Status Assessment Report for the spectaclecase, *Cumberlandia monodonta*, occurring in the Mississippi River system (U.S. Fish and Wildlife Service Regions 3, 4, 5, and 6)

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Disclaimer

This document is a compilation of biological data and a description of past, present, and likely future threats to the spectaclecase (*Cumberlandia monodonta*). 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: spectaclecase

Scientific name: *Cumberlandia monodonta*

Controversial or unsettled taxonomic issues: Although a member of the mussel family Margaritiferidae, the spectaclecase was originally described as *Unio monodonta* Say, 1829. The type locality is the Falls of the Ohio (on the Ohio River in the vicinity of Louisville, Kentucky, and adjacent Indiana), and the Wabash River (probably the lower portion in Illinois and Indiana) (Parmalee and Bogan 1998). Parmalee and Bogan (1998) summarized the synonomy of the spectaclecase. The spectaclecase has been placed in the genera *Margaritana, Alasmidonta, Margarita, Margaron,* and *Margaritifera* at various times in history. It was placed in the monotypic genus *Cumberlandia* by Ortmann (1912). Smith (2001) reassigned the spectaclecase to the Holarctic genus *Margaritinopsis* based on shell and gill characters. However, the Service will defer to the Committee on Scientific and Vernacular Names of Mollusks of the Council of Systematic Malacologists, American Malacological Union (Turgeon et al. 1998), on whether the genus *Margaritinopsis* is accepted as valid for the spectaclecase. Until an official decision is made, the Service will use the commonly accepted *Cumberlandia* for the genus of this taxon. The Service recognizes *Unio soleniformis* as a synonym of *Cumberlandia monodonta*.

Physical description of the taxon: The following description of the spectaclecase is generally summarized from Oesch (1984), Parmalee and Bogan (1998), and Baird (2000). The spectaclecase is a large mussel that reaches at least 9.25 inches in length. The shape of the shell is greatly elongated, sometimes arcuate, and moderately inflated, with the valves being solid and moderately thick. Both anterior and posterior ends of the shell are rounded with a shallow depression near the center of the valve. The anterior end is higher than the posterior end. The posterior ridge is low and broadly rounded. Year one specimens have heavy ridges running parallel with the growth rests. The periostracum (external shell surface) is somewhat smooth, rayless, and light yellow, greenish-tan, to brown in young specimens becoming rough and dark brown to black in old shells. The shell will commonly crack posteriorly when dried. A line drawing of the species is in Appendix I (Burch 1975).

Internally, the single pseudocardinal tooth is simple and peg-like in the right valve, fitting into a depression in the left. The lateral teeth are straight and single in the right valve, double in the left valve, but with age become fused and represented by an indistinct raised hingeline. The color of the nacre (mother-of-pearl) is white, occasionally granular and pitted, mostly iridescent in young specimens, but becoming iridescent posteriorly in older shells. There is no sexual dimorphism in the shells of this species. The soft anatomy was described by Oesch (1984). Key characters useful for distinguishing the spectaclecase from other mussels is its large size, elongate shape, arcuate ventral margin, dark coloration, roughened surface, poorly developed teeth, and white nacre. No other North American mussel species has this suite of characters.

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). The biggest change in growth rate appears to occur at 10-15 years of age, which suggests that significant reproductive investment does not occur until spectaclecase specimens reach 10 years of age (Baird 2000).

As a group, mussels are extremely long-lived, particularly among the margaritiferids (e.g., eastern pearlshell, *Margaritifera margaritifera*, up to 200 years [Mutvei et al. 1994]; Louisiana pearlshell, *M. hembeli*, up to 75 years [Johnson and Brown 1998]). Baird (2000) aged 278 specimens of the spectaclecase in Missouri by sectioning the hinge ligament. The maximum age he determined was 56 years, but surmised that some large individuals may have been older. A very large specimen (9.25 inches) from the St. Croix River, Minnesota and Wisconsin, was estimated (qualitatively based on external growth rings counts) to be aged at ~70 years (Havlik 1994).

