). A Corps proposal to enlarge locks and dams on the upper Mississippi River would add to the degradation of potential sheepnose habitat in project river reaches by creating more unsuitable habitat in the longer pools.

Chemical Contaminants

Contaminants contained in point and non-point discharges can degrade water and substrate quality and adversely impact, if not destroy, mussel populations. Although chemical spills and other point sources of contaminants may directly result in mussel mortality, widespread decreases in density and diversity may result in part from the subtle, pervasive effects of chronic, low-level contamination (Naimo 1995). The effects of heavy metals and other contaminants on freshwater mussels were reviewed by Mellinger (1972), Fuller (1974), Havlik and Marking (1987), Naimo (1995), Keller and Lydy (1997), and Neves et al. (1997).

The effects of contaminants are especially profound on juvenile mussels (Robison et al. 1996), which can readily ingest contaminants adsorbed to sediment particles while feeding (see "Summary of biology and natural history"), and on the glochidia, which appear to be very sensitive to toxicants (Goudreau et al. 1993, Jacobson et al. 1997) (both of these studies were conducted in the Clinch River). Mussels are very intolerant of heavy metals (Keller and Zam 1991, Havlik and Marking 1987), and even at low levels, certain heavy metals may inhibit glochidial attachment to fish hosts (Huebner and Pynnönen 1992). Cadmium appears to be the heavy metal most toxic to mussels (Havlik and Marking 1987), although chromium, copper, mercury, and zinc also negatively affect biological processes (Naimo 1995, Keller and Zam 1991, Jacobson et al. 1997, Keller and Lydy 1997).

Among pollutants, ammonia has been shown to be lethal to mussels at concentrations of 5.0 ppm (Havlik and Marking 1987). Ammonia is oftentimes associated with animal feedlots, nitrogenous fertilizers, and the effluents of out-dated municipal wastewater treatment plants (Goodreau et al. 1993). In stream systems, ammonia is most prevalent at the substrate/water interface (Frazier et al. 1996). Due to its high level of toxicity and the fact that the highest concentrations occur in the microhabitat where mussels live, ammonia should be considered among the factors potentially limiting survival and recovery of mussels at some locations (Augspurger et al. in prep.). Contaminants associated with households and urban areas, particularly those from industrial and municipal effluents, may include heavy metals, chlorine, phosphorus, and numerous organic compounds. Wastewater is discharged through National Pollution Discharge Elimination System (NPDES) permitted (and some non-permitted) sites throughout the country. Elimination sites are ubiquitous in watersheds with sheepnose populations, providing ample opportunities for some pollutants to enter streams. For instance, over 250 NPDES sites are located in the Meramec River system alone (Figure 28, Roberts and Bruenderman 2000).

Agricultural sources of chemical contaminants are considerable, and include two broad categories: nutrient enrichment (e.g., runoff from livestock farms and feedlots, fertilizers from row crops) and pesticides (e.g., from row crops) (Frick et al. 1998). Nitrate concentrations are particularly high in surface waters downstream of agricultural areas (Mueller et al. 1995). Stream ecosystems are impacted when nutrients are added at concentrations that cannot be assimilated, resulting in over-enrichment, a condition exacerbated by low-flow conditions. Juvenile mussels utilizing interstitial habitats are particularly affected by depleted dissolved levels resulting from over-enrichment (Sparks and Strayer 1998). Increased risks from bacterial and protozoan infections to eggs and glochidia may also pose a threat (Fuller 1974). Pesticide runoff commonly ends up in streams. The effects of pesticides on laboratory-tested mussels may be particularly profound (Fuller 1974, Havlik and Marking 1987), and commonly used pesticides have been directly implicated in a North Carolina mussel die-off (Fleming et al. 1995). Once widely used in parts of the Midwest and Southeast, organochlorine pesticides are still detected in streams and aquatic organisms decades after their use has been banned, and may still be found at levels in streams that often exceed chronic exposure criteria for the protection of aquatic life (Buell and Couch 1995, Frick et al. 1998). Fertilizers and pesticides are also commonly used in developed areas. These contaminants have the potential to impact all extant populations of the sheepnose.

Sediment from the upper Clinch River has been found to be toxic to juvenile mussels (Robison et al. 1996, Ahlstedt and Tuberville 1997). It was speculated that the presence of toxins in the Clinch River may explain the decline and lack of mussel recruitment at some sites in the Virginia portion of that stream (S.A. Ahlstedt, USGS, pers. comm., 2002).

Numerous streams throughout the range of the sheepnose have experienced mussel and fish kills from toxic chemical spills, particularly in the upper Tennessee River system in Virginia where several major spills have been documented (Neves 1986, 1991; Jones et al. 2001). Catastrophic pollution events, coupled with pervasive sources of contaminants (e.g. municipal and industrial pollution, coal-processing wastes), have contributed to the decline of the sheepnose in the Clinch over the past several decades (Neves 1991). An alkaline fly ash pond spill in 1967 and a sulfuric acid spill in 1970 on the Clinch River at Carbo, Virginia, caused a massive mussel kill for up to 12 miles downstream from a power plant site (Cairns et al. 1971). Natural recolonization has not occurred in the impacted river reach (Ahlstedt 1991b), possibly due to persistent copper contamination from the power plant at Carbo (Wilcove and Bean 1994).

One recent major spill in the upper Clinch River in 1998 eliminated over 7,000 mussel specimens of several species found freshly dead (Jones et al. 2001). The death toll included at least 254 specimens of three federally listed species, but was thought to be much higher (S.A. Ahlstedt, USGS, pers. comm., 2001). An especially catastrophic spill in 1999 impacted an approximately 10 mile stretch of the Ohio River and resulted in a total loss of mussels. Roughly one million mussels, including the sheepnose and two federally listed species, were estimated lost (W.A. Tolin, Service, pers. comm., 2002). Given the relative abundance of the sheepnose in the Ohio from other studies (see "Current and historical populations, and population trends" above), it is not inconceivable that potentially thousands of sheepnose specimens were eliminated in this single event. Chemical spills will invariably continue to occur and have the potential to completely eliminate sheepnose populations from restricted stream reaches and possibly entire streams.

Mining

Heavy metal-rich drainage from coal mining and associated sedimentation has adversely impacted portions of the upper Tennessee River system in Virginia. The low pH commonly associated with mine runoff can reduce glochidial encystment rates (Huebner and Pynnönen 1992). Acid mine runoff may thus be having local impacts on recruitment of the sheepnose. Mine discharge from the 1996 blowout of a large tailings pond on the upper Powell River resulted in a major fish kill (L.M. Koch, Service, pers. comm., 1996). The impact on the mussel fauna was not readily apparent, but presumed to be detrimental (S.A. Ahlstedt, USGS, pers. comm., 2002). Powell River mussel populations were inversely correlated with coal fines in the substrate; when coal fines were present, decreased filtration times and increased movements were noted in laboratory-held mussels (Kitchel et al. 1981). In a quantitative study in the Powell River, a decline of federally listed mussels and the long-term decrease in overall species composition since about 1980 was attributed to general stream degradation due primarily to coal mining activities in the headwaters (Ahlstedt and Tuberville 1997). If coal mining activities are reinitiated in western Pennsylvania, they could become a threat to the sheepnose in the Allegheny River. Oil and gas exploration is accelerating in western Pennsylvania. Pollutants from these activities include brines and organics, and potentially threaten the sheepnose population in the Allegheny.

Various mining activities take place in other systems that potentially impact current sheepnose populations. Lead and barite mining is common in the Big River, Meramec River system, Missouri. The Big River is impacted by a massive 1977 lead mine tailings-pond blowout that discharged 81,000 cubic yards of mine tailings that covered 25 stream miles and impacted the lower 80 miles of stream (Buchanan 1980, Roberts and Bruenderman 2000). High levels of zinc and lead are still found in river samples (Roberts and Bruenderman 2000) and may act as a hindrance to stream recovery. Forty-five tailings ponds and numerous other waste piles remain in the watershed (Roberts and Bruenderman 2000). A single live sheepnose specimen was reported from the Big River in 1978, but no live sheepnose have been recorded in the Big since that time (S.A. Bruenderman, MDC, pers. comm., 2002). These impacts may have contributed to the extirpation of the sheepnose from the Big River.

Instream gravel mining has been implicated in the destruction of mussel populations (Hartfield 1993). Negative impacts associated with gravel mining include stream channel modifications (e.g., altered habitat, disrupted flow patterns, sediment transport), water quality modifications (e.g., increased turbidity, reduced light penetration, increased temperature), macroinvertebrate population changes (e.g., elimination, habitat disruption, increased sedimentation), and changes in fish populations (e.g., impacts to spawning and nursery habitat, food web disruptions) (Kanehl and Lyons 1992, Roell 1999).

Gravel mining activities may be a localized threat in some streams with extant sheepnose populations. This activity is pervasive in the Meramec River system. The U.S. Army Corps of Engineers (Corps) has issued 230 permits for gravel mining in the Meramec system (Roberts and Bruenderman 2000). Although rigid guidelines prohibited instream mining and required streamside buffers, a court ruling deauthorized the Corps from regulating these habitat protective measures. The Corps still retains oversight for gravel mining, but many mining operations do not fall under Corps purview (Roberts and Bruenderman 2000). In the lower Tennessee River, mining is permitted in 18 reaches for a total of 47.9 river miles between the Duck River confluence and Pickwick Landing Dam, a distance of over 95 miles (D.W. Hubbs, TWRA, pers. comm., 2002). This is the reach where good mussel recruitment has been noted for many otherwise rare species in recent years. These activities have the potential to impact the river's precarious sheepnose population.

Sedimentation

Siltation and general sedimentation runoff is a pervasive problem in streams and has been implicated in the decline of stream mussel populations (Ellis 1936, Marking and Bills 1979, Vannote and Minshall 1982, Dennis 1985, Brim Box 1999, Fraley and Ahlstedt 2000). Sources, biological effects, and the control of sediment in streams were thoroughly reviewed by Waters (1995), while Brim Box and Mossa (1999) reviewed how mussels are specifically affected by sediment and discussed land-use practices that may impact mussels. Specific biological impacts on mussels from excessive sediment include reduced feeding and respiratory efficiency from clogged gills, disrupted metabolic processes, reduced growth rates, increased substrate instability, limited burrowing activity, and physical smothering (Ellis 1936, Stansbery 1971, Marking and Bills 1979, Vannote and Minshall 1982, Waters 1995). Studies tend to indicate that the primary impacts of excess sediment on mussels are sublethal, with detrimental effects not immediately apparent (Brim Box and Mossa 1999). The physical effects of sediment on mussels appear to be multifold, and include changes in suspended and bed material load; bed sediment composition associated with increased sediment production and run-off in the watershed; channel changes in form, position, and degree of stability; changes in depth or the width/depth ratio that affects light penetration and flow regime; actively aggrading (filling) or degrading (scouring) channels; and changes in channel position that may leave them high and dry (Vannote and Minshall 1982, Kanehl and Lyons 1992, Brim Box and Mossa 1999).

Interstitial spaces in the substrate provide crucial habitat for juvenile mussels. When clogged, interstitial flow rates and spaces may become reduced (Brim Box and Mossa 1999), thus reducing juvenile habitat. Sediment may act as a vector for delivering contaminants such as nutrients and pesticides to streams. Juveniles can readily ingest contaminants adsorbed to silt particles during normal feeding activities (see "Summary of biology and natural history"). These factors may help explain, in part, why so many mussel populations, including potentially those of the sheepnose, appear to be experiencing recruitment failure.

Many Midwestern and Southeastern streams have increased turbidity levels due to siltation. The sheepnose produces conglutinates that appear to function in attracting potential hosts (see "Summary of biology and natural history"). Such a reproductive strategy depends on clear water during the critical time of the year when mussels are releasing their glochidia (Hartfield and Hartfield 1996). In addition, mussels may be indirectly affected when turbidity levels significantly reduce the amount of light available for photosynthesis and the production of unionid food items (Kanehl and Lyons 1992).

The Chippewa River has a tremendous bedload composed primarily of sand that requires a significant amount of dredging to maintain barge traffic on the main stem Mississippi below its confluence (Thiel 1981). The mussel diversity below the Chippewa has predictably declined from historical times, due to the increase in unstable sand substrates. Lake Pepin, a once natural "lake" formed in the upper Mississippi River upstream from the mouth of the Chippewa River, has become increasingly silted in over the past century, reducing habitat for the sheepnose and other mussels (Thiel 1981).

Agricultural activities produce the most significant amount of sediment that enters streams (Waters 1995). Neves et al. (1997) stated that agriculture (including both sediment and chemical run-off) affects 72 percent of the impaired river miles in the country. Unrestricted access by livestock is a significant threat to many streams and their mussel populations (Fraley and Ahlstedt 2000). Grazing may reduce infiltration rates, increase run-off, and trampling reduces a bank's resistance to erosion (Armour et al. 1991, Trimble and Mendel 1995, Brim Box and Mossa 1999). Fraley and Ahlstedt (2000) attributed the decline of the Copper Creek (an upper Clinch River tributary) mussel fauna between 1980 and 1998, among other factors, to an increase in cattle grazing and loss of riparian vegetation along the stream. These impacts may potentially affect the sheepnose population in the Clinch below the confluence of Copper Creek.

Other Activities Affecting Mussels

Silvicultural and developmental activities may also impact streams where adequate buffers are not maintained and erosion of impacted lands is allowed to freely enter streams. Due to its proximity to the metropolitan St. Louis area, the lower Meramec River is increasingly becoming developed and threatens its sheepnose population. Despite the level of protection provided to the St. Croix River by the St. Croix National Scenic Riverway (SCNSR), the sheepnose population there is threatened by the nearby Minneapolis/St. Paul metropolitan area. Droughts may also be a threat, exacerbated by global warming and water withdrawals for agricultural irrigation, municipal, and industrial water supplies. These anthropogenic activities act insidiously to lower water tables, thus making sheepnose and other mussel populations susceptible to depressed stream levels.

B. Overutilization for commercial, recreational, scientific, or educational purposes. Native Americans were known to have harvested the sheepnose for food (Morrison 1942, Bogan 1990). The sheepnose was probably collected by pearlers circa 1900 and other commercial interests in later times (Anthony and Downing 2001). Although not included in a list of the most actively sought species for pearls (Anthony and Downing 2001), the sheepnose was probably sacrificed for this purpose. For instance, Wilson and Clark (1914) documented many portions of the Cumberland River where large piles with tons of shells were left on streambanks by pearlers hoping to get rich quick. Single beds were sometimes harvested for pearls a decade or more by pearlers. Böpple and Coker (1912) reported a particularly habitat disruptive method of harvest where "a plow drawn by a strong team" was sometimes used in shallow Clinch River shoals, enabling pearlers to pick up mussels that had been buried in the substrate. Considering that perhaps only 1 in 15,000 mussels may produce a commercially valuable pearl (Anthony and Downing 2001), it may be safe to assume that hundreds of thousands, if not millions, of mussels were sacrificed in regional streams by harvesters over several decades.

Anthony and Downing (2001) included the sheepnose in a list of the 50 most popular species collected for the button industry. Its commercial appeal was diminished by the fact that its shell is extremely hard and was ill suited for pearl button manufacture. Hence a former common name used on at least the Cumberland, "clear profit," as the clammers were "the only ones who [get any money] out of it" (Wilson and Clark 1914). Despite the alarm generated over exploitation events in historical times, the collective impact from human harvest of mussels pales in the shadow of the impacts realized from habitat alteration (see "Factor A. The present or threatened destruction, modification, or curtailment of its habitat or range" above). It is unlikely that exploitation activities have eliminated sheepnose populations.

The sheepnose is not currently a commercially valuable species, but it may be inadvertently harvested as "by catch" or by inexperienced musselers unfamiliar with commercial species identification. Mussel harvest is illegal in some states (e.g., Indiana, Ohio), but tightly regulated in others (e.g., Alabama, Kentucky, Tennessee, Wisconsin). Most states with commercial harvest allow musselers to dive for mussels. In Kentucky, mussels may legally be harvested only by brail. Most states that allow commercial harvest have established mussel sanctuaries where harvest is off limits. Sanctuaries are generally associated with beds that have State or federally listed mussels in them. Although illegal harvest of protected off-limits mussel beds occurs (Watters and Dunn 1993-94), rangewide, commercial harvest is not thought to have a significant impact on the sheepnose.

An increasingly rare species like the sheepnose may increasingly be sought by lay and experienced collectors. Most stream reaches inhabited by this species are restricted, and its' populations are small. Although scientific collecting is not thought to represent a significant threat, localized populations could become impacted and possibly extirpated by overcollecting, particularly if this activity is unregulated.