Most mussels, including the spectaclecase, generally have separate sexes. Age at sexual maturity was estimated to be 4-5 years for males and 5-7 years for females (Baird 2000). He examined 317 individuals from the Gasconade and Meramec Rivers in Missouri and found a sex ratio of 51.7% male and 48.3% female, a non-significant deviation from the expected 50:50. Males expel clouds of sperm into the water column, which 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 spectaclecase utilizes all four gills as a marsupium for its glochidia, although Howard (1915) thought the inner pair produced more glochidia. It is thought to be a short-term brooder, with glochidial release occurring from early April to late May in Missouri streams (Baird 2000). Both Howard (1915) and Gordon and Smith (1990) reported it as producing two broods, one in spring or early summer and the other in the fall, also based on Meramec River specimens. Baird (2000), however, found no evidence of two spawns in a given year.

Hermaphroditism may occur in the spectaclecase (van der Schalie 1966), although it is not generally reported in the literature, nor from Baird's (2000) life history study in Missouri. Another margaritiferid, the eastern pearlshell, has been shown to produce glochidia hermaphroditically (Bauer 1987). 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 spectaclecase, it may explain the occurrence of small, but persistent populations (e.g., in cold tailwaters receiving hypolimnetic discharges from large dams [Gordon and Layzer 1989]; 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). Spectaclecase conglutinates are flat and white, and some may be forked (Knudsen and Hove 1997, Baird 2000). They are otherwise variably shaped with simple branches or lobes that are 0.04-0.16 inches long on one or both sides and oriented at a 45E angle to the main axis of the conglutinate (Knudsen and Hove 1997). The angle of branches appears to be more acute in several conglutinates figured in Baird (2000). The dimensions of conglutinates from the Gasconade and Meramec Rivers, Missouri, measured 0.40-0.63 inches long and 0.10-0.15 inches wide (Baird 2000), while in the St. Croix River, Minnesota and Wisconsin, they measured 0.12-0.24 inches wide and 0.20-0.52 inches long (Knudsen and Hove 1997). The variable size of conglutinates was thought to be due to breakage upon release (Baird 2000). Conglutinates typically contain not only glochidia, but embryos and undeveloped ova as well. Based on eight Missouri specimens, the number of conglutinates released per individual varied from 53-88, with a mean of 64.5 (Baird 2000).

Spectaclecase glochidia are the smallest known for any North American mussel; they measure approximately 0.0024 inches in both length and height (Baird 2000). Tens to hundreds of thousands of the hookless glochidia may occur in each conglutinate. Total fecundity (including glochidia and ova) in Baird's (2000) Missouri study varied from 1.93-9.57 million per female. Fecundity is positively related to body size and inversely related to glochidia size (Bauer 1994). The reproductive potential of the spectaclecase is therefore phenomenal. However, the fact that extant populations are generally skewed towards larger adults, strongly indicates that survival rates to the adult stage must conversely be extraordinarily low.

Researchers in Minnesota have observed females in the lab and under boulders in the St. Croix River simultaneously releasing their conglutinates (Lee and Hove 1997). The conglutinates are entrained along a transparent, sticky mucous strand up to several feet in length (M.C. Barnhart, Southwest Missouri State University, pers. comm., 2002). Baird (2000) observed the release of loose glochidia and small fragments of conglutinates. Based on his observations, he hypothesized that conglutinates may typically contain mostly immature glochidia, and that conglutinates primarily with immature glochidia may be aborted when disturbed.

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. The host(s) for the spectaclecase is unknown, although over 60 species of potential fishes and amphibians have been tested in the lab during host suitability studies (Knudsen and Hove 1997, Lee and Hove 1997, Hove et al. 1998, Baird 2000, R.J. Neves, U.S. Geological Survey [USGS], pers. comm., 2002). Two of 690 wild-collected fish checked by Baird (2000) had spectaclecase glochidia attached to their gills. These fish were the bigeye chub, *Hybopsis amblops,*[1] and pealip redhorse, *Moxostoma macrolepidotum pisolabrum.*[1] However, these fish are not confirmed as hosts,

[1] Baird (2000) stated this species as being in the genus *Notropis*, but actually it should be assigned to *Hybopsis* (Warren et al. 2000). It was collected in the Meramec River, but not the Gasconade River, making it unlikely as a host for the spectaclecase (Baird 2000).

[2] Baird (2000) stated this species as being the shorthead redhorse, *M. macrolepidotum*, but failed to report whether he sampled the specimen from the Gasconade or Meramec River. Based on fish distributional information presented in Warren et al. (2000), *Moxostoma macrolepidotum pisolabrum* is the subspecies known from the Meramec River, although intergrades between this subspecies and *M. m. macrolepidotum* also occur in the Meramec. These

because the encycsted glochidia had not grown measurably. More importantly, glochidial transformation was not observed (Baird 2000). Salmoides (e.g., salmon, trout) and madtoms are the host fish for other margaritiferids (Baird 2000). Since there are no native salmoides co-occuring with the spectaclecase, it is unlikely that they serve as its hosts. Two of the three madtoms found in the Gasconade and Meramec Rivers were unsuccessfully tested for host suitability during Baird's (2000) study.

In other species of mussels, a few weeks are spent parasitizing 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. The fact that spectaclecase populations are oftentimes highly aggregated (see "Habitat requirements") with apparently many even-aged individuals indicates that glochidia may excyst simultaneously from a host (Gordon and Layzer 1989). Thus, the complex life history of the spectaclecase and other mussels has many weak links that may prevent successful reproduction and/or recruitment of juveniles into existing populations.

Habitat requirements: The spectaclecase is apparently more of a habitat specialist than are most mussel species. Primarily a large-river species, Baird (2000) noted its occurrence on outside river bends below bluff lines. It appears to most often inhabit riverine microhabitats sheltered from the main force of current. The occurrence of this species in the "Northwest Missouri Lakes" (Utterback 1915) is puzzling, but may have referred to seasonally flooded oxbow lakes along the Missouri River. It occurs in substrates from mud and sand to gravel, cobble, and boulders in relatively shallow riffles and shoals with slow to swift current (Buchanan 1980, Parmalee and Bogan 1998, Baird 2000). According to Stansbery (1967), this species is usually found in firm mud between large rocks in quiet water very near the interface with swift currents. Specimens have also been reported in tree stumps, root masses, and in beds of rooted vegetation (Stansbery 1967, Oesch 1984). Similar to other margaritiferids, spectaclecase occurrences throughout much of its range tend to be aggregated (Gordon and Layzer 1989), particularly under slab boulders or under bedrock shelves (Call 1900, Hinkley 1906, Buchanan 1980, Parmalee and Bogan 1998, Baird 2000), where they are protected from the current. Up to 200 specimens have been reported from under a single large slab in the Tennessee River at Muscle Shoals (Hinkley 1906). Unlike most species that move about to some degree, the spectaclecase may seldom if ever move except to burrow deeper, and may die from stranding during droughts (Oesch 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.

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intergrades are the only reported form of *M. macrolepidotum* in the Gasconade River.

Historical and current range: The distributional history of the spectaclecase presented in this section is detailed in tabular form in Appendix II. Information in Appendix II is presented by major river drainage (i.e., upper Mississippi, lower Missouri, Ohio, Cumberland, Tennessee, and 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 spectaclecase occurred throughout much of the Mississippi River system with the exception of the upper Missouri River system, the uppermost Ohio River system, the Cumberland and Tennessee River systems, and some lowland tributaries in the Mississippi Delta region of Mississippi and Louisiana. This species is known from the Mississippi, Ohio, and Missouri (see Appendix II, Footnote 1) main stems, and dozens of tributary streams rangewide. The spectaclecase was historically known from 45 streams in 15 states and 4 Service regions (Appendix III). In the order presented in Appendix II, these include by stream system (with tributaries) the following: upper Mississippi River system (Mississippi River [St. Croix (Rush Creek), Chippewa, Rock, Salt, Illinois (Des Plaines, Kankakee Rivers), Meramec (Bourbeuse, Big Rivers), Kaskaskia Rivers; Joachim Creek]); lower Missouri River system (Missouri River? [see Appendix II, Footnote 1] [Platte, River Aux Vases, Osage (Sac, Marais des Cygnes Rivers), Gasconade (Osage Fork; Big Piney River) Rivers]); Ohio River system (Ohio River [Muskingum, Kanawha, Green, Wabash Rivers]; Cumberland River system (Cumberland River [Big South, Caney Forks; Stones, Red Rivers]); Tennessee River system (Tennessee River [Holston, Nolichucky, Little, Little Tennessee, Clinch (Powell River), Sequatchie, Elk, Duck Rivers]); and lower Mississippi River system (Mulberry, Ouachita Rivers). The spectaclecase historically occurred in Alabama, Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Minnesota, Missouri, Nebraska (see Appendix II, Footnote 1), Ohio, Tennessee, Virginia, and Wisconsin. These states comprise Service regions 3 (Midwest), 4 (Southeast), 5 (Northeast, specifically southwestern Virginia), and 6 (Great Plains).