C. Disease or predation.
The occurrence of disease in mussels is virtually unknown. Several mussel dieoffs have been documented during the past 20 years (Neves 1986). Although the ultimate cause is unknown, some researchers believe that disease may be a factor. Parasites on mussels include water mites, trematodes, leeches, bacteria, and some protozoa, but are not suspected to be a major limiting factor for mussel populations (Oesch 1984).

Based on a study of muskrat predation on imperiled mussels in the upper North Fork Holston River in Virginia, Neves and Odum (1989) concluded that this activity could limit the recovery potential of endangered mussel species or contribute to the local extirpation of already depleted mussel populations. Predation by muskrats may represent a seasonal and localized, but probably not a significant, threat to the sheepnose. Although other mammals (e.g., raccoon, mink, otter, hogs) occasionally feed on mussels, the threat from these species is not significant. Some species of fish feed on mussels (e.g., freshwater drum, redear sunfish), and potentially upon this species. According to R.J. Neves (USGS, pers. comm., 2002), newly metamorphosed juvenile mussels may be fed upon by various invertebrates (e.g., flatworms, hydra, non-biting midge larvae, dragonfly larvae, crayfish). The overall threat posed by piscine and invertebrate predators of the sheepnose is not thought to be significant.

D. The inadequacy of existing regulatory mechanisms.
Most states with extant sheepnose populations prohibit the taking of mussels for scientific purposes without a State collecting permit. However, enforcement of this permit requirement is difficult. Furthermore, State regulations do not generally protect mussels from other threats. See also the discussion in "Factor B" above relating to commercial harvest.

Existing authorities available to protect riverine ecosystems, such as the Clean Water Act (CWA), administered by the Environmental Protection Agency and the Corps, may not have been fully utilized. This may have contributed to the general habitat degradation apparent in riverine ecosystems and loss of populations of aquatic species in the Southeast and Midwest. Although the sheepnose coexists with other federally listed mussels and fishes throughout a portion of its' range, listing under the Endangered Species Act (Act) would provide additional layers of protection. Federal permits would be required to take the species, and Federal agencies would be required to consult with the Service when activities they fund, authorize, or carry out may adversely affect the species.

E. Other natural or manmade factors affecting its continued existence.
Population Fragmentation and Isolation
The majority of the remaining populations of the sheepnose are generally small and geographically isolated. The patchy distributional pattern of populations in short river reaches makes them much more susceptible to extirpation from single catastrophic events, such as toxic chemical spills (Watters and Dunn 1993-94). Furthermore, this level of isolation makes natural repopulation of any extirpated population impossible without human intervention. Population isolation prohibits the natural interchange of genetic material between populations, and small population size reduces the reservoir of genetic diversity within populations, which can lead to inbreeding depression

(Avise and Hambrick 1996).

Genetic Considerations

The likelihood is high that some populations of the sheepnose are below the effective population size (Soulé 1980) required to maintain long-term genetic and population viability. Recruitment reduction or failure is a potential problem for many small sheepnose populations rangewide, a potential condition exacerbated by its reduced range and increasingly isolated populations. If these trends continue, further significant declines in total sheepnose population size and consequent reduction in long-term viability may soon become apparent. The present distribution and status of the sheepnose may be indicative of the detrimental bottleneck effect resulting when the effective population size is not attained. A once diffuse population of this species occurred throughout much of the upper two-thirds of the Mississippi River system and in several larger tributary systems. Historically, there were presumably no absolute barriers preventing genetic interchange among its' tributary sub-populations that occurred in various streams. With the completion of numerous dams on streams, such as the Cumberland and Tennessee Rivers during primarily the first half of this century, some main stem sheepnose populations were lost, and other populations became isolated.

Whereas small isolated tributary populations of imperiled short-lived species (e.g., most fishes) would have theoretically died out within a decade or so after impoundment, the long-lived sheepnose (see "Description, Biology, and Life History" section above), would potentially take decades to expire post-impoundment. Without the level of genetic interchange the species experienced historically (i.e., without barriers such as reservoirs), small isolated populations that may now be comprised predominantly of adult specimens could be slowly dying out. Even given the improbable absence of the impacts addressed in "Factors A through D" above, we may lose smaller isolated populations of this species to the devastating consequences of below-threshold effective population size. In reality, degradation of these isolated stream reaches resulting in ever decreasing patches of suitable habitat is contributing to the decline of the sheepnose. The fact that only 26 of 77 streams of historical occurrence continue to harbor populations of the sheepnose may be mute testimony to this phenomenon.

Alien Species

Various alien or nonnative species of aquatic organisms are firmly established in the range of the sheepnose. The alien species that poses the most significant threat to the sheepnose is the zebra mussel (*Dreissena polymorpha*). The invasion of the zebra mussel poses a threat to mussel faunas in many regions, and species extinctions are expected as a result of its continued spread in the eastern United States (Ricciardi et al. 1998). Strayer (1999b) reviewed in detail the mechanisms through which zebra mussels impact native mussels. The primary means of impact is direct fouling of the shells of live native mussels, as zebra mussels have attached in large numbers to the shells of live native mussels and have been implicated in the loss of mussel beds. Fouling impacts include impeding locomotion (both laterally and vertically), interfering normal valve movements, deforming valve margins, and locally depleting food resources and increasing waste products. Heavy infestations of zebra mussels on mussels may overly stress the animals by reducing their energy stores. They may also reduce food concentrations to levels too low to support reproduction or even survival in extreme cases. Other ways that zebras may impact native mussels is potentially through filtering their sperm and possibly even their tiny glochidia from the water column. Habitat for native mussels may also be degraded by large deposits of zebra mussel pseudofeces (Vaughan 1997).

Overlapping much of the current range of the sheepnose, zebra mussels are thoroughly established in the upper Mississippi, St. Croix, Ohio, and Tennessee Rivers, and have been reported from the lower Meramec and Muskingum Rivers. In 2000, nearly 1% of the unionids in the lower St. Croix River were infested with zebra mussels (Kelner and Davis 2002). The extent of their impact upon the sheepnose in most areas is largely unknown. The greatest potential for present zebra mussel impacts to the sheepnose appears to be in the upper Mississippi River. Kelner and Davis (2002) considered zebra mussels in the Mississippi River from MRP 4 downstream to be "extremely abundant and are decimating the native mussel communities." Huge numbers of dead and live zebra mussels cover the bottom of the river in some localities up to 1-2 inches deep (Havlik 2001), where they have significantly reduced the quality of the habitat with their pseudofeces (S.J. Fraley, NCWRC, pers. comm., 2000). Zebra mussels have undoubtably reduced sheepnose populations in these heavily infested waters. Until 2002, zebra mussel densities in the Tennessee River remained low, but are now abundant enough below Wilson Dam to be measured quantitatively (G.T. Garner, ADNR, pers. comm., 2002). As zebra mussels may maintain high densities in big rivers, large tributaries, and below infested reservoirs, sheepnose populations in affected areas may be significantly impacted. In addition, there is long-term potential for zebra mussel invasions into other systems that currently harbor sheepnose populations.

The Asian clam (*Corbicula fluminea*) has spread throughout the Mississippi River system since its introduction into the basin in the mid-1900s. This species has been implicated as a competitor with native mussels for resources such as food, nutrients, and space, particularly as juveniles (Neves and Widlak 1987). According to Strayer (1999b), dense populations of Asian clams may ingest large numbers of unionid sperm, glochidia, and newly-metamorphosed juveniles. He also thought they actively disturb sediments, so dense populations may reduce habitable space for juvenile native mussels. Periodic dieoffs may produce enough ammonia and consume enough oxygen to kill native mussels (Strayer 1999b). However, specific impacts upon native mussels remain largely unresolved (Leff et al. 1990, Strayer 1999b). Yeager et al. (2001) determined that high densities of Asian clams negatively impacted the survival and growth of newly metamorphosed juvenile mussels and thus reduced recruitment. They proved from laboratory experiments that Asian clams readily ingested glochidia, clam density and juvenile mussel mortality were positively correlated, growth rates were reduced with the presence of clams, and juvenile mussels were displaced in greater numbers downstream in laboratory tests with clams.

Native to China, the black carp (*Mylopharyngodon piceus*) is a potential threat (Strayer 1999b). Nico and Williams (1996) prepared a risk assessment of the black carp and summarized all known aspects of its ecology, life history, and intentional introduction (since the 1970s) into North America. A molluscivore (mollusk eater), the black carp has been proposed for widespread use by aquaculturists to control snails, the intermediate host of a trematode (flatworm) parasite affecting catfish in ponds in the Southeast and lower Midwest. Another Asian carp species intentionally brought to the United States, they are known to eat clams (*Corbicula* spp.) and unionid mussels in China, in addition to snails. They are the largest of the Asiatic carp species, reaching more than 4 feet in length and achieving a weight in excess of 150 pounds (Nico and Williams 1996). During 1994, 30 black carp escaped from an aquaculture facility in Missouri during a flood. Other escapes into the wild by nonsterile black carp is deemed imminent by conservation biologists. If these species invade streams with mussel communities, they could wreak havoc on already stressed native mussel populations.

Current protective status under state/provincial/tribal/Federal laws and regulations: The sheepnose is State-listed in every state that keeps such a list (in addition to Pennsylvania and West Virginia, which do not keep official imperiled species lists). The level of protection it receives from State-listing varies from state to state. The Nature Conservancy considers it to be a G3 species. The American Malacological Society and American Fisheries Society consider the sheepnose to be threatened (Williams et al. 1993).

Summary of land ownership and existing habitat protection: Numerous parcels of public land (e.g., state parks, state forests, wildlife management areas) occur along historical and extant streams of occurrence for the sheepnose or in their respective watersheds. However, vast tracts of riparian lands in sheepnose streams are privately owned. The sheepnose is a larger river species. The prevalence of privately held riparian lands in streams with extant populations somewhat diminishes the level of importance afforded by public lands that may implement various landuse restrictions. Riparian activities that occur outside or upstream of public lands may be pervasive and have a profound impact on their populations. Habitat protection benefits on public lands may therefore easily be negated by detrimental activities upstream in the watershed. Following are some of the more significant public lands associated with important sheepnose populations.

The Upper Mississippi River National Wildlife and Fish Refuge manages scores of islands and shoreline acreage throughout a significant portion of the upper Mississippi. In-holdings of the refuge extend from the mouth of the Chippewa River downstream to Muscadine, Iowa. Between Muscatine and Keithsburg, Illinois, the Mark Twain National Wildlife Refuge (MTNWR), Keithsburgs Division, has numerous in-holdings. A small, disjunct portion of MTNWR, the Gardner Division, occurs in the Canton and La Grange, Missouri, area.

Other sheepnose populations in the upper Mississippi River system are associated with some public lands. The St. Croix River population of the sheepnose receives protection by being located in the SCNSR, Minnesota and Wisconsin. Riparian lands associated with the SCNSR provide a buffer between the river and activities that occur in adjacent areas. In addition, several State public lands lie adjacent to some sections of the SCNSR providing additional buffering lands along the St. Croix. Dunnville and Washington Creek State Wildlife Areas are located on the banks of the lower Chippewa and lower Flambeau Rivers, respectively. Much of the lower Wisconsin River is bordered by units of the Lower Wisconsin River State Wildlife Area. Other public lands include Badger Army Ammunition Plant, and Tower Hill and Wyalusing State Parks.

Small units of public land along the Meramec River include Meramec, Pacific Palisades, and River Round Conservation Areas; and Meramec, Onandaga Cave, and Robertsville State Parks. Parts of the lower Big Piney River and significant reaches of the upper Gasconade River flow adjacent or through the Mark Twain National Forest, while the lower Big Piney also flows through Ft. Leonard Wood Military Reservation.

The most important public land holding in the Ohio River is the Ohio River Islands National Wildlife Refuge. The refuge includes all or parts of 21 islands and 3 mainland tracts totaling 3,220 acres in the Ohio from RM 35 (Shippingport, Pennsylvania) downstream to RM 397 (Manchester, Ohio, and adjacent Kentucky). Lands are actively managed in six Ohio River pools (i.e., New Cumberland, Hannibal, Willow Island, Belleville, Racine, Meldahl. A refuge expansion is planned to ultimately include potentially thousands of acres of additional islands and mainland parcels from RM 0 at Pittsburgh to RM 437 at Meldahl Lock and Dam, Kentucky and Ohio, in the last three intervening pools (P. Morrison, Service, pers. comm., 2002). Tippecanoe River public lands include Tippecanoe River State Park, where sheepnose are known to be extant, and Potawatomi Wildlife Park.

The Nature Conservancy (TNC) has made some stream systems harboring extant populations of the sheepnose bioreserves: the upper Clinch/Powell River, Tennessee and Virginia; and upper Green River, Kentucky. A third, on the lower Licking River, Kentucky, is in the formative stages of development. Although TNC has few riparian inholdings in these watersheds, they have carried out aggressive and innovative community-based projects in both watersheds that address aquatic species and instream habitat conservation on multiple scales. They have worked with scores of riparian landowners to help them restore and protect streambanks and riparian zones and partner with various other stakeholders in conserving aquatic resources. In addition to the sheepnose, these activities aid in the recovery of 19 listed mussels and fishes in the Clinch (the largest concentration of aquatic listed species in North America) and 5 listed mussels and a cave shrimp in the Green. The location of MCNP in the upper Green River provides a significant level of localized watershed protection for the sheepnose population in that system. A small portion of the Clinch River watershed (e.g., several small tributaries) is located in the Jefferson National Forest.

Past, current, and anticipated conservation activities undertaken for the benefit of the species or its habitat: The Service's Partners for Fish and Wildlife program has funded millions of dollars in projects in Service Regions 3, 4, and 5. Funding in this program has been provided to landowners to enhance riparian habitat in streams with sheepnose populations. For instance, specific watershed level projects that have benefitted habitat for the sheepnose include the TNC Bioreserves in the Clinch and Green Rivers (see "Summary of land ownership and existing habitat protection" above) in Region 4.

Other funding sources play significant roles in the Service's riparian habitat protection program. These include CWA Section 319, Natural Resource Conservation Service programs (e.g., Environmental Quality Incentives Program, Wildlife Habitat Improvement Program, Conservation Reserve Enhancement Program [CREP]), Landowners Incentives Program, National Fish and

Wildlife Foundation (NFWF) habitat programs, and numerous other Federal programs are potential sources of money for sheepnose habitat restoration and conservation. For instance, a huge CREP grant of $110 million has been secured by Kentucky to take up to 100,000 acres of riparian lands out of agricultural production in the upper Green River watershed. Efforts will focus on areas that should be of direct benefit to the Green's sheepnose population.

The St. Croix River Research Rendezvous is an annual meeting of biologists and conservationists dedicated to managing the St. Croix River and its diverse mussel fauna, including the sheepnose. Participants annually present their research abstracted in *Ellipsaria*, the newsletter of the Freshwater Mollusk Conservation Society. Recent research subjects involving mussels have included sediment contamination, juvenile toxicity, status surveys, population dynamics, and zebra mussel control. Vaughan (1997) outlined various measures implemented for mussel conservation in the St. Croix River.

The Green River Bioreserve TNC staff have contracted with the Corps to explore ways in which flow releases from the Green River dam can be modified to improve seasonal flow patterns and instream habitat in the Green. These efforts may pay dividends in improving conditions for the sheepnose and a host of other imperiled aquatic organisms in the upper Green River.

Several settlements from large chemical spills are currently being negotiated (J. Schmerfeld, Service, pers. comm., 2002). Money from these court cases have the potential to fund significant recovery-type projects benefitting a suite of imperiled species like the sheepnose. Similarly, money from an illegal harvest case was used to establish a Mussel Mitigation Trust Fund (MMTF). This trust is used to fund imperiled mussel recovery work.

Relocation of a mussel community is often used to minimize the impact of specific developmental projects (e.g., highway crossings, channel dredging, mooring cells) on important mussel resources, including listed species. This technique, however, may provide limited benefit for overall species conservation and recovery. Further, failed relocation attempts have resulted in increased mortality of both relocated and resident populations in some circumstances. During Interagency Consultation, or in the development of a Habitat Conservation Plan, minimization and mitigation of adverse effects to listed mussel species should consider conservation measures, in addition to relocation to further species recovery goals. Species of concern and candidate species, such as the sheepnose, receive no regulatory protection under the Act, however, the Service strongly encourages federal agencies and other planners to consider them when planning and implementing their projects. Efforts to conserve these species now may include options that may not be available if the species population declines further. Such efforts now may preclude the need to list them as endangered or threatened under the Act in the future.