Current distribution: Populations of the spectaclecase were generally considered extant if live or FD specimens have been collected since the mid-1980s. Extant populations of the spectaclecase are known from 20 streams in 10 states and 3 Service regions (Appendix III). In the order presented in Appendix II, these include by stream system (with tributaries) the following: upper Mississippi River system (Mississippi River [St. Croix, (Rush Creek), Chippewa, Meramec (Bourbeuse, Big Rivers) Rivers]; lower Missouri River system (Gasconade [Big Piney River, Osage Fork] River); lower Ohio River system (lowermost Ohio River [Kanawha, Green Rivers]); Cumberland River system (Caney Fork); Tennessee River system

(Tennessee River [Clinch, Nolichucky, Duck Rivers]); and lower Mississippi River system (Mulberry, Ouachita Rivers). The 20 extant spectaclecase populations occur in the following 10 states (with streams): Alabama (Tennessee River), Arkansas (Mulberry, Ouachita Rivers), Illinois (Mississippi, Ohio Rivers), Iowa (Mississippi River), Kentucky (Ohio, Green Rivers), Minnesota (Mississippi, St. Croix Rivers; Rush Creek), Missouri (Mississippi, Meramec, Bourbeuse, Big, Gasconade, Big Piney Rivers; Osage Fork), Tennessee (Tennessee, Clinch, Nolichucky, Duck Rivers; Caney Fork), Virginia (Clinch River), West Virginia (Kanawha River), and Wisconsin (Mississippi, St. Croix, Chippewa Rivers).

Current and historical populations and population trends: During historical times, the spectaclecase was fairly widespread and locally common in many Mississippi River system streams based on collections made over 100 years ago (see Appendix II). 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 miscellaneous collections primarily from the Meramec, Gasconade, Clinch, Powell, and Nolichucky Rivers. However, assessing its relative abundance, particularly in historical times before its specialized habitat was generally known, is not an easy chore. Not surprisingly, again given its habitat, the spectaclecase is oftentimes absent from archaeological shell middens (e.g., Morrison 1942) and is generally difficult to find due to its habit of occurring under rocks or ledges, and burrowing deep into the substrate (Call 1900). The chance of casually finding it where population numbers are low is therefore remote.

The spectaclecase was considered a rare species by mussel experts as early as 1970 (Stansbery 1970, 1971), which represents the first attempt to compile a list of imperiled mussels. In their field guide to Midwestern mussels, Cummings and Mayer (1992), describe the spectaclecase as "widely distributed but absent from many areas where it formerly occurred." The American Malacological Union considers the spectaclecase to be threatened (Williams et al. 1993). Seven of the 20 streams (or big river reaches) considered to harbor extant populations of the spectaclecase are represented by single recent specimens (e.g., Chippewa, Ohio, Kanawha, Duck, Mulberry Rivers; Tennessee River below Guntersville Dam; Caney Fork), making them of questionable recovery importance, but contributing significantly to its imperilment status rangewide.

The last reported records for the spectaclecase in some streams occurred decades ago (e.g., Rock, Des Plaines, Kaskaskia, Platte, Wabash, Stones, Red, Little Rivers; River Aux Vases; Big South Fork) (Appendix II). Parmalee (1967) considered it to be "rare and of local occurrence" in Illinois in the 1960s, but that it had "[a]pparently already been extirpated from the Illinois and Kankakee Rivers." The only records known from some streams are relic specimens collected since circa 1975 (e.g., Marais des Cygnes, Muskingum, Elk Rivers).

Although quantitative historical abundance data for the spectaclecase 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 spectaclecase populations thought to be extant by stream system, as outlined in the "Current

Distribution" above.

Upper Mississippi River system

The spectaclecase was historically known from 14 streams in the Mississippi River system. Currently, only seven streams are thought to have extant spectaclecase populations in the system. The percentage of stream population losses in the Mississippi River system (7 of 14, 50%) is several percentage points less than that recorded rangewide (25 of 45, 56%).

Mississippi River main stem: Paul Bartsch conducted sampling at 140 upper Mississippi River sites in 1907. Although the work is unpublished, M. Havlik, Malacological Consultants, presented findings of Bartsch's survey work at the second annual meeting of the Freshwater Mollusk Conservation Society in Pittsburgh, Pennsylvania, in March 2001. Bartsch found the spectaclecase at approximately nine sites (i.e., 34, 36, 38, 65, 66, 70, 79, 88, and 102) from what is now Mississippi River Pools (MRP) 9-22 (K.S. Cummings, INHS, pers. comm., 2001). Grier (1922) sampled portions of what are now parts of MRP 4-6 finding 37 species, but failed to find the spectaclecase. Sampling mussels primarily with a dredge, M.M. Ellis in 1930 and 1931 floated the upper Mississippi River from Lake Pepin, Minnesota and Wisconsin, downstream to near the mouth of the Missouri River. In reporting Ellis' findings, van der Schalie and van der Schalie (1950) considered the spectaclecase to be so rare that it was simply "a matter of chance" to find one. None were found live in their study, despite the occurrence of 38 species from 86 sites that harbored mussels of a total of 254 sites sampled.

Sampling efforts over the past 25 years show the spectaclecase to be extremely rare. Havlik and Stansbery (1978) thought the spectaclecase had disappeared from the Prairie du Chien, Wisconsin area (MRP 8) in the 1920s. Thiel (1981) failed to locate living spectaclecase in the Wisconsin portion of the upper Mississippi River (between MRP 3-11) using brail and SCUBA, but reported dead shells in MRP 11. Whitney et al. (1996) recorded a single specimen collected from 1994-95 in MRP 15, for a density of 0.004/foot^2.

Today, the spectaclecase is thought to be extant in at least seven pools, albeit in very low numbers. Records include MRP 15 (Quad Cities area, Illinois and Iowa; last seen live/FD 1998, INHS museum number 22881), MRP 16 (Muscatine area, Iowa and Illinois; 1997, INHS 21355), MRP 19 (Nauvoo area, Illinois and Iowa; 1987, INHS 2989), MRP 22 (Quincy, Illinois and Hannibal, Missouri area; 1996, INHS 21446), MRP 23 (Saverton area, Missouri and Illinois; 1986, INHS 14762), MRP 24 (Louisiana area, Missouri and Illinois; 1987, INHS 14800), and MRP 26 (Clarksville area, Missouri and Illinois; 1984, INHS 2667). Populations may still persist in MRP 9 and MRP 10, where specimens were found in the early 1980s (D.J. Heath, Wisconsin Department of Natural Resources (WDNR), pers. comm., 2002). Survey work in the Minnesota portion of the Mississippi in 2001 located only a relic spectaclecase shell, in MRP 3 above the St. Croix River confluence (D.E. Kelner, Minnesota Department of Natural Resources, pers. comm., 2002). In general, upper Mississippi River spectaclecase population levels appear to have always been fairly small, difficult to locate, and are now of questionable long-term viability. Cummings and Mayer (1997a) considered the "sporadic and very rare" in the

Mississippi River bordering Illinois.

The spectaclecase 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"). Species diversity of mussels in the upper Mississippi has declined from historical times (Thiel 1981); this trend is likely to continue. Even if some level of spectaclecase recruitment was documented in the upper Mississippi, the status of this species is highly jeopardized. 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).

St. Croix River: The northernmost and one of the three most significant extant populations of the spectaclecase rangewide occurs in the St. Croix River, Minnesota and Wisconsin. The population is primarily found in the middle reaches of the river in Chisago and Washington Counties, Minnesota, and Polk and St. Croix Counties, Wisconsin. Havlik (1994) reported the spectaclecase in the St. Croix Wild River State Park portion of the river (approximately river miles [RM] 62-65) and the recruiting population below the Northern States Power Dam at St. Croix Falls, Wisconsin (dam located at approximately RM 52). Additional survey work in the lower river at Afton State Park (approximately RM 7-9) failed to find the spectaclecase (Havlik 1994).

Hornbach (2001) reported 68 live specimens from 4 of 16 river reaches. Relative abundance for the spectaclecase varied from 0.67% in reach 7 from RM 78-92 (20 live, 17 species), 0.008% in reach 8 from RM 63-78 (41, 24), 0.0006% in reach 10 from RM 42-52 (6, 33), and 0.003% in reach 11 from RM 40-42 (1, 21). Overall relative abundance would be much lower when all live mussels (n = 46,140) throughout the study area were considered. Reaches where the spectaclecase is extant are divided by the pool formed from the power dam at St. Croix Falls, with reaches 7 and 8 above the pool and reaches 10 and 11 below the dam.