Some of the Service ecosystems in the range of the sheepnose have made imperiled mussels a high priority resource for conservation. The Ohio River Valley Ecosystem (ORVE), Mollusk Subgroup, put the sheepnose on the Service radar screen by determining the need for this status review. Ecosystem teams will be a source for identifying future funding needs for the sheepnose.

Most Service field offices now have public outreach/environmental education staff. These staff members are involved in various efforts to educate the general public as to the benefits of habitat preservation and water quality. For instance, in the Southern Appalachian Ecosystem, comprising the headwaters of the Tennessee River system (among other drainages), aquatic issues form a major part of the outreach efforts in the ecosystem among Service representatives and partners. Representative projects have included posters and videos highlighting aquatic faunal groups, a riparian restoration and conservation video for streamside landowners, endangered species pamphlets, and mussel trunks (outreach/education kits) for educators.

Groundwork for a national wildlife refuge on the Clinch River has been planned. This non-traditional fish and wildlife refuge is planned to be slowly implemented over time. Other refuges may be established in other stream systems harboring sheepnose populations in the future.

Reservoir releases from TVA dams have been modified in recent years improving water quality and habitat conditions in many tailwaters. Improvements have enabled partners to attempt the reintroduction of extirpated species. Numerous experimental populations of federally listed species are now in various stages of planning and implementation.

Age and growth, reproductive potential, and habitat requirements of the sheepnose and other mussel species in the lower Holston River are presently being investigated by J.B. Layzer, B.D. Adair, and J.M. Wisniewski (USGS, Cooperative Fisheries Research Unit, Tennessee Technical University, Cookeville, Tennessee); and R.J. Neves and B.J. Ostby (USGS, Cooperative Fisheries Research Unit, Virginia Polytechnic Institute and State University, Blacksburg, Virginia).

Survey work continues in many portions of the range of the sheepnose. For instance, intensive sampling is currently planned for portions of the lower Allegheny River (R. Villella Baumgardner, USGS, pers. comm., 2002). Information gathered from these surveys will help determine its population status, and generates other data useful for conservation management and recovery efforts.

Management actions (species, habitat, or people management) needed: Refer to the national strategy for the conservation of mussels, compiled by the National Native Mussel Conservation Committee (1998) for detailed information on conserving North America's imperiled mussel fauna. Shute et al. (1997) also outlined management and conservation considerations for imperiled mussels and other aquatic organisms, while incorporating ecosystem management into the equation. Following is a summary of the most important aspects of research, surveys, and monitoring needed to recover the sheepnose.

In order for effective recovery to occur, it is critical to the survival of the sheepnose that Federal and State agencies continue to protect its extant populations with those laws and regulations that address protection and conservation of the species and its habitats.

Streams, stream reaches, and watersheds should be prioritized for protection based on a variety of factors, with emphasis on conserving the best existing populations and stream reaches as opposed to restoring habitats. These factors include high endemicity; high diversity of imperiled species; biogeographic history of rare species; highly fragmented habitats; cost effectiveness and ease of preservation, management, recovery, and restoration; landowner complexity; watershed size; existing land-use patterns; public accessability; likelihood for success; and those systems exhibiting low resilience to disturbance.

The assistance of various stakeholders, working at the ecosystem and watershed levels, will be essential for the conservation and restoration of imperiled mussel populations. More importantly, the support of the local community, including agricultural, silvicultural, mining, construction, and other developmental interests; local individuals; and landowners, will be essential in order to meet sheepnose recovery goals. Without a partnership with the people who live and work in these watersheds and who have an influence on habitat quality, recovery efforts will be doomed.

Seeking funding from various sources will be crucial in the recovery of the sheepnose. Sources such as Section 6 of the Act, and other funds administered by the Service, MMTF, NFWF, USGS, and many others will be necessary to aid in the recovery of the sheepnose and other mussels.

Maintaining vegetated riparian buffers is a well-known method of reducing stream sedimentation and runoff of chemicals and nutrients. Buffers reduce impacts to fish and other aquatic faunas and are particularly crucial for mussels. Other Best Management Practices should be implemented on riparian lands throughout the range of the sheepnose.

More watershed level, community-based riparian habitat restoration projects should be initiated in high biodiversity streams harboring the sheepnose (see "Summary of land ownership and existing habitat protection" above). By establishing Bioreserves and other large-scale projects, significant levels of habitat can be restored and protected for the betterment of the Nation's imperiled mussel resources.

Where current numerical criteria of certain pollutants may not be protective of the sheepnose and other mussels, these standards should be adjusted to better conserve mussel resources.

A monitoring program should be developed and implemented to evaluate efforts and monitor population levels and habitat conditions and assess the long-term viability of extant, newly discovered, augmented, and reintroduced sheepnose populations.

Roell (1999) makes management recommendations to reduce the impacts upon streams from sand and gravel mining. These recommendations should be implemented wherever impacts from these activities are occurring in sheepnose habitat.

Public outreach and environmental education is crucial for effective recovery programs. The role of this program should be to promote aquatic ecosystem management and a community-based watershed restoration approach to managing water and aquatic habitat quality in river systems harboring sheepnose populations or in unoccupied habitat essential for its recovery.

Stress analyses should be undertaken in at least those watersheds with significant extant sheepnose populations. The purpose of a stress analysis is determine the entire suite of stressors to the sheepnose and its habitat, to locate the sites of the various stressors, and to outline management activities to eliminate or at least minimize each stressor. Freeman et al. (2002) presents a good example of a stress analysis report.

A comprehensive Geographic Information System database to incorporate information on the species' distribution, population demographics, and various threats identified during monitoring activities should be established.

Research, surveys, and monitoring needed: Additional survey work may be warranted in some river systems (e.g., Kentucky River). However, the ORVE Mollusk Subgroup believes that there is enough information on the distribution, population trends, status, and threats compiled in this status review to accurately assess the sheepnose for consideration for candidate status.

The sauger has been determined to be a host fish for the sheepnose, but other fishes must serve as host for this species (see "Summary of biology and natural history"). Research into other hosts is critical. Knowing all its host fishes rangewide will facilitate sheepnose recovery.

Neves and Ahlstedt (2001) outlined mussel recovery programs focusing on propagation and translocation of laboratory-reared progeny to the wild. To this end, propagation technology for the sheepnose should be developed. By propagating significant numbers of juveniles in laboratory or hatchery settings, population augmentation and reintroduction into historical habitats will become much more feasible.

Very little information is available with regard to the life history of the sheepnose. Much life history information in addition to determining its host species will be needed in order to successfully implement the recovery tasks. In addition, the sheepnose's habitats (e.g., relevant physical, biological, chemical components) for all life history stages needs to be elucidated. Each life history stage's sensitivity to contaminants and general threats to the species also need investigating.

Monitoring existing populations of the zebra mussel and its spread into new systems should be implemented in the most at-risk systems. These include, among others, the Mississippi, Chippewa, Meramec, Ohio, and Tennessee Rivers.

Criteria that determine long-term population viability are crucial if we are to understand what constitutes a healthy sheepnose population. Detailed information is needed on the demographic structure, effective population size, and other genetic attributes of extant populations.

A set of biological, ecological, and habitat parameters will need to be developed to determine if an extant sheepnose population will be suitable for species augmentation. This is particularly important in habitats that may be considered marginal (e.g., where the sheepnose appears to be barely hanging on). Prioritized populations and potential augmentation sites for this task will be selected based on present population size, demographic composition, population trend data, potential site threats, habitat suitability, and any other limiting factor that might decrease the likelihood of long-term benefits from population augmentation efforts. Augmentation activities should not be conducted at totally unprotected sites or at sites with significant uncontrollable threats.

A set of biological, ecological, and habitat characterization parameters will need to be developed to determine if a site will be suitable for sheepnose reintroduction. These will include habitat suitability, substrate stability, presence of host fishes, potential site threats, and any other limiting factor that might decrease the likelihood of long-term benefits from population reintroduction efforts. Reintroduction activities should not be conducted at totally unprotected sites or at sites with significant uncontrollable threats.

The loss of much of its historical habitat, coupled with past and ongoing threats, clearly indicates the heightened level of imperilment of the sheepnose. However, survey work to search for potentially new sheepnose populations, thought to be extirpated populations, and to assess the status of presumably small populations would be beneficial in several rivers for recovery and conservation purposes. These streams should be prioritized in order of importance to achieve this recovery goal with limited funding resources.

A rangewide phylogenetic study on the sheepnose should be conducted to determine if there are any populations that may be taxonomically distinct. There is a possibility that disjunct populations, such as the upper Tennessee River system (*Unio compertus*, a synonym of *Plethobasus cyphyus*, was described from the Clinch and Holston Rivers; see "Controversial or unsettled taxonomic issues") or the Ozark populations in Missouri, may represent undescribed taxa. Numerous endemic mussels, fishes, and other aquatic organisms are known particularly from the Tennessee River system, which has been geologically stable for eons longer than glaciated streams in much of the remainder of the sheepnose's range.

Developing and implementing cryogenic techniques to preserve the sheepnose' genetic material until such time as conditions are suitable for reintroduction may be beneficial to recovery. If a population were lost to a catastrophic event, such as a toxic chemical spill, cryogenic preservation could allow for the eventual reestablishment of the population using genetic material preserved from that population.

References:

Ahlstedt, S.A. 1991a. Cumberlandian Mollusk Conservation Program: mussel surveys in six Tennessee Valley streams. Walkerana 5(13):123-160.

Ahlstedt, S.A. 1991b. Twentieth century changes in the freshwater mussel fauna of the Clinch River (Tennessee and Virginia). Walkerana 5(13):73-122.

Ahlstedt, S.A., and S.R. Brown. 1980. The naiad fauna of the Powell River in Virginia and Tennessee. Bulletin of the American Malacological Union for 1979:40-43.

Ahlstedt, S.A., and T.A. McDonough. 1993. Quantitative evaluation of commercial mussel populations in the Tennessee River portion of Wheeler Reservoir, Alabama. Pp. 38-49 *in*: K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, October 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Ahlstedt, S.A., and T.A. McDonough. 1995-96. Summary of pre-operational monitoring of the mussel fauna in the upper Chickamauga Reservoir (Tennessee River) in the vicinity of TVA's Watts Bar Nuclear Plant, 1983-1993. Walkerana 8(19):107-126.

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

Allan, J.D., and A.S. Flecker. 1993. Biodiversity conservation in running waters. BioScience 43(1):32-43.

Anthony, J.L., and J.A. Downing. 2001. Exploitation trajectory of a declining fauna: a century of freshwater mussel fisheries in North America. Canadian Journal of Fisheries and Aquatic Sciences 58(10):2071-2090.

Armour, C.L., D.A. Duff, and W. Elmore. 1991. The effects of livestock grazing on riparian and stream ecosystems. Fisheries 16(1):7-11.

Augspurger, T., A.E. Keller, M.C. Black, W.G. Cope, and F.J. Dwyer. In prep. Evaluation of water quality criteria for protection of freshwater mussels (Unionidae) from acute ammonia exposure.

Avise, J.C., and J.L. Hambrick, eds. 1996. Conservation genetics: case histories from nature. Chapman and Hall, New York.

Baird, M.S. 2000. Life history of the spectaclecase, *Cumberlandia monodonta* Say, 1829 (Bivalvia, Unionoidea, Margaritiferidae). Unpublished master's thesis, Southwest Missouri State University, Springfield. 108 pp.

Baker, F.C. 1906. A catalogue of the Mollusca of Illinois. Illinois State Laboratory of Natural History Bulletin 7(6):53-136.

Balding, T. 1992. Distribution, abundance, and diversity of mollusks (Bivalvia: Unionidae) from the lower Chippewa River, Wisconsin. Transactions of the Wisconsin Academy of Sciences, Arts and Letters 80:163-168.

Balding, T. 2001. Letter dated 28 August 2001.

Balding, T., and N. Balding. 1996. A qualitative survey of bivalve mollusks of the Chippewa River, Wisconsin: from Eau Claire, Wisconsin, to the Chippewa Flowage. Transactions of the Wisconsin Academy of Sciences, Arts and Letters 84:1-9.

Barr, W.C., S.A. Ahlstedt, G.D. Hickman, and D.M. Hill. 1993-94. Cumberlandian Mollusk Conservation Program. Activity 8: analysis of macrofauna factors. Walkerana 7(17-18): 159-224.

Bates, J. 1970. Ohio mussel fisheries investigation. May 15, 1967 - September 1, 1970. Final Report - Part 1. Mussel Studies. Unpublished report, U.S. Bureau of Commercial Fisheries Contract No. 14-17-0004-433, Sub-Project No. 4-28-R. 108 pp.

Bates, J.M. 1975. Overbank and tailwater studies. Unpublished report, Tennessee Valley Authority. 158 pp.

Bates, J.M., and S.D. Dennis. 1978. The mussel fauna of the Clinch River, Tennessee and Virginia. Sterkiana 69-70:3-23.

Bates, J.M., and S.D. Dennis. 1981. Preliminary analysis of the mussel stocks of Kentucky Reservoir. Unpublished report, Tennessee Wildlife Resources Agency, Nashville.

Bates, J.M., and S.D. Dennis. 1983. Mussel (naiad) survey: St. Francis, White, and Cache Rivers, Arkansas and Missouri. Unpublished Report, U.S. Army Corps of Engineers, Memphis District, Memphis, Tennessee. 89 pp.

Bauer, G. 1987. Reproductive strategy of the freshwater pearl mussel *Margaritifera margaritifera*. Journal of Animal Ecology 56:691-704.

Bauer, G. 1994. The adaptive value of offspring size among freshwater mussels (Bivalvia: Unionidae). Journal of Animal Ecology 63:933-944.

Belt, C.B., Jr. 1975. The 1973 flood and man's constriction of the Mississippi River. Science 189:681-684.

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

Böpple, J.F., and R.E. Coker. 1912. Mussel resources of the Holston and Clinch River, Tennessee and Virginia. U.S. Bureau of Fisheries Document No. 765:3-13.

Bowen, Z.H., S.P. Malvestuto, W.D. Davies, and J.H. Crance. 1994. Evaluation of the mussel fishery in Wheeler Reservoir, Tennessee River. Journal of Freshwater Ecology 9:313-319.

Branson, B.A. 1982. The mussels (Unionacea: Bivalvia) of Oklahoma--Part 1--Ambleminae. Proceedings of the Oklahoma Academy of Science 62:38-45.

Brim Box, J. 1999. Community structure of freshwater mussels (Bivalvia: Unionidae) in Coastal Plain streams of the Southeastern United States. Unpublished doctoral dissertation, University of Florida, Gainesville. 107 pp.

Brim Box, J., and J. Mossa. 1999. Sediment, land use, and freshwater mussels: prospects and problems. Journal of the North American Benthological Society 18(1):99-117.

Bruenderman, S.A., J.S. Faiman, and A.C. Buchanan. 2001. Survey for endangered and other unionid species in the upper Gasconade River basin, Missouri. Unpublished report, Missouri Department of Conservation, Columbia. 97 pp.

Buchanan, A.C. 1980. Mussels (naiades) of the Meramec River basin. Missouri Department of Conservation Aquatic Series 17. 69 pp.

Buell, G.R., and C.A. Couch. 1995. National Water Quality Assessment Program: environmental distribution of organochlorine compounds in the Apalachicola-Chattahoochee-Flint River basin. Proceedings of the 1995 Georgia Water Resources Conference, April 11-12, 1995, University of Georgia, Athens. 7 pp.

Cairns, J., Jr., J.S. Crossman, K.L. Dickman, and E.E. Herrick. 1971. Chemical plants leave unexpected legacy in two Virginia rivers. Science 198:1015-1020.

Call, R.E. 1900. A descriptive illustrated catalogue of the Mollusca of Indiana. 24th Annual Report of the Indiana Department of Geology and Natural Resources for 1899:335-535, 1013-1017.

Cicerello, R.R. 1994. Status survey of the Kentucky creekshell, *Villosa ortmanni*, a United States Fish and Wildlife Service candidate for listing. Unpublished report, Kentucky State Nature Preserves Commission, Frankfort. 34 pp.

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

Cicerello, R.R., and R.R. Hannan. 1990. Survey of the freshwater unionids (mussels) (Bivalvia: Margaritiferidae and Unionidae) in the Green River in Mammoth Cave National Park, Kentucky. Unpublished report, Kentucky State Nature Preserves Commission, Frankfort. 44 pp.

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

Clarke, A.H. 1983. The distribution and relative abundance of *Lithasia pinguis* (Lea), *Pleurobema plenum* (Lea), *Villosa trabalis* (Conrad), and *Epioblasma sampsoni* (Lea). American Malacological Bulletin 1:27-30.