A length frequency distribution bar graph for the spectaclecase in the St. Croix from an unpublished 1989 study by D.J. Heath was presented in Baird (2000). Specimens (n = 962) were fairly evenly distributed over the length scale, indicating multiple age classes including healthy numbers of young spectaclecase recruiting into the population. Baird (2000) used growth curves determined from his Missouri study to estimate the ages of Heath's spectaclecase specimens of known size in the St. Croix. The percentages of newly recruited individuals (i.e., $\leq$10 years of age) in the St. Croix was an astonishing 40%, considerably higher than that noted from the Gasconade (10.4%) and Meramec (2.8%) Rivers in Missouri, two other streams with abundant spectaclecase populations. The St. Croix spectaclecase population, while among the largest known, may also be the healthiest based on this metric. The spectaclecase is currently distributed from RM 15 to 118 and appears to be recruiting over the entire reach (D.J. Heath, WDNR, pers. comm., 2002). Numbers of apparently even-aged juveniles can be found under slab boulders.

The long-term health of St. Croix mussel populations may be in jeopardy, however. 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 spectaclecase and other mussel populations in the lower St. Croix. 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 (e.g., developmental activities and associated runoff, nutrient enrichment, other pollutants, recreational activities) to the spectaclecase (Vaughan 1997). Discharge flows from St. Croix River dams may also impact habitat for the spectaclecase.

Rush Creek: A tributary of the St. Croix River in Chisago County, Minnesota, Rush Creek empties into the river at approximately RM 80. The spectaclecase was discovered in the stream in the late 1980s. The population may well be dependent on the source population in the main stem St. Croix for continued survival.

Chippewa River: The Chippewa River is located in western Wisconsin. The spectaclecase is known from the Chippewa as a single specimen found in 1989. The specimen was located during a 78-site survey of the upper river, specifically from a less than 6-mile riverine reach below Chippewa Falls Dam (Balding and Balding 1996) No other specimens were located during “an extensive search in the area (Balding and Balding 1996)”. They stated that the spectaclecase “is a relic species not likely to be found in the Chippewa again.” An earlier study that surveyed 37 sites in the lower Chippewa failed to locate even a shell of the spectaclecase (Balding 1992). In addition, Balding (in litt., 2001) wrote that he had “much more data” on mussels in the Chippewa River collected since 1994, but reported no other spectaclecase specimens. It appears doubtful that the spectaclecase population in the Chippewa is viable. The tremendous sedimentation load in the Chippewa (Thiel 1981) has undoubtedly reduced suitable areas for this habitat specialist to exist, and may have contributed to its demise.

Meramec River: The Meramec River flows into the Mississippi River downstream of St. Louis in east-central Missouri. Its spectaclecase population represents one of the best remaining rangewide. In the late 1970s, Buchanan (1980) reported this species from 31 sites, 19 with live individuals. Live or FD individuals stretched from RM 17.5 to 145.7. Buchanan (1980) considered it to be “common” in the lower 108 miles of the Meramec, but “locally abundant” between RM 17.5 and 83.9. In 1997, Roberts and Bruenderman (2000) using similar sampling methods resurveyed the Meramec River system and also collected the spectaclecase from 31 sites, 21 represented by live specimens. They found their largest populations between RM 56.7 and 118.8.

When sites that yielded evidence of the spectaclecase during both surveys are compared (n = 17), the trend clearly shows that the spectaclecase was more common in the former survey (9 sites with higher population numbers in the late 1970s) than in the latter survey (5 sites with higher population numbers in 1997). At three sites, relic shells were found during both surveys. In the 1970s, Buchanan (1980) reported 465 live individuals at the 17 shared sites, while Roberts and Bruenderman (2000) recorded 198. A huge reduction in spectaclecase numbers (260 to 33) at

RM 59.5 accounted for the majority of the population decrease noted at shared collecting sites between the studies. However, confounding the population trend information in the Meramec was the fact that Roberts and Bruenderman (2000) found 3 sites unsampled by Buchanan (1980) with 500, 538, and 856 live individuals between RM 56.7 and 118.8, while the most specimens found at a single site in the earlier study was 260 (RM 59.5). Currently, the population in the Meramec stretches over much of the main stem, a distance of over 100 miles from RM 18.5 to 120.4. At Buchanan's (1980) upstream-most site for the spectaclecase (RM 145.7), he found fresh-dead shells, while Roberts and Bruenderman (2000) found only relic ones, making the spectaclecase reach of river similar over the 20-year period.