Clarke, A.H. 1995. Survey of mussel beds in the lower Ohio River (ORM 438.1 to 981.0). Unpublished report, U.S. Army Corps of Engineers, Louisville District. 123 pp.

Clench, W.J., and H. van der Schalie. 1944. Notes on naiades from the Green, Salt, and Tradewater rivers in Kentucky. Papers of the Michigan Academy of Science, Arts and Letters 29:223-228.

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

Cummings, K.S., and J.M.K. Berlocher. 1990. The naiades or freshwater mussels (Bivalvia: Unionidae) of the Tippecanoe River, Indiana. Malacological Review 23(1/2):83-98.

Cummings, K.S., and C.A. Mayer. 1992. Field guide to freshwater mussels of the Midwest. Illinois Natural History Survey, Manual 5. 194 pp.

Cummings, K.S., and C.A. Mayer. 1997. Distributional checklist and status of Illinois freshwater mussels (Mollusca: Unionacea). Pp. 129-145 *in*: K.S. Cummings, A.C. Buchanan, C.A. Mayer, and T.J. Naimo, eds. Conservation and management of freshwater mussels II: initiatives for the future. Proceedings of a UMRCC symposium, October 1995, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

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

Cummings, K.S., L. Suloway, and L.M. Page. 1988b. The freshwater mussels (Mollusca: Bivalvia: Unionidae) of the Embarras River in Illinois: thirty years of stream change. Illinois Natural History Survey Technical Report 1988(2). 67 pp.

Cummings, K.S., C.A. Mayer, and L.M. Page. 1992. Survey of the freshwater mussels (Mollusca: Unionidae) of the Wabash River drainage: Final Report. Illinois Natural History Survey Technical Report 1992(1). 201 pp.

Cummings, K.S., C.A. Mayer, L.M. Page, and J.M.K. Berlocher. 1987. Survey of the freshwater mussels (Mollusca: Unionidae) of the Wabash River drainage. Phase I: lower Wabash and Tippecanoe Rivers. Illinois Natural History Survey Technical Report 1987(5). 149 pp.

Danglade, E. 1914. The mussel resources of the Illinois River. U.S. Bureau of Fisheries, appendix 6 to the report of the U.S. Commissioner of Fisheries for 1913. 48 pp.

Danglade, E. 1922. The Kentucky River and its mussel resources. U.S. Bureau of Fisheries Document No. 934:1-8.

Dawley, C.W. 1944. Distribution and growth studies of the Unionidae and aquatic Gastropoda fauna found in Minnesota. Unpublished doctoral dissertation, University of Minnesota, St. Paul. 307 pp.

Dawley, C.W. 1947. Distribution of aquatic mollusks in Minnesota. American Midland Naturalist 38:671-697.

Dennis, S.D. 1981. Mussel fauna of the Powell River, Tennessee and Virginia. Sterkiana 71:1-7.

Dennis, S.D. 1985. Distributional analysis of the freshwater mussel fauna of the Tennessee River system, with special reference to possible limiting effects of siltation. Tennessee Wildlife Resources Agency Report No. 85-2, Nashville. 171 pp.

Dennis, S.D. 1989. Status of the freshwater mussel fauna Pendleton Island Mussel Preserve, Clinch River, Virginia. Sterkiana 72:19-27.

Dunn, H.L., and B.E. Seitman. 1997. Guidelines used in four geographically diverse unionid relocations. Pp. 176-183 *in*: K.S. Cummings, A.C. Buchanan, C.A. Mayer, and T.J. Naimo, eds. Conservation and management of freshwater mussels II: initiatives for the future. Proceedings of a UMRCC symposium, October 1995, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Ecologists Specialists, Inc. 1993. Mussel habitat suitability and impact analysis of the Tippecanoe River. Unpublished report, Indiana Department of Natural Resources, Indianapolis; and U.S. Fish and Wildlife Service, Bloomington, Indiana. 102 pp.

Ecological Specialists, Inc. 1996. Ohio River unionid survey in and adjacent to Posey, Warrick, Vanderburgh, and Spencer counties, Indiana. Unpublished report, Indiana Department of Natural Resources, Indianapolis. 30 pp.

Ecological Specialists, Inc. 2000. Final report: freshwater mussels (Bivalvia: Unionidae) of the upper Ohio River. Unpublished report, Mussel Mitigation Trust Fund Committee, Cincinnati, Ohio, and U.S. Fish and Wildlife Service, Cookeville, Tennessee. 99 pp.

Eldridge, J.A. 1914. The mussel fishery of the Fox River. Report of the U.S. Commissioner of Fisheries for 1913, Appendix 7:1-8.

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

Fleming, W.J., T.P. Augspurger, and J.A. Alderman. 1995. Freshwater mussel die-off attributed to anticholinesterase poisoning. Environmental Toxicology and Chemistry 14(5):877-879.

Fraley, S.J., and S.A. Ahlstedt. 2000. The recent decline of the native mussels (Unionidae) of Copper Creek, Scott County, Virginia. Pp. 189-195 *in*: P.D. Johnson and R.S. Butler, eds. Freshwater Mollusk Symposium Proceedings--Part II: Proceedings of the First Symposium of the Freshwater Mollusk Conservation Society, March 1999, Chattanooga, Tennessee. Ohio Biological Survey, Columbus.

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

Freeman, B.J., S. Winger, S. McClurg, and C. Straight. 2002. Etowah River Basin stressors analysis. Unpublished report, University of Georgia Institute of Ecology, Athens. 60 pp.

Frick, E.A., D.J. Hippe, G.R. Buell, C.A. Couch, E.H. Hopkins, D.J. Wangsness, and J.W. Garrett. 1998. Water quality in the Apalachicola-Chattahoochee-Flint River basin, Georgia, Alabama, and Florida, 1992-95. U.S. Geological Survey Circular 1164. 38 pp.

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

Garner, J.T. 1997. 1997 records of Alabama endangered species. Unpublished report, Triannual Unionid Report No. 13:13.

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

Gooch, C.H., W.J. Pardue, and D.C. Wade. 1979. Recent mollusk investigations on the Tennessee River: 1978. Unpublished report, Tennessee Valley Authority, Muscle Shoals, Alabama, and Chattanooga, Tennessee. 126 pp.

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

Gordon, M.E., L.R. Kraemer, and A.V. Brown. 1980. Unionacea of Arkansas: historical review, checklist, and observations on distributional patterns. Bulletin of the American Malacological Union for 1979:31-37.

Gordon, M.E., and G. Sherman. 1995. Survey of endangered mussels in the Barren and Green Rivers. Unpublished report, Kentucky Department of Fish and Wildlife Resources, Frankfort.

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

Graf, D.L. 1997. Distribution of unionoid (Bivalvia) faunas in Minnesota, USA. The Nautilus 110(2):45-54.

Grant, U.S. 1885. Conchological notes. Minnesota Geological and Natural History Survey Annual Report 14:114-124.

Grier, N.M. 1915. List of naiades of the Meramec River, Missouri. American Midland Naturalist 4(12):517-518.

Grier, N.M. 1922. Final report on the study and appraisal of mussel resources in selected areas of the upper Mississippi River. American Midland Naturalist 8:1-33.

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

Hartfield, P.W., and E. Hartfield. 1996. Observations on the conglutinates of *Ptychobranchus greeni* (Conrad 1834) (Mollusca: Bivalvia: Unionoidea). American Midland Naturalist 135:370-375.

Hatcher, R.M. 1982. Survey of endangered and threatened mollusks in Tennessee streams. Unpublished report, Tennessee Wildlife Resources Agency, Nashville. 23 pp.

Havlik, M.E. 2001. Are unionids capable of reproduction in upper Mississippi River areas with large *Dreissena polymorpha* populations? Unpublished report, Ellipsaria 3(1):16.

Havlik, M.E., and L.L. Marking. 1981. A quantitative analysis of naiad mollusks from the Prairie du Chien, Wisconsin dredge material site on the Mississippi River. Bulletin of the American Malacological Union for 1980:30-34.

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

Havlik, M.E., and D.H. Stansbery. 1978. The naiad mollusks of the Mississippi River in the vicinity of Prairie du Chien, Wisconsin. Bulletin of the American Malacological Union for 1977:9-12.

Heath, D.J. 1989. St. Croix River U.S. Highway 10 bridge freshwater mussel relocation project at Prescott, Wisconsin. Phase I: mussel removal. Unpublished report, Ayres Associates, Madison, Wisconsin. 26 pp.

Hickman, M.E. 1937. A contribution to mollusca of east Tennessee. Unpublished master's thesis, University of Tennessee, Knoxville. 165 pp.

Higgins, F. 1858. A catalogue of the shell-bearing species, inhabiting the vicinity of Columbus, Ohio, with some remarks thereon. 12th Annual Report, Ohio State Board of Agriculture for 1857:548-555.

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

Hoggarth, M.A. 1995-96. The Unionidae (Mollusca: Bivalvia) of the Walhonding River, Coshocton County, Ohio, including the federally endangered catspaw *(Epioblasma obliquata obliquata)*, fanshell (*Cyprogenia stegaria*), and clubshell (*Pleurobema clava*) mussels. Walkerana 8(20):149-176.

Hornbach, D.J. 2001. Macrohabitat factors influencing the distribution of naiads in the St. Croix River, Minnesota and Wisconsin, USA. Pp. 213-230 *in*: G. Bauer and K. Wächtler, eds. Ecology and evolution of the freshwater mussels Unionoida. Springer-Verlag, Berlin Heidelberg.

Hornbach, D.J., M. Hove, S. Clarkson, L. Gilles, I. Harmon, E. Nelson, K. Paulson, C. Salazar, E. Peters, and J. Lynch. 2001. Long-term dynamics of mussel populations in the St. Croix River. Unpublished report, Ellipsaria 4(1):12-13.

Hubbard, W.D., D.C. Jackson, and D.J. Ebert. 1993. Channelization. Pp. 135-155 *in*: E.F. Bryan and D.A. Rutherford, eds. Impacts on warm-water streams: guidelines for evaluation. Warm-water Stream Committee, Southern Division, American Fisheries Society, Little Rock, Arkansas.

Huebner, J.D., and K.S. Pynnönen. 1992. Viability of glochidia of *Anodonta* exposed to low pH and selected metals. Canadian Journal of Zoology 70:2348-2355.

Isom, B.G. 1972. Mussels in the unique Nickajack Dam construction site, Tennessee River, 1965. Malacological Review 5:4-6.

Jacobson, P.J., R.J. Neves, D.S. Cherry, and J.L. Farris. 1997. Sensitivity of glochidial stages of freshwater mussels (Bivalvia: Unionidae) to copper. Environmental Toxicology and Chemistry 16:2384-2392.

Johnson, R.I. 1980. Zoogeography of North American Unionacea (Mollusca: Bivalvia) north of the maximum Pleistocene glaciation. Bulletin of the Museum of Comparative Zoology 149(2):77-189.

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

Kanehl, P., and J. Lyons. 1992. Impacts of in-stream sand and gravel mining on stream habitat and fish communities, including a survey on the Big Rib River, Marathon County, Wisconsin. Wisconsin Department of Natural Resources Research Report 155. 32 pp.

Keller, A.E., and M. Lydy. 1997. Biomonitoring and the hazards of contaminants to freshwater mollusks. Unpublished report *in*: Freshwater mollusks as indicators of water quality: a workshop. U.S. Geological Survey Biological Resources Division and National Water Quality Assessment Program. 55 pp.

Keller, A.E., and S.G. Zam. 1991. The acute toxicity of selected metals to the freshwater mussel *Anodonta imbecilis* [sic]. Environmental Toxicology and Chemistry 10:539-546.

Kelner, D.E. 1995. A qualitative and quantitative survey of unionid populations from portions of the Red Cedar and Flambeau Rivers, Wisconsin. Unpublished report, Triannual Unionid Report No. 6:16.

Kelner, D.E., and M. Davis. 2002. Freshwater mussel survey of the upper Mississippi (Dayton, MN to Lock and Dam 3), lower St. Croix, and lower Minnesota rivers, 2000-01. Unpublished report, Ellipsaria 4(1):9.

Kitchel, H.E., J.C. Widlak, and R.J. Neves. 1981. The impact of coal-mining waste on endangered mussel populations in the Powell River, Lee County, Virginia. Unpublished Report to the Virginia State Water Control Board, Richmond. 26 pp.

Koch, L.M. 1983. Observations concerning mussels from the Cumberland River during July 1982, June 1983, and September 1983. Unpublished report. 7 pp.

Laudermilk, E.L. 1993. A survey of the unionids (Bivalvia: Unionidae) of the mainstream Licking River and selected tributaries below Cave Run Reservoir, Kentucky. Unpublished master's thesis, Eastern Kentucky University, Richmond. 73 pp.

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

Leff, L.G., J.L. Burch, and J.V. McArthur. 1990. Spatial distribution, seston removal, and potential competitive interactions of the bivalves *Corbicula fluminea* and *Elliptio complanata* in a coastal plain stream. Freshwater Biology 24:409-416.

Lewis, J. 1870. On the shells of the Holston River. American Journal of Conchology 6:216-226.

Manning, D. 1989. Freshwater mussels (Unionidae) of the Hatchie River, a tributary of the Mississippi River, in west Tennessee. Sterkiana 72:11-18.

Marking, L.L., and T.D. Bills. 1979. Acute effects of silt and sand sedimentation on freshwater mussels. Pp. 204-211 *in*: J.R. Rasmussen, ed. Proceedings of the UMRCC symposium on Upper Mississippi River bivalve mollusks. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Mathiak, H.A. 1979. A river survey of the unionid mussels of Wisconsin 1973-1977. Sand Shell Press, Horicon, Wisconsin. 75 pp.

McGregor, S.W., P.E. O'Neil, and J.T. Garner. 1998. A survey of the Tennessee River and its tributaries in north Alabama for freshwater mussels: year 4. Unpublished report, Geological Survey of Alabama, Tuscaloosa. 13 pp.

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

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

Mueller, D.K., P.A. Hamilton, D.R. Helsel, K.J. Hitt, and B.C. Ruddy. 1995. Nutrients in ground water and surface water of the United States--an analysis of data through 1992. U.S. Geological Survey, Water-Resources Investigations Report 95-4031. 74 pp.

Murray, H.D., and A.B. Leonard. 1962. Handbook of the unionid mussels of Kansas. University of Kansas Museum of Natural History Miscellaneous Publication 28. 184 pp.

Mutvei, H., T. Westmark, E. Dunca, B. Carell, S. Forberg, and A. Bignert. 1994. Methods for the study of environmental changes using the structural and chemical information in molluscan shells. Pp. 163-186 *in*: Past and present biomineralization processes: considerations about the carbonate cycle. Bulletin of the Institute of Oceanography, Monaco. Special No. 13.

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

National Native Mussel Conservation Committee. 1998. National strategy for the conservation of native freshwater mussels. Journal of Shellfish Research 17(5):1419-1428.

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

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

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

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

Neves, R.J., and S.A. Ahlstedt. 2001. The status of species and recovery programs for endangered freshwater mussels in the Southern Appalachians. Pp. 67-72 *in*: D.B. Adams, K. Burke, B. Hemingway, J. Keay, and M. Yurewicz, compilers. U.S. Geological Survey Appalachian Region Integrated Science Workshop Proceedings, October 2001, Gatlinburg, Tennessee.

Neves, R.J., A.E. Bogan, J.D. Williams, S.A. Ahlstedt, and P.W. Hartfield. 1997. Status of aquatic mollusks in the southeastern United States: a downward spiral of diversity. Pp. 43-85 *in*: G.W. Benz and D.E. Collins, eds. Aquatic fauna in peril: the southeastern perspective, March-April 1994, Chattanooga, Tennessee. Special Publication 1, Southeast Aquatic Research Institute, Chattanooga.

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

Neves, R.J., and J.C. Widlak. 1987. Habitat ecology of juvenile freshwater mussels (Bivalvia: Unionidae) in a headwater stream in Virginia. American Malacological Union Bulletin 5(1):1-7.

Nico, L.G., and J.D. Williams. 1996. Risk assessment on black carp (Pisces: Cyprinidae). Unpublished report, U.S. Geological Survey, Gainesville, Florida. 61 pp.

Oesch, R.D. 1984. Missouri naiades: a guide to the mussels of Missouri. Missouri Department of Conservation, Jefferson City. 270 pp.

Ortmann, A.E. 1909. A preliminary list of the Unionidae of western Pennsylvania, with new localities for species from eastern Pennsylvania. Annals of the Carnegie Museum 5(2-3):178-210.

Ortmann, A.E. 1911. A monograph of the naiades of Pennsylvania. Parts I and II: systematic account of the genera and species. Memoirs of the Carnegie museum 4(6):279-347.

Ortmann, A.E. 1912. Notes upon the families and genera of the najades. Annals of the Carnegie Museum 8(2):222-365.

Ortmann, A.E. 1913. The Alleghenian Divide, and its influence upon the freshwater fauna. Proceedings of the American Philosophical Society 52(210):287-390.

Ortmann, A.E. 1918. The nayades (freshwater mussels) of the upper Tennessee drainage with notes on synonymy and distribution. Proceedings of the American Philosophical Society 77:521-626.

Ortmann, A.E. 1919. A monograph of the naiades of Pennsylvania, Part III: systematic account of the genera and species. Memoirs of the Carnegie Museum 8(1):1-384.

Ortmann, A.E. 1925. The naiad-fauna of the Tennessee River system below Walden Gorge. American Midland Naturalist 9(7):321-372.

Ortmann, A.E. 1926. The naiades of the Green River drainage in Kentucky. Annals of the Carnegie Museum 17(1):167-188.

Pardue, W.J. 1981. A survey of the mussels (Unionidae) of the upper Tennessee River--1978. Sterkiana 71:41-51.

Parmalee, P.W. 1967. The fresh-water mussels of Illinois. Illinois State Museum, Popular Science Series Vol. 8. 108 pp.

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

Parmalee, P.W., and A.E. Bogan. 1986. Molluscan remains from aboriginal middens at the Clinch River Breeder Reactor Plant site, Roane County, Tennessee. American Malacological Bulletin 4(1):25-37.

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

Parmalee, P.W., and M.H. Hughes. 1994. Freshwater mussels (Bivalvia: Unionidae) of the Hiwassee River in east Tennessee. American Malacological Bulletin 11(1):21-27.

Parmalee, P.W., W.E. Klippel, and A.E. Bogan. 1980. Notes on the prehistoric and present status of the naiad fauna on the middle Cumberland River, Smith County, Tennessee. The Nautilus 94(3):93-105.

Parmalee, P.W., W.E. Klippel, and A.E. Bogan. 1982. Aboriginal and modern freshwater mussel assemblages (Pelecypoda: Unionidae) from the Chickamauga Reservoir, Tennessee. Brimleyana 8:75-90.

Patch, D.C. 1976. An analysis of the archaeological shell of fresh water [sic] mollusks from the Carlston Annis Shellmound, west central Kentucky. Unpublished bachelor's thesis, Washington University. 98 pp.

Peacock, E., and T.R. James. 2002. A prehistoric unionid assemblage from the Big Black River drainage in Hinds County, Mississippi. Journal of the Mississippi Academy of Sciences 47:119-123.

Price, S.F. 1900. Mollusca from southern Kentucky. The Nautilus 1914:75-79.

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

Roberts, A., and S.A. Bruenderman. 2000. A reassessment of the status of freshwater mussels in the Meramec River basin, Missouri. Unpublished report, Missouri Department of Conservation, Columbia. 141 pp.

Robison, W.A., S.R. Alexander, T. Hibner, and M. Wilson. 1996. Clinch River Project: sediment contaminants in the lower Clinch River. Unpublished report, U.S. Fish and Wildlife Service, Cookeville, Tennessee. 52 pp.

Roell, M.J. 1999. Sand and gravel mining in Missouri stream systems: aquatic resources effects and management alternatives. Unpublished report, Missouri Department of Conservation, Columbia. 34 pp.

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

Schuster, G.A., and J.C. Williams. 1989. Freshwater mussel investigations of the Ohio River: mile 317.0 to mile 981.0. Unpublished report, Kentucky Department of Fish and Wildlife Resources, Frankfort. 57 pp.

Scruggs, G.D., Jr. 1960. Status of fresh-water mussel stocks in the Tennessee River. U.S. Fish and Wildlife Service Fisheries Special Report No. 370:1-41.

Shoup, C.S., J.H. Peyton, and G. Gentry. 1941. A limited biological survey of the Obey River and adjacent streams in Tennessee. Journal of the Tennessee Academy of Science 16(1):48-76.

Shute, P.W., R.G. Biggins, and R.S. Butler. 1997. Management and conservation of rare aquatic resources: a historical perspective and recommendations for incorporating ecosystem management. Pp. 445-466 *in*: G.W. Benz and D.E. Collins, eds. Aquatic fauna in peril: the southeastern perspective, March-April 1994, Chattanooga, Tennessee. Special Publication 1, Southeast Aquatic Research Institute, Chattanooga.

Sickel, J.B. 1985. Biological assessment of the freshwater mussels in the Kentucky Dam tailwaters of the Tennessee River. Unpublished report, Kentucky Division of Water, Frankfort. 42 pp.

Sickel, J.B., and M.D. Burnett. 2001. Mussel relocation from two proposed fishing jetty sites downstream from Kentucky Lock and Dam, Tennessee River Mile 21.6, Marshall County, Kentucky. Unpublished report, Murray State University, Murray, Kentucky.

Simpson, C.T. 1914. A descriptive catalogue of the naiads or fresh-water pearly mussels. Privately published, Bryant Walker, Detroit. 1,540 pp.

Soulé, M.E. 1980. Threshold for survival: maintaining fitness and evolutionary potential. Pp. 151-169 *in*: M.E. Soulé and B.A. Wilcox, eds. Conservation biology. Sinauer Associates, Inc., Sunderland, Massachusetts.

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

Stansbery, D.H. 1961. The naiads (Mollusca, Pelecypoda, Unionacea) of Fishery Bay, South Bass Island, Lake Erie. Sterkiana 5:1-37.

Stansbery, D.H. 1964. The Mussel (Muscle) Shoals of the Tennessee River revisited. American Malacological Union Annual Reports for 1963:25-28.

Stansbery, D.H. 1965. The naiad fauna of the Green River at Munfordville, Kentucky. Bulletin of the American Malacological Union Annual Reports for 1964:13-14.

Stansbery, D.H. 1970. Eastern freshwater mollusks (I): the Mississippi and St. Lawrence River systems. Pp. 9-21 *in*: A.H. Clarke, ed. Proceedings of the American Malacological Union Symposium on Rare and Endangered Mollusks. Malacologia 10(1).

Stansbery, D.H. 1971. Rare and endangered molluscs in the eastern United States. Pp. 5-18 *in*: S.E. Jorgensen and R.W. Sharpe, eds. Proceedings of a Symposium on Rare and Endangered Mollusks (Naiads) of the United States, April 1971, Columbus, Ohio. U.S. Fish and Wildlife Service, Twin Cities, Minnesota.

Stansbery, D.H., and C.C. King. 1983. Management of Muskingum River mussel (unionid mollusk) populations. Ohio State University Museum of Zoology Reports for 1983(5). 79 pp.

Starrett, W.C. 1971. A survey of the mussels (Unionacea) of the Illinois River: a polluted stream. Illinois Natural History Survey Bulletin 30(5):265-403.

Stinson, C.W., G.A. Conover, and M.L. Thomas. 2000. Biological assessment of the fish and mussel fauna of the Kankakee River Basin. Unpublished report, U.S. Fish and Wildlife Service, Marion, Illinois.

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

Strayer, D.L. 1999b. Effects of alien species on freshwater mollusks in North America. Journal of the North American Benthological Society 18(1):74-98.

Surber, T. 1913. Notes on the natural hosts of fresh-water mussels. Bulletin of U. S. Bureau of Fisheries 32:101-115.

Taylor, R.W., and B.D. Spurlock. 1982. The changing Ohio River naiad fauna: a comparison of the early Indian middens with today. The Nautilus 96(2):49-51.

Tennessee Valley Authority. 1971. Stream length in the Tennessee River Basin. Unpublished Report, Knoxville, Tennessee. 25 pp.

Tennessee Valley Authority. 1976. Mussel fauna of the Cumberland River in Tennessee (September 1976). Unpublished report. 14 pp.

Thiel, P.A. 1981. A survey of unionid mussels in the upper Mississippi River (Pools 3-11). Wisconsin Department of Natural Resources Technical Bulletin No. 124. 24 pp.

Trimble, S.W., and A.C. Mendel. 1995. The cow as a geomorphic agent: a critical review. Geomorphology 13:233-253.

Turgeon, D.D., J.F. Quinn, Jr., A.E. Bogan, E.V. Coan, F.G. Hochberg, W.G. Lyons, P.M. Mikkelsen, R.J. Neves, C.F.E. Roper, G. Rosenberg, B. Roth, A. Scheltema, F.G. Thompson, M. Vecchione, and J.D. Williams. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks, 2nd edition. American Fisheries Society Special Publication 26, Bethesda, Maryland. 277 pp.

Utterback, W.I. 1915. The naiades of Missouri. American Midland Naturalist 4(3-8):1-200.

Utterback, W.I. 1917. Naiad geography of Missouri. American Midland Naturalist 5(1):26-30.

van der Schalie, H. 1939. Additional notes on the naiades (fresh-water mussels) of the lower Tennessee River. American Midland Naturalist 22(2):452-457.

van der Schalie, H. 1966. Hermaphroditism among North American freshwater mussels. Malacologia 5:77-78.

van der Schalie, H., and A. van der Schalie. 1950. The mussels of the Mississippi River. American Midland Naturalist 44(2):448-466.

Vannote, R.L., and G.W. Minshall. 1982. Fluvial processes and local lithology controlling abundance, structure, and composition of mussel beds. Proceedings of the National Academy of Sciences 79:4103-4107.

Vaughan, P.W. 1997. Winged mapleleaf mussel (*Quadrula fragosa*) recovery plan. U.S. Fish and Wildlife Service, Fort Snelling, Minnesota.

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

Waters, T.F. 1995. Sediment in streams: sources, biological effects, and control. American Fisheries Society Monograph 7. 251 pp.

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

Watters, G.T., and H.L. Dunn. 1993-94. The Unionidae of the lower Muskingum River (RM 34.1-0), Ohio, U.S.A. Walkerana 7(17/18):225-263.

Way, C.M., and D.N. Shelton. 1997. Quantitative ecological survey of a mussel bed at Ohio River Mile 617.0 to 617.5. Pp. 63-67 *in*: K.S. Cummings, A.C. Buchanan, C.A. Mayer, and T.J. Naimo, eds. Conservation and management of freshwater mussels II: initiatives for the future. Proceedings of a UMRCC symposium, October 1995, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Whitney, S.D., K.D. Blodgett, and R.E. Sparks. 1996. A comprehensive evaluation of three mussel beds in Reach 15 of the upper Mississippi River. Illinois Natural History Survey, Aquatic Ecology Technical report 96/7. 132 pp.

Wilcove, D.S., and M.J. Bean, eds. 1994. The big kill: declining biodiversity in America's lakes and rivers. Unpublished report, Environmental Defense Fund, Washington, DC. 275 pp.

Williams, J.C. 1969. Mussel fisheries investigation, Tennessee, Ohio, and Green rivers. Unpublished report, Kentucky Department of Fish and Wildlife Resources, Frankfort. 107 pp.

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

Wilson, C.B. 1914. Copepod parasites of fresh-water fishes and their economic relations to mussel glochidia. Bulletin of the Bureau of Fisheries 34:331-379.

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

Winston, M.R., and R.J. Neves. 1997. Survey of the freshwater mussel fauna of unsurveyed streams of the Tennessee River drainage, Virginia. Banisteria 10:3-8.

Wolcott, L.T., and R.J. Neves. 1994. Survey of the freshwater mussels of the Powell River, Virginia. Banisteria 3:3-14.

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

Yeager, M.M., R.J. Neves, and D.S. Cherry. 2001. Competitive interactions between early life stages of *Villosa iris* (Bivalvia: Unionidae) and adult Asian clams (*Corbicula fluminea*). Pp. 252-259 *in*: P.D. Johnson and R.S. Butler, eds. Freshwater Mollusk Symposium Proceedings--Part II: Proceedings of the First Symposium of the Freshwater Mollusk Conservation Society, March 1999, Chattanooga, Tennessee. Ohio Biological Survey, Columbus.

Yokley, P. 1972. Freshwater mussel ecology, Kentucky Lake, Tennessee: May 1, 1969 - June 15, 1972. Unpublished report, Tennessee Game and Fish Commission, Nashville. 133 pp.

Zeto, M.A., W.A. Tolin, and J.E. Schmidt. 1987. The freshwater mussels (Unionidae) of the upper Ohio River, Greenup and Belleville Pools, West Virginia. The Nautilus 101(4):182-185.

APPENDIX I

Sheepnose (*Plethobasus cyphyus*) Distributional History

Occurrence by stream (main stem working downstream, then tributaries), county, and state; authority (primary literature and other records); and chronology of occurrence (last record first).

Locality (Stream, County, State)	Authority	Date
Upper Mississippi River Main Stem (above Ohio River confluence)		
Mississippi River, Goodhue County, MN; Pierce County, WI	INHS 16818 D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001)	1994 R <1980
Mississippi River, Wabasha, Winona Counties, MN; Buffalo, Pepin, Trempealeau Counties, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001) Thiel (1981) van der Schalie & van der Schalie (1950) JFBMNH 3203, Grant (1885)	<1980 1977-79 R 1930-31 <1885
Mississippi River, Houston County, IA; La Crosse County, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001) OSUM 1977:0380	>1980 1977
Mississippi River, Allamakee, Clayton Counties, IA; Crawford Grant, Vernon Counties, WI	OSUM 1981:0284, 0310, 0338 D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001) Thiel (1981) Havlik & Stansbery (1978), OSUM 1976:0096 Shimek (1921) [in Havlik & Stansbery (1978)] Baker (1905) [in Havlik & Stansbery (1978)] OSUM 1980:0564	1981 <1980 1977-79 R 1976 <1921 1904 A
Mississippi River, Carroll, Jo Daviess Counties, IL; Jackson County, IA	USNM 746188, 746244, 746269	1907

Mississippi River, Rock Island County, IL; Muscatine, Scott Counties, IA	INHS 22893 Whitney et al. (1996) INHS 17390 INHS 10221 INHS 4452, 4633 INHS 9432 OSUM 1978:0091, 0143 OSUM 1976:0060, 0160 FMNH 22293 MCZ 270087 MCZ 270089 MCZ 570083 van der Schalie & van der Schalie (1950) UMMZ 81922 MCZ 4941, 4944 FSM 20628 USNM 755277, 755316, 755332, 755366 UMMZ 81059 USNM 528795, 540360 ANSP 129884 INHS 4961 CHAS 17912, 17913; FMNH 120221; FSM 175101, 229654; MCZ 219089	1998 1994-95 1994 R 1990 1987 1979 1978 1976 <1958 <1956 1940 <1932 1930-31 1921 <1918 1911 1907 1890-99 1886 1860-69 1829 ?
Mississippi River, Mercer County, IL; Louisa County, IA	INHS 9470 OSUM 1975:0197 ISM 677167 van der Schalie & van der Schalie (1950) INHS 22553 USNM 755716 USNM 528799 CM 61.10424; MCZ 4940, 231200	1979 1975 1955 1930-31 <1921 1907 1897 ?
Mississippi River, Henderson County, IL; Des Moines County, IA	USNM 755751 UMMZ ? (K.S. Cummings, INHS, pers. comm., 2001)	1907 ?
Mississippi River, Hancock County, IL; Clark, Lee, Lewis Counties, IA	INHS 15659 USNM 535257 OSUM 1929:0040, MCZ 85432 USNM 755820, 755842 UMMZ ? (K.S. Cummings, INHS, pers. comm., 2001)	1986 <1938 1929 1907 ?
Mississippi River, Adams County, IL; Marion County, MO	INHS 14795 INHS 68287 INHS 22564	1987 <1960 1879-80
Mississippi River, Marion County, MO; Pike County, IL	ISM 677173 ISM 677170-72 ISM 677168-69 van der Schalie & van der Schalie (1950) Utterback (1915) USNM 755944	1959 1956 1955 1930-31 <1915 1907
Upper Mississippi River System		
Minnesota River, ? County, MN	Dawley (1944, 1947), Graf (1997)	<1944