The spectaclecase represented 21% of all mussels sampled in the Meramec River (Roberts 1998). Baird (2000) extensively studied the demographics of the Meramec River spectaclecase population in the late 1990s. The mean estimated age of the population was 32 years. Individuals less than 10 years of age comprised only 2.8% of the Meramec population sampled (n = 2,983). Densities at the 4 sites he intentionally selected for their large spectaclecase populations ranged from 0.01-0.12/foot^2 while estimated population numbers at these selected sites ranged from 933-22,697. Baird (2000) thought that conditions for spectaclecase recruitment in the Meramec have apparently declined in the past 20-30 years, but that causes were undetermined. The preponderance of larger adults in the Meramec population may be cause for concern.

Detailed information on threats to the mussel communities of the Meramec River system (including the tributaries Bourbeuse and Big Rivers discussed below) was 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; they documented the loss of suitable stable habitat and mussel beds at many sites in the system where mussels occurred in the late 1970s. Particularly noteworthy is their 1999 report of a zebra mussel in the lower main stem. Recreational and commercial boating in the Meramec could enable zebra mussels to spread upstream into spectaclecase 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. Its spectaclecase population was sampled in 1997 at a single site (RM 10.3), and 7 live individuals were found. Sampling very near the mouth (RM 0.4), Buchanan (1980) found only relic shells in the Bourbeuse. The population may be dependent upon the much larger Meramec population for long-term sustainability.

Big River: Another Meramec tributary with a population of the spectaclecase, the Big River flows northward into the Meramec at RM 38. It is only known from the extreme lower end (RM 1.3), where 14 live specimens were sampled in 1997. At RM 0.4, Buchanan (1980) found only relic shells. Similar to the Bourbeuse, the population in the Big may be dependent upon the much larger Meramec population for sustainability. The Meramec River system, including the lower Bourbeuse, lower Big, and Meramec main stems, can be considered a single spectaclecase metapopulation.

Lower Missouri River system

The spectaclecase was historically known from 10 streams in the Missouri River system. Currently, only three of these streams are thought to have extant spectaclecase populations. The percentage of stream population losses in this river system (7 of 10, 70%) is considerably higher than that recorded rangewide (25 of 45, 56%).

Gasconade River: The Gasconade River is a southern tributary of the Missouri River, south central Missouri, flowing into the main stem east of Jefferson City. When Stansbery (1970) included this species in the first compiled list of imperiled mussels, he noted that “the only population of substantial size presently known is found in the Gasconade River.” Today, one of the three best spectaclecase populations remaining rangewide occurs in the Gasconade. The spectaclecase population occurs over approximately 200 miles of the main stem from RM 4.9 upstream (Bruenderman et al. 2001). Baird (2000) extensively studied the demographics of the Gasconade River spectaclecase population in the late 1990s. Based on his albeit limited number of sampling sites, this species comprised about 20% of the entire mussel fauna in this system. The mean estimated age of the population was 25 years. Individuals less than 10 years of age comprised 10.4% of the Gasconade population sampled (n = 2,111), indicating a significant level of recent recruitment.

Historically, Stansbery (1967) noted that “[t]he size of some aggregation[s]...is impressive,” and that “the number of individuals may reach a density of well over a dozen per square foot.” Both statements are probably in reference to the Gasconade River, Missouri population, which he had described in the text of his note. Densities at the four sites Baird (2000) intentionally selected for their large spectaclecase populations ranged from 0.03-0.06/foot$^{2;}$ estimated population numbers at these selected sites ranged from 2,156-4,766. He thought that conditions for spectaclecase recruitment in the Gasconade had apparently declined in the past 20-30 years, but that causes were undetermined. The prevalence of larger adults in the population may be cause for long-term concern.

Threats to the spectaclecase in the Gasconade were outlined by Bruenderman et al. (2001). They noted