St. Croix River, Chisago County, MN; Polk County, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001)	<1980
St. Croix River, Washington County, MN; Pierce County, WI	Heath (1989)	1988
Chippewa River, Rusk County, WI	Balding & Balding (1996), OSUM 1992:0096, 0097, 0099	1989-94
Chippewa River, Dunn, Eau Claire Counties, WI	Balding (1992), T. Balding (Univ. Wisconsin-Eau Claire, pers. comm., 2001)	1986-89
Chippewa River, Buffalo, Pepin Counties, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001)	>1980
Flambeau River, Rusk County, WI	Kelner (1995) OSUM 1993:0090 D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001)	~1994 1993 <1980
Wisconsin River, Oneida County, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001)	<1980
Wisconsin River, Lincoln County, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001)	<1980
Wisconsin River, Marathon County, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001)	<1980
Wisconsin River, Portage County, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001)	<1980
Wisconsin River, Wood County, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001)	<1980
Wisconsin River, Adams, Juneau Counties, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001)	<1980
Wisconsin River, Columbia, Dane, Iowa, Sauk Counties, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001) OSUM 1977:0384, Mathiak (1979) ? Mathiak (1979) INHS 22567 INHS 22566 OSUM 18-B:0681	~2000 1977 1975 1922 <1921 <1900 R
Wisconsin River, Crawford, Grant, Richland Counties, WI	B. Seitman (Minnesota Department of Natural Resources, pers. comm., 2002) OSUM 1981:0090, 0305 OSUM 1979:0216 OSUM 1976:0242, Mathiak (1979)? OSUM 1962:0394	2002 1981 1979 1976 A
Rock River, Winnebago County, IL	INHS 22552	<1921
Rock River, Whiteside County, IL	INHS 9907 INHS 910 INHS 908, 909, 22562, 22563	1989 R 1926 1925

Rock River, Rock Island County, IL	INHS 23338 INHS 18099 INHS 10598, 23325	1999 R 1995 R 1988 R
Iowa River, Johnson County, IA	OSUM 1925:0003 ANSP 129887	1925 ?
Skunk River, ? County, IA	ANSP uncat.	?
Des Moines River, Polk County, IA	FSM 20445 FSM 20631	1908 1890
Des Moines River, Lee County, IA; Clark County, MO	Utterback (1915)	<1915
Illinois River, Grundy County, IL	INHS 23880 USNM 515034	1999 R ?
Illinois River, LaSalle County, IL	MCZ 270080 Calkins (1874) [in Starrett (1971)], USNM 84315 UMMZ 81913	1940 <1874 ? ?
Illinois River, Fulton, Mason Counties, IL	INHS 19160 Danglade (1914) Baker (1906)	1996 R 1912 <1906
Illinois River, Cass, Schuyler Counties, IL	Starrett (1971), OSUM 1966:0388	1966 R
Illinois River, Morgan, Pike, Scott Counties, IL	Starrett (1971) Danglade (1914)	1955 R 1912
Illinois River, Fulton, Mason Counties, IL	Danglade (1914) INHS 913	1912 1897
Des Plaines River, Will County, IL	Cummings & Mayer (1997) OSUM 18--:0596	<1970 <1900
Kankakee River, Jasper, Porter Counties, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001)	2000 R
Kankakee River, Lake, Newton Counties, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) UMMZ 81908, 81911 MCZ 270087, Stinson et al. (2000)? UMMZ 81925	2000 R 1915 1913 1909
Kankakee River, Kankakee County, IL	INHS 24391 Page et al. (1998) [in Stinson et al. (2000)] INHS 16244 INHS 12026 INHS 14232 INHS 10427, 11340 OSUM 1909:0013	2000 1996 1994 1991 R 1986 1960 1909
Kankakee River, Will County, IL	INHS 12051, 12075 INHS 5825 INHS 2598 INHS 11500 INHS 1929	1991 R 1988 R 1986 1985 R 1984

Illinois & Michigan Canal, Grundy County, IL	OSUM 1982:0166	1982 R
Fox River, Kane County, IL	Eldridge (1914), Cummings & Mayer (1997) CHAS 5748	~1913 ?
Mackinaw River, ? Counties, IL	Cummings & Mayer (1997)	<1970
Quiver Creek, Mason County, IL	INHS 912	1881
Spoon River, Fulton County, IL	MCZ 85447 INHS 22561	1929 1890-1899
Sangamon River, Menard County, IL	INHS 9237 INHS 914 ANSP 129888	1989 R <1919 ?
Sangamon River, Sangamon County, IL	INHS 7294 MCZ 4942	1988 R <1918
Salt Creek, Mason, Menard Counties, IL	INHS 16883	1989 R
Meramec River, Jefferson, St. Louis Counties, MO	Roberts & Bruenderman (2000) Dunn & Seitman (1997) S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001) Buchanan (1980) FSM 4200	1997 1994 1983, 1981 1977-78 1920s
Meramec River, Franklin County, MO	Roberts & Bruenderman (2000) S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001) Buchanan (1980) OSUM 1970:0352	1997 1981 1977-78 1970
Meramec River, Crawford County, MO	Roberts & Bruenderman (2000) MFM 16072 Buchanan (1980), OSUM 1977:0058, 0059 OSUM 1964:0160	1997 R 1981 1977-78 1964
Bourbeuse River, Franklin County, MO	Roberts & Bruenderman (2000) S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001) Buchanan (1980) OSUM 1963:0356 Oesch (1984)	1997 1980 1977-78 1963 ?
Big River, Jefferson County, MO	S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001), Buchanan (1980)	1978
Kaskaskia River, Shelby County, IL	INHS 7662	1970
Kaskaskia River, Fayette County, IL	INHS 16914 ISM 677148-49	1956 1954
Kaskaskia River, Clinton County, IL	INHS 1236	1929
Kaskaskia River, Washington County, IL	INHS 22550	<1921

Saline Creek, St. Genevieve County, MO	map in Oesch (1984)	A
Castor River, Madison County, MO	map in Oesch (1984)	>1965
Whitewater River, Cape Girardeau County, MO	Buchanan (1980)	1970s?
Lower Missouri River System		
Little Sioux River, Dickinson County, IA	D. Howell (Iowa Department of Natural Resources, pers. comm., 2002)	1916
Little Blue River, Jackson County, MO	Utterback (1915, 1917)	<1915
Gasconade River, Osage County, MO	Utterback (1915, 1917)	<1915
Gasconade River, Gasconade County, MO	map in Oesch (1984)	>1965
Osage Fork Gasconade River, Laclede County, MO	Bruenderman et al. (2001)	1999
Ohio River Main Stem		
Ohio River, Allegheny County, PA	Ortmann (1919) Rhoads (1899) [in Ortmann (1909)] [1] Simpson (1914)	~1910 1898 <1827
Ohio River, Beaver County, PA	Ortmann (1909, 1919)	~1908
Ohio River, Jefferson County, OH; Hancock County, WV	P. Morrison (Service, pers. comm., 2000) Taylor & Spurlock (1982)	1998, 1995 A?
Ohio River, Washington County, OH; Wood County, WV	Ecological Specialists, Inc. (2000) OSUM 1988:0259 Zeto et al. (1987) OSUM 1879:0001	1997-98, 1993-95 1988 1983 1879
Ohio River, Meigs County, OH; Jackson County, WV	J.L. Clayton (West Virginia Division of Natural Resources, pers. comm., 2001) INHS 1654	1993 1900
Ohio River, Gallia County, OH; Cabell, Mason Counties, WV	Ecological Specialists, Inc. (2000) J.L. Clayton (West Virginia Division of Natural Resources, pers. comm., 2001) MUMC:4887 OSUM 1988:0260, 0262 OSUM 1987:0300 MUMC:4059 Zeto et al. (1987) OSUM 1983:0045 OSUM 1967:0024, 0029	~1993-98 1992-93 1989 R 1988 1987 1985 R 1983 1983 1967
Ohio River, Lawrence County, OH; Wayne County, WV	MUMC:4644	1988 R
Ohio River, Greenup County, KY; Scioto County, OH	Ecological Specialists, Inc. (2000) OSUM 1981:0111 Schuster (1988) OSUM 1909:0023	~1993-98 1981 1910 1909

Ohio River, Lewis County, KY; Adams County, OH	Schuster (1988), OSUM 1929:0034, 0036, 1928:0028, 1909:0020 OSUM 1938:0001	1981-82, 1928-29, 1909 1938
Ohio River, Bracken, Mason, Pendleton Counties, KY; Brown, Clermont Counties, OH	Ecological Specialists, Inc. (2000) Clarke (1995) OSUM 1987:0059 Schuster (1988), OSUM 1984:0067, 0098, 0120	~1993-98 1993-94 1987 1982-84
Ohio River, Boone, Campbell, Kenton Counties, KY; Hamilton County, OH	OSUM 1997:0097 OSUM 1987:0779 OSUM 1984:0014, 0085, 0090, 0093, 0095, 0104, 0147, 0161, 0300 Schuster (1988), OSUM 1965:0307, 1943:0001 OSUM 18--:0598, 18-B:0444, 0445, 0446, 0830, 0833 OSUM 1838:0011, 0014 FSM 4018, 66458; MFM 294	1997 1987 1984 1981-82, 1965, 1943, 1895, ? <1900 1838 ?
Ohio River, Carroll, Trimble Counties, KY; Jefferson, Switzerland Counties, IN	Schuster (1988), OSUM 1963:0192, 1962:0064 UMMZ 81914 OSUM 1909:0035	1982, 1962-63 1919 1909
Ohio River, Jefferson, Oldham Counties, KY; Clark, Floyd Counties, IN [Type Locality]	OSUM 1988:0135 Rafinesque (1820) [in Parmalee & Bogan (1998)] Schuster (1988)	1988 <1820 ?
Ohio River, Jefferson, Meade Counties, KY; Harrison County, IN	Way & Shelton (1997) Schuster (1988), OSUM 1909:0027 USNM 677765	1995 R 1982 1909
Ohio River, Daviess, Hancock Counties KY; Spencer County, IN	Ecological Specialists, Inc. (1996) Clarke (1995) Schuster (1988) USNM 677070	1994 1993-94 1982, 1927 1908
Ohio River, Henderson County, KY; Vanderburgh, Warrick Counties, IN	Ecological Specialists, Inc. (1996) Schuster (1988) Bogan (1990)	1994 1982, ? A
Ohio River, Union County, KY; Gallatin County, IL	ISM 677159	1954
Ohio River, Pope County, IL; Livingston County, KY	OSUM 18-B:0027	<1900

Ohio River, Ballard, McCracken counties, KY; Alexander, Massac, Pulaski Counties, IL	INHS 24529 INHS 23028 INHS 21961, 21969 INHS 16318 OSUM 1992:0108 INHS 3979, 4002 OSUM 1981:0172 INHS 14333 FMNH 103656 ISM 677163-66 ISM 677160-62 ISM 677150-58 USNM 756547, 756575, uncat. INHS 4800 FMNH 16157	1999 R 1998 R 1997 R 1994 R 1992 1987 1981 1980 1960 1958 1955 1954 1907 1879 ?
Ohio River System		
Allegheny River, Forest County, PA	T. Proch (Pennsylvania Department of Natural Resources, pers. comm., 2001)	1991
Allegheny River, Venango County, PA	G. Zimmerman (EnviroScience, Inc., pers. comm., 2002)	2002
Allegheny River, Armstrong County, PA	Ortmann (1912, 1919), FSM 66453 Ortmann (1909)	1911 ~1908
Hemlock Creek, Venango County, PA	T. Proch (Pennsylvania Department of Natural Resources, pers. comm., 2001)	1991 R
[?] Monongahela River, Washington, Westmoreland Counties, PA	Ortmann (1913, 1919)	<1897
Beaver River, Lawrence County, PA	Ortmann (1919) Rhoads (1899) [in Ortmann (1909)]	~1910 1898
Duck Creek, Washington County, OH	OSUM 1930:0063	1930
Muskingum River, Coshocton County, OH	OSUM 1979:0054	1979
Muskingum River, Morgan County, OH	OSUM 1980:0257, 0258, 0259, 0261 OSUM 1977:0063, 0517 OSUM 1969:0357 OSUM 1966:0246 OSUM 1930:0019 OSUM 1929:0016 OSUM 1927:0068	1980 1977 1969 1966 1930 1929 1927

Muskingum River, Washington County, OH	Watters & Dunn (1993-94) Stansbery & King (1983) OSUM 1981:0035, 0036, 0045 OSUM 1980:0044, 0269, 0330, 0333 OSUM 1977:0007, 0010, 0167, 0281 OSUM 1973:0343 Bates (1970) OSUM 1969:0179 OSUM 1967:0001, 0022, 0168 OSUM 1966:0067, 0245 OSUM 1965:0563 OSUM 1964:0006, 0007 OSUM 1963:0004, 0195, 0196 OSUM 1962:0023, 0024, 0037, 0038, 0039, 0040, 0127 OSUM 1930:0031, 0040 OSUM 1929:0018	1992-93 1979-81 1981 1980 1977 1973 1967-70 1969 1967 1966 1965 1964 1963 1962 1930 1929
Tuscarawas River, Tuscarawas County, OH	OSUM 1998:0075	1998 R
Walhonding River, Coshocton County, OH	Hoggarth (1995-96), OSUM 1991:0125, 0126 OSUM 1989:0190 OSUM 1980:0542 OSUM 1979:0173 OSUM 1977:0098 OSUM 1973:0100 OSUM 1971:0112 OSUM 1969:0001 OSUM 1968:0001 OSUM 1967:0103, 0126, 0127, 0161, 0175, 0200, 0358, 0390, 0392 OSUM 1964:0215, 0277 OSUM 1963:0059, 0198, 0201, 0202 OSUM 1962:0030, 0031 OSUM 1961:0120, 0123 OSUM 1960:0061, 0062	1991-93 1989 R 1980 1979 R 1977 R 1973 1971 1969 1968 1967 1964 1963 1962 1961 1960
Mohican River, Coshocton County, OH	OSUM 1977:0097 OSUM 1971:0014, 0113 OSUM 1969:0172 OSUM 1968:0050 OSUM 1967:0038, 0105, 0178, 0186, 0224 OSUM 1965:0250 OSUM 1964:0223 OSUM 1963:0058 OSUM 1961:0135	1977 1971 1969 1968 1967 1965 1964 1963 1961
Otter Fork Licking River, Licking County, OH	OSUM 1973:0405	1973
Kanawha River, Fayette County, WV	J.L. Clayton (West Virginia Division of Natural Resources, pers. comm., 2001) OSUM 1970:0048	1999, 1990, 1987, 1982 1970
Scioto River, Pike County, OH	OSUM 1963:0113	1963
Little Miami River, Hamilton County, OH	Mattox (1953) [in Hoggarth (1992)] OSUM 18-B:0673	<1953 <1900

Licking River, Bath, Fleming, Nicholas, Rowan Counties, KY	R.R. Cicerello (Kentucky State Nature Preserves Commission, pers. comm., 2001) Laudermilk (1993) OSUM 1983:0183; MFM 16126 Schuster (1988), OSUM 1971:0205	1998 1991, 1987 1983 1971
Kentucky River, Garrard, Jessamine Counties, KY	R.R. Cicerello (Kentucky State Nature Preserves Commission, pers. comm., 2001)	1996
Salt River, ? County, KY	OSUM 18-A:0220	<1900
Green River, Hart County, KY	J.B. Layzer (USGS, pers. comm., 2001) R.R. Cicerello (Kentucky State Nature Preserves Commission, pers. comm., 2001) Cicerello (1994) INHS 12902 INHS 7470 OSUM 1981:0072 OSUM 1972:0156 OSUM 1971:0135 OSUM 1968:0439, 1966:0089, 1965:0196, 0239, 1964:0166, 0193, OSUM 1961:0087	2000 1998, 1995, 1993, 1988 1993 1989 R 1988 1981 1972 1971 1964-68 1961
Green River, Edmonson County, KY	R.R. Cicerello (Kentucky State Nature Preserves Commission, pers. comm., 2001) INHS 12958, 15730, 15767, 15858 Cicerello & Hannan (1990) Schuster (1988), OSUM 1961:0171 Bogan (1990)	1995 1989 1987-89, 1981-82 1961, 1908 A
Green River, Butler, Warren counties, KY	Gordon & Sherman (1995) Cochran & Layzer (1993) P.W. Shute (TVA, pers. comm., 2001) Schuster (1988), OSUM 1979:0118, 1970:0147, 1969:0011 OSUM 1972:0164 Patch (1976)	1993 1990-91 1981 1979, 1969-70 1972 A
Barren River, Warren County, KY	Gordon & Sherman (1995) Clarke (1983) Schuster (1988)	1993 R 1981 R ?
Wabash River, Carroll County, IN	Meyer (1968) [in Cummings et al. (1988a)]	1966

Wabash River, Tippecanoe County, IN	OSUM 1992:0041 INHS 6644 OSUM 1976:0112 MCZ 268103; OSUM 1964:0066, 0154 ; UMMZ ? (K.S. Cummings, INHS, pers. comm., 2001) OSUM 1963:0332, UMMZ ? (K.S. Cummings, INHS, pers. comm., 2001) INHS 1391 INHS 1383, 1417 INHS 22555 UMMZ ? (K.S. Cummings, INHS, pers. comm., 2001) MCZ 63110, UMMZ 81918	1992 R 1988 1976 1964 1963 1927 1926 <1918 1897 ?
Wabash River, Clark County, IL; Vigo County, IN	Cummings et al. (1988a), INHS 5720, 6430 USNM 677035 OSUM 18--:0398 UMMZ 81915	1988 R 1907 <1900 ?
Wabash River, Crawford County, IL; Sullivan County, IN	Cummings et al. (1988a), INHS 6180 FMNH 22298, 68404a	1988 R <1958
Wabash River, Lawrence County, IL; Knox County, IN	INHS 19011 Cummings et al. (1988a), INHS 6271 INHS 6303 OSUM 1961:0152 [5411], [5302] ISM 677177-79 Bogan (1990)	1996 R 1988 1988 R 1961 1954 A
Wabash River, Wabash County, IL; Gibson County, IN	INHS 24526 INHS 18880, 18928 Cummings et al. (1987), INHS 4388 MFM 15661 CHAS 5749 OSUM 1977:0287	1999 R 1996 R 1987 R 1986 R ? A
Wabash River, White County, IL; Posey County, IN	Cummings et al. (1987), INHS 4764 ISM 677174-76 USNM 539978 INHS 22549, 22551, 22557, 22559, 22560 FSM 66457 CM 61.9004; INHS 22558 INHS 22556 USNM 515035, 515036, 515038 USNM 84317 CHAS 18224; MCZ 91442; UMMZ 81917, 81923, 81926	1987 R 1954 1935 <1921 1917 1916 1899 1890-99 <1887 ?
[3] Mississinewa River, Wabash County, IN	USNM 420775	1899
Eel River, Cass County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2000) FMNH 90150	1997 ?
Eel River, Miami County, IN	MFM 15625	1986 R

Eel River, Wabash County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001)	1986 R
Eel River, ? County, IN	MCZ 270086	?
Tippecanoe River, Marshall County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001)	1995
Tippecanoe River, Fulton County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) Cummings & Berlocher (1990), INHS 3489, 3531, 3544, 4065, 4084 MCZ 270088 Daniels (1903) ? [in Cummings & Berlocher (1990)] USNM 420730	1995, 1991-92 1987 1908 <1903 1899
Tippecanoe River, Starke County, IN	INSM 1102	1983
Tippecanoe River, Pulaski County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) OSUM1992:0136 Cummings & Berlocher (1990), INHS 3915, 4179, 4332 UMMZ ? (K.S. Cummings, INHS, pers. comm., 2001) Daniels (1903) ? [in Cummings & Berlocher (1990)]	1995, 1991-92 1992 1987 1946 <1903
Tippecanoe River, White County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) Daniels (1903) ? [in Cummings & Berlocher (1990)]	1995 <1903
Tippecanoe River, Carroll County, IN	OSUM 1992:0115, 0116 B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) Cummings et al. (1992), INHS 3594	1992 1991 1987 R
Tippecanoe River, Tippecanoe County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) OSUM 1992:0112, 0114 INHS 3619	1995, 1991 1992 1987
Vermilion River, Vermilion County, IN	UMMZ 81065	?
Embarras River, Jasper County, IL	Cummings et al. (1988b), FMNH 54802	1953
White River, Gibson, Knox, Pike Counties, IN	OSUM 1913:0013 OSUM 1908:0026; USNM 677069 USNM 84316 FMNH 140882; UMMZ ? (K.S. Cummings, INHS, pers. comm., 2001)	1913 1908 <1887 ?
East Fork White River, Jackson County, IN	ANSP 127377	<1883
East Fork White River, Martin County, IN	OSUM 1964:0069 OSUM 1961:0138	1969 1961

West Fork White River, Madison County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2000)	2000 R
West Fork White River, Marion County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2000) UMMZ 81927 CHAS 20154	2000 R 1908 ?
Cumberland River Main Stem		
Cumberland River, Wayne County, KY	Wilson & Clark (1914)	1911
Cumberland River, Cumberland, Russell Counties, KY	OSUM 1982:0272 Neel & Allen (1964) Schuster (1988) Wilson & Clark (1914)	1982 R 1947-48 1925 1910
Cumberland River, Monroe County, KY	Wilson & Clark (1914)	1910
Cumberland River, Jackson County, TN	Wilson & Clark (1914)	1910-11
Cumberland River, Smith County, TN	Koch (1983) Parmalee et al. (1980) TVA (1976) Wilson & Clark (1914)	1983 1979, A 1976 1910-11
Cumberland River, Sumner, Trousdale, Wilson Counties, TN	Koch (1983) OSUM 1980:0554 [4] TVA (1976) Wilson & Clark (1914), FSM 4017	1982 1980 1976 1910-11
Cumberland River, Davidson County, TN	Wilson & Clark (1914) INHS 22569, 22571	1910-11 1884
Cumberland River, Cheatum County, TN	Wilson & Clark (1914)	1910-11
Cumberland River, Montgomery County, TN	Wilson & Clark (1914)	1910-11
Cumberland River, Stewart County, TN	Wilson & Clark (1914)	1910-11
Cumberland River, Trigg County, KY	UMMZ 235074	?
Cumberland River, Livingston County, KY	R.R. Cicerello (Kentucky State Nature Preserves Comm., pers. comm., 2001)	1987
Cumberland River System		
Obey River, Pickett County, TN	Shoup et al. (1941)	1939
Caney Fork River, Smith County, TN	Layzer et al. (1993) OSUM 1988:0095 OSUM 1981:0093 MFM 8770	~1990 R 1988 R 1981 R 1961 R
Harpeth River, ? counties, TN	Parmalee & Bogan (1998 map)	?
Tennessee River Main Stem		
Tennessee River, Knox County, TN	OSUM 18-B:0683 Lewis (1870) Ortmann (1918)	<1900 <1870 ?

Tennessee River, Meigs, Rhea Counties, TN	Ahlstedt & McDonough (1995-96) [5] Pardue (1981) Bates (1975) Scruggs (1960) Parmalee et al. (1982), Bogan (1990)	1992, 1983-85, 1965, <1918 1975-77 1972-74 1957 A
Tennessee River, Jackson County, AL	Isom (1972) Scruggs (1960) MFM 1010 Bogan (1990)	1972 1957 1949 A
Tennessee River, Limestone, Madison, Marshall, Morgan Counties, AL	OSUM 1999:0044, 0045 OSUM 1997:0035, 0037 Bowen et al. (1994) INHS 14337 Gooch et al. (1979), Ahlstedt & McDonough (1993) Scruggs (1960), FSM 20571 OSUM 1952:0006; MFM 2691 van der Schalie (1939) FSM 175103	1999 1997 ~1993 1980 1976-78 1956-57 1952 1931 ?
Tennessee River, Colbert, Lauderdale Counties, AL	J.T. Garner (Alabama Department of Natural Resources, pers. comm., 2001) McGregor et al. (1998), Garner & McGregor (2001) OSUM 1998:0061 Garner (1997) Garner & McGregor (2001) Stansbery (1964), OSUM 1963:0191 van der Schalie (1939) Ortmann (1925) FSM 66459 Hinkley (1906), FSM 66454 INHS 22568 Morrison (1942)	1999-2000 1998 1998 1997 1976-78 1963 1931 1924 1909 1904 1894 A
Tennessee River, Hardin County, TN	OSUM 1981:0129 INHS 14325 INHS 14531 Gooch et al. (1979) Yokley (1972), Dennis (1985) OSUM 1964:0624, 0640 Scruggs (1960), Dennis (1985) van der Schalie (1939), Dennis (1985)	1981 1980 1979 1978 <1972 1964 1957 1931
Tennessee River, Decatur, Perry, Wayne Counties, TN	OSUM 1964:0303, 0603	1964
Tennessee River, Benton, Humphreys Counties, TN	Bates (1967) [in Dennis (1985)] Ortmann (1925), Dennis (1985)	<1967 1924

Tennessee River, Livingston, Marshall Counties, KY	Sickel & Burnett (2001) R.R. Cicerello (Kentucky State Nature Preserves Comm., pers. comm., 2001) Sickel (1985) Schuster (1988) Gooch et al. (1979) Williams (1969)	2001 1999 1985 1981-85, 1960 1978 1966-67
Tennessee River System		
Holston River, Gainger, Hamblen Counties, TN	Ortmann (1918) Böpple & Coker (1912)	1913 1909
Holston River, Jefferson, Knox Counties, TN	S.J. Fraley (North Carolina Wildlife Resources Comm., pers. comm., 2002) S.A. Ahlstedt (USGS, pers. comm., 2001) Ahlstedt (1991a) MFM 10527 Ortmann (1918) Böpple & Coker (1912)	2002 2000 1981 1963 1913-15 1909
North Fork Holston River, Hawkins, Sullivan Counties, TN	Ortmann (1918)	1913
French Broad River, Sevier County, TN	Ortmann (1918)	1914
French Broad River, Knox County, TN	S.A. Ahlstedt (USGS, pers. comm., 2001)	1998 R
Little Pigeon River, Sevier County, TN	Parmalee (1988), Bogan (1990)	A
Little Tennessee River, Monroe County, TN	Bogan (1990)	A
Little Tennessee River, Loudon County, TN	MFM 21733, 21761	1971 R
Clinch River, Russell County, VA	J.W. Jones (Virginia Tech, pers. comm., 2001) Ahlstedt (1991b)	1998-99 1978-83
Clinch River, Scott County, VA	S.A. Ahlstedt (USGS, pers. comm., 2001) P.W. Shute (TVA, pers. comm., 2001) Dennis (1989) OSUM 1983:0147 OSUM 1981:0256 Ahlstedt (1991b) OSUM 1981:0001 OSUM 1978:0152 Bates & Dennis (1978) OSUM 1973:0186 OSUM 1971:0194 OSUM 1970:0072 MFM 15295, 20642 OSUM 1966:0033, 0073 OSUM 1965:0227, 0228, 0229 OSUM 1964:0111 OSUM 1963:0091, 0092, 0093, 0094, 0108, 0194 MFM 3916 Ortmann (1918) OSUM 1909:0005 (Böpple) FSM 229653	2001 1999, 1996 1987-88 1983 1981 1978-83 1981 1978 1973-75 1973 1971 1970 1969 1966 1965 1964 1963 1953 1913 1909 ?

Clinch River, Hancock County, TN	S.A. Ahlstedt (USGS, pers. comm. 2001)	1999-2001
	INHS 16647	1992
	Ahlstedt & Tuberville (1997)	1988, 1979
	FSM 195055	1981
	Ahlstedt (1991b)	1978-83
	OSUM 1978:0157	1978
	OSUM 1977:0300	1977
	Bates & Dennis (1978)	1973-75
	OSUM 1974:0033	1974
	OSUM 1972:0178	1972
	OSUM 1971:0195	1971
	OSUM 1970:0283	1970
	OSUM 1969:0318, 0319	1969
	OSUM 1968:0133, 0134; MFM 18276	1968
	OSUM 1967:0143, 0144, 0164, 0165, 0166	1967
	OSUM 1965:0234; MFM 14661	1965
	Ortmann (1918)	1899
Clinch River, Claiborne, Grainger Counties, TN	Ortmann (1918)	1913-15
	OSUM 1909:0009 (Böpple)	1909
Clinch River, Campbell, Union Counties, TN	Ortmann (1918)	1915, 1899
	OSUM 1909:0007 (Böpple)	1909
Clinch River, Anderson, Knox Counties, TN	MFM 6114	1956 R
	Ortmann (1918)	1914-15
	Böpple & Coker (1912)	1909
Clinch River, Loudon, Roane Counties, TN	S.A. Ahlstedt (USGS, pers. comm., 2001)	1994
	Parmalee & Bogan (1986)	A
North Fork Clinch River, Hancock County, TN	INHS 22570	<1921
Powell River, Lee County, VA	S.A. Ahlstedt (USGS, pers. comm., 2001)	2000
	P.W. Shute (TVA, pers. comm., 2001)	1999, 1987
	Ahlstedt & Tuberville (1997)	1994
	Wolcott & Neves (1994)	1988-89
	Barr et al. (1993-94)	1981
	Ahlstedt (1991a)	1979
	Ahlstedt & Brown (1980)	1975-78
	Dennis (1981, 1985)	1973-78
	MCZ 190483	1954
Powell River, Hancock County, TN	S.A. Ahlstedt (USGS, pers. comm., 2001)	2000
	J.W. Jones (Virginia Tech, pers. comm., 2001)	1998-2000
	Ahlstedt & Tuberville (1997)	1994, 1983, 1979
	Dennis (1981), Dennis (1985)	1973-81
	Ahlstedt (1991a)	1979
	Ahlstedt & Brown (1980)	1975-78

Powell River, Claiborne County, TN	Ahlstedt & Tuberville (1997) Dennis (1985) Ahlstedt (1991a) Ahlstedt & Brown (1980) OSUM 1971:0343 OSUM 1969:0320 OSUM 1968:0223 OSUM 1967:0131, 0145, 0146, 0163 OSUM 1964:0533; MFM 11426 Hickman (1937) Ortmann (1918)	1994, 1988, 1983, 1979 1973-81 1979 1975-78 1971 1969 1968 1967 1964 1936 1913-15, 1899
Hiwassee River, Polk County, TN	Parmalee & Hughes (1994)	1975 R
Hiwassee River, Bradley County, TN	Parmalee & Hughes (1994)	A
Duck River, ? County, TN	ANSP 127384	?
Lower Mississippi River System		
Hatchie River, Haywood, Lauderdale, Tipton Counties, TN	Manning (1989), map in Parmalee & Bogan (1998) Hatcher (1982)	1980-83 1980-81 R
[6] Black River, Randolph County, AR	FSM 175102	?
[7] Verdigris River, Montgomery County, KS	Murray & Leonard (1962) Scammon (1906) [in Murray & Leonard (1962)]	1909 <1906
[7] Neosho River, ? County, ?	Johnson (1980)	<1980
Yazoo River, ? Counties, MS	Bogan (1990)	A
Big Sunflower River, Sunflower County, MS	R.L. Jones (Mississippi Museum of Natural Science, pers. comm., 2001)	2000, A
Big Black River, Hinds, Madison, Yazoo Counties, MS	Peacock and James (2002)	A

Footnotes:

[1] Simpson (1914) states the type locality of a synonym, *Unio aesopus* Green, 1827 (in Parmalee and Bogan 1998), as being "Pittsburgh, Pa." while Ortmann (1909) stated that it was "[d]escribed from the 'rivers in the neighborhood of Pittsburgh.'" I have assumed that this record was from the mainstem Ohio River, although it could actually be from either the Allegheny or Monongahela River, Ortmann (1912, 1913) having reported it from both rivers, or possibly from a combination of these three streams.

[2] Ortmann (1913) reported *Plethobasus cyphyus* from the Monongahela River. Noting that "this fauna is now destroyed," he states that faunal knowledge rests upon a <1897 collection "in the vicinity of Chareloi, Washington Co., Pa." then further noted that there were "a few scattered additional records secured by others" from this stream. I do not know precisely where this species was secured in the Monongahela, but have assumed it was from the Chareloi area.

[3] According to the computer printout of museum records provided by K.S. Cummings, INHS, this specimen "may be *Epioblasma torulosa* [*torulosa*]."

[4] This record is from a commercial musselers cull pile (Leroy Koch, Service, pers. comm., 2001),

so the label gives a long river reach where Sumner, Trousdale, and Wilson Counties are near the center.

[5] Ahlstedt & McDonough (1995-96) do not specifically give a reference for the <1918 collection of this species from this river reach in their table. They simply list it in a column labeled "1850-1918." Since Ortmann (1918) did not list *Plethobasus cyphyus* from this Tennessee River reach, but did include it from just upstream in Knox County, Ahlstedt and McDonough (1995-96) may have assumed that it also must have occurred in the Meigs and Rhea counties reach.

[6] This record represents the only known occurrence of *Plethobasus cyphyus* for Arkansas.

[7] Published records of *Plethobasus cyphyus* from Kansas (e.g., Parmalee 1967) have been disregarded by modern Kansas malacologists (B.K. Obermeyer, Prairie Research, pers. comm., 2001). Thus, this species is not considered a member of the historical Kansas malacofauna. The status of the record of this species in the Neosho River, Kansas or Oklahoma, by Johnson (1980), should also be considered spurious. To further substantiate its absence from Kansas, this species has never been reported from either Oklahoma nor from Arkansas portion of the Arkansas River system.

Codes:

< = collected before [date], > = collected after [date], ANSP = The Academy of Natural Sciences of Philadelphia, CHAS = Chicago Academy of Science, CM = Carnegie Museum, FMNH = Field Museum of Natural History, INHS = Illinois Natural History Survey, INSM = Indiana State Museum, ISM = Illinois State Museum, MUMC = Marshall University Mollusk Collection, MFM = Museum of Fluviatile Mollusks, OSUM = Ohio State University Museum of Biological Diversity, R = relic shells only, TUR = Triannual Unionid Report, UMMZ = University of Michigan Museum of Zoology, USNM = U.S. National Museum.

Notes:

Citations used in Appendix I are in the Literature Cited section of the status review. A shell considered relic in this report may have been reported as either weathered or subfossil in the original citation. Sites where only weathered (relic) shells are encountered probably indicates that the population in question is extirpated (Watters and Dunn 1993-94). Sites where only relic shells are encountered probably indicates that the population in question is extirpated (Watters and Dunn 1993-94).

Bates & Dennis (1983) note this species in a list of common names of mussels from the St. Francis and White Rivers, Arkansas and Missouri, but no other mention of it was found in their report on mussels from those rivers. This species was not reported from Arkansas by Gordon et al. (1980), but see footnote 6 above.

Call (1900) reported this species as being common in the Wabash River without giving site specific information.

Dennis (1985) reported this species in 1976-83 survey work from the Clinch River (RM 190-280), Powell River, and Cumberland River without giving site specific information.

B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2000) stated that it is extant in the Ohio River (RM 726-798) without giving site specific information.

Grier (1915) presented a list of naiades of the Meramec River without giving specific locality data.

Harn (1891) [in Ortmann (1909)] reported this species in a list of shells from western

Pennsylvania without giving locality data. Ortmann (1909) states "...apparently most of his Unionidae were from the Kiskiminetas or the Conemaugh drainage[s]."

Johnson (1980) recorded this species from the Neosho River in a table in his paper, but gives no specific information on this record. Branson (1982) fails to note its occurrence in Oklahoma, but Murray and Leonard (1962) report it from the adjacent Verdigris River in Kansas, lending credence to Johnson's record.

Pardue (1981) stated that Bates (1975) reported this species from the upper Tennessee River, but did not give specific site information.

Price (1900) listed this species from the Green River system (probably Barren River) without giving site specific information.

Williams (1969) reported this species in 1967-68 survey work from the Ohio River (RM317-981) without giving site specific information. *Plethobasus cyphyus* in this survey, which covered the entire northern boundary of Kentucky, represented 0.7% (41 specimens) of the total harvest data, and was most prevalent in northeastern Kentucky upstream of RM 538. Williams & Schuster (1989) resurveyed the same Ohio River reach as did Williams (1969), but found this species represented only 0.3% (21 specimens) of the total harvest. Most of their specimens were also found in the upper portion of the river. Their records are incorporated in the table as Schuster (1988) records.

Williams (1969) also reported this species in 1968 survey work from the upper Green River (Butler County upstream) without giving site specific information. Only 11 specimens were found, all but 1 from Hart County upstream.

APPENDIX II

Sheepnose (*Plethobasus cyphyus*) extant populations*

Stream/Service Region	State	Last Observed	Recruiting?
Region 3			
Mississippi River (a few reaches)	Minnesota, Wisconsin, Iowa, Illinois, Missouri	1998	Yes?
St. Croix River	Minnesota, Wisconsin	1988	No?
Chippewa River	Wisconsin	1989-94	Yes
Flambeau River	Wisconsin	1994	Yes
Wisconsin River	Wisconsin	late 1990s	Yes
Kankakee River	Illinois	2000	?
Meramec River	Missouri	1997	Yes
Bourbeuse River	Missouri	1997	Yes
Osage Fork Gasconade River	Missouri	1998-99	No (1 spec.)
Ohio River (several reaches)	Ohio, West Virginia, Indiana, Kentucky, Illinois	1998	Yes?
Wabash River	Indiana	1988	No
Tippecanoe River	Indiana	1995	Yes
Eel River	Indiana	1997	Yes?
Muskingum River	Ohio	1992-93	Yes?
Walhonding River	Ohio	1991-93	?
Region 4 (see also Ohio River under Region 3)			
Licking River	Kentucky	1998	?
Kentucky River	Kentucky	1996	?
Green River	Kentucky	2002	Yes
Cumberland River (lowermost mainstem)	Kentucky	1987	?
Tennessee River (4-5 tailwaters)	Alabama, Kentucky, Tennessee	2000	Yes (below Wilson Dam)

Holston River	Tennessee	2000	No
Clinch River (see also Region 5)	Tennessee	2001	Yes
Powell River (see also Region 5)	Tennessee	2000	?
Big Sunflower River	Mississippi	2000	No
Region 5 (see also Ohio River under Region 3)			
Allegheny River	Pennsylvania	2002	Yes
Kanawha River	West Virginia	1999	Yes?
Clinch River (see also Region 4)	Virginia	2001	Yes
Powell River (see also Region 4)	Virginia	2000	?

* Generally, a population is considered extant if live or fresh dead specimens have been located in the past 15 or so years.

NOTE: The sheepnose was historically known from 77 streams in 14 states and 3 Service regions (3, 4, & 5). Currently, it is known from 26 streams in these 14 states and all 3 regions. Region 3 has the most extant streams of occurrence (some streams may have multiple extant sites) with 15, while Region 4 has 9, and Region 5 has 5 occurrences.

APPENDIX III

List of primary individuals who actually provided status information on the sheepnose

Steven A. Ahlstedt
USGS
1827 Midpark Drive
Knoxville TN 37921
ahlstedt@usgs.gov
865/545-4140 X 17

Robert M. Anderson
U.S. Fish and Wildlife Service
312 South Allen Street
Suite 322
State College PA 16801
robert_m_anderson@fws.gov
814/234-4090 X 228

Herbert T. Athearn
Museum of Fluviatile Mollusks
5819 Benton Pike NE
Cleveland TN 37323
423/476-4923

Terry Balding
Department of Biology
University of Wisconsin-Eau Claire
PO Box 4004
Eau Claire WI 54702
baldinta@uwec.edu
715/836-5089

Richard G. Biggins (retired)
U.S. Fish and Wildlife Service
160 Zillicoa Street
Asheville NC 28801
rgbiggins@aol.com

Sue A. Bruenderman
Missouri Department of Conservation
1110 South College Avenue
Columbia MO 65201
bruens@mail.conservation.state.mo.us
573/882-9880

Stuart L. Butler
346 Laval Heights #16
Versailles KY 40383
859/873-4076

Ronald R. Cicerello
Kentucky State Nature Preserves Commission
801 Schenkel Lane
Frankfort KY 40601
ronald.cicerello@mail.state.ky.us
502/573-2886

Janet L. Clayton
West Virginia Division of Natural Resources
PO Box 67
Elkins WV 26241
jclayton@mail.dnr.state.wv.us
304/637-0245

Kevin S. Cummings
Illinois Natural History Survey
Champaign IL 61820
ksc@inhs.uiuc.edu
217/33-1623

Mike Davis
Minnesota Department of Natural Resources
1801 South Oak Street
Lake City MN 55041
mike.davis@dnr.state.mn.us
651/345-3331

Heidi L. Dunn
Ecological Specialists, Inc.
1417 Hoff Industrial Drive
O'Fallon MO 63366
hdunn@ecologicalspecialists.com
636/281-1982

Brant E. Fisher
Indiana Department of Natural Resources
Atterbury Fish and Wildlife Area
7970 Suth Rowe Street
Edinburgh IN 46124
bfisher@dnr.state.in.us
812/526-5816

Steven J. Fraley
North Carolina Wildlife Resources Comm.
833 7th Avenue NW
Hickory NC 28601
fraleysj@charter.net
828/442-3744

Jeffrey T. Garner
State Malacologist
Alabama Department of Conservation and Natural Resources
350 County Road 275
Florence AL 35633
bleufer@aol.com
256/767-7673

Daniel L. Graf
Assistant Curator of Malacology
The Academy of Natural Sciences
1900 Benjamin Franklin Parkway
Philadelphia PA 19103
graf@acnatsci.org
215/299-1132

John L. Harris
Arkansas Highway and Transportation Department
Environmental Division
P.O. Box 2261
Little Rock AR 72212
john.harris@ahtd.state.ar.us
501/569-2522

Marian E Havlik
Malacological Consultants
1603 Mississippi Street
La Crosse WI 54601
havlikme@aol.com
608/782-7958

David J. Heath
Mississippi River Fisheries Biologist
Wisconsin Department of Natural Resources
3550 Mormon Coulee Road
La Crosse WI 54601
david.heath@dnr.state.wi.us
608/785-9993

Mark C. Hove
University of Minnesota
Department of Fisheries
1980 Folwell Avenue
St. Paul MN 55108
Mark.Hove@fw.umn.edu
612/624-3019

Don W. Hubbs
Mussel Program Coordinator
Tennessee Wildlife Resources Agency
PO Box 70
Camden TN 38320
tnmussels@aol.com
731/584-9032

Jess W. Jones
Virginia Polytechnic Institute and State Univ.
Department of Fisheries and Wildlife Sciences
100 Cheatham Hall
Blacksburg VA 24061
vtaquaculture@hotmail.com
540/231-7241

Robert L. Jones
Mississippi Museum of Natural Science
2148 Riverside Drive
Jackson MS 39202
bob.jones@mmns.state.ms.us
601/354-7303

Daniel E. Kelner
U.S. Army Corps of Engineers
190 5th Street East
St. Paul, MN 55110
daniel.e.kelner@mvp02.usace.army.mil
651/290-5277

Helen E. Kitchel
Wisconsin Department of Natural Resources
101 South Webster Street
Madison WI 53715
kitchl@mail01.dnr.state.wi.us
608/266-5248

James B. Layzer
Tennessee Technological University
PO Box 5114
Cookeville TN 38505
jim_layzer@tntech.edu
931/372-3032

Patricia Morrison
U.S. Fish and Wildlife Service
Ohio River Islands National Wildlife Refuge
PO Box 1811
Parkersburg WV 26102
patricia_morrison@fws.gov
304/422-0752

Richard J. Neves
Virginia Polytechnic Institute and State Univ.
Department of Fisheries and Wildlife Sciences
100 Cheatham Hall
Blacksburg VA 24061
mussel@vt.edu
540/231-5927

Thomas Proch
Pennsylvania Department of Environmental Protection
2721 Cedric Avenue
Pittsburgh PA 15226
proch.thomas@dep.state.pa.us
412/442-4051

Andy Roberts
U.S. Fish and Wildlife Service
901 East Cherry Street, Room 200
Columbia MO 65201
andy_roberts@fws.gov
573/876-1911 X 110

Randy Sanders
Ohio Department of Natural Resources
1840 Belcher Dr. G-3
Columbus OH 43224
randy.sanders@dnr.state.oh.us
614/265-6344

Bernard Sietman
Minnesota Department of Natural Resources
500 Lafayette Road
PO Box 225
St. Paul MN 55155
bernard.sietman@dnr.state.mn.us
651/282-2509

Robert Tawes
U.S. Fish and Wildlife Service
446 Neal Street
Cookeville TN 38501
robert_tawes@fws.gov
931/528-6481 X 213

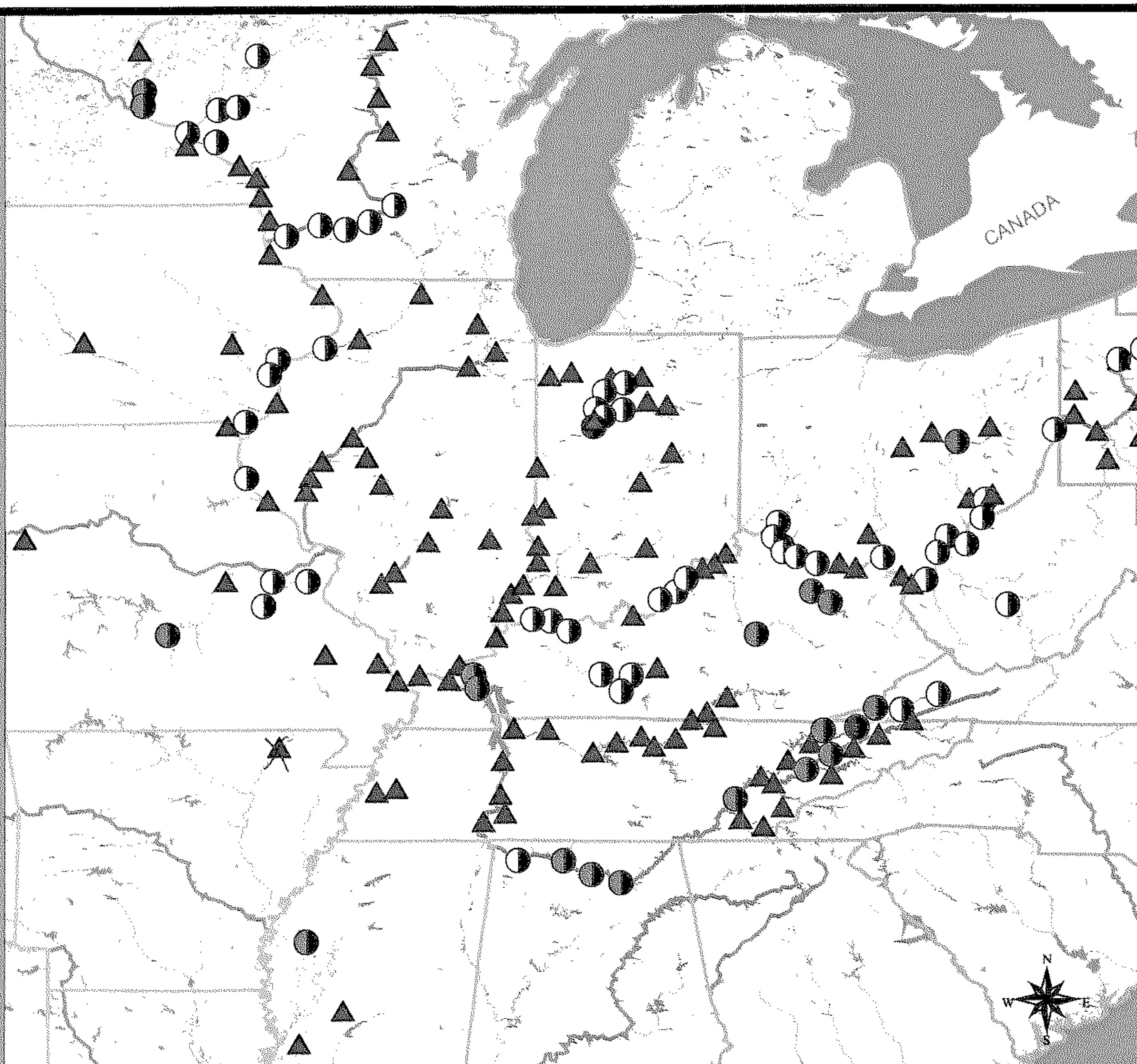
William A. Tolin
U.S. Fish and Wildlife Service
694 Beverly Pike
Elkins WV 26241
william_tolin@fws.gov
304/636-6586

James Widlak
U.S. Fish and Wildlife Service
446 Neal Street
Cookeville TN 38501
james_widlak@fws.gov
931/528-6481 X 202

G. Thomas Watters
Ohio Biological Survey and Aquatic Ecology Laboratory
Ohio State University
1315 Kinnear Road
Columbus OH 43212
gwatters@postbox.acs.ohio-state.edu
614/292-6170

Gregory Zimmerman
EnviroScience, Inc.
3781 Darrow Road
Stow OH 44224
gzimmerman@enviroscienceinc.com
330/688-0111

FIGURE 8. STATUS AND DISTRIBUTION OF THE SHEEPNOSE

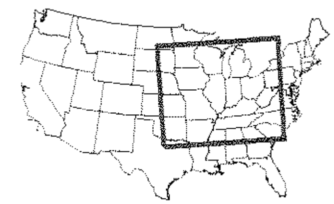


Legend

- ▲ Extirpated
- Non-Viable or Unknown
- Some Evidence of Viability
- Both Viable and Unknown

0 90 180 270

Miles



Map Location

Sheepnose
(Plethobasus cyphyus)

This map is the product of the Ohio River Valley Ecosystem Team Mussel Subgroup and was produced with the intent that it be displayed at a scale of 1:10,500,000. There are no warranties made as to the fitness of this map for any unlisted purpose or reproduction at any other than the original scale.

March 12, 2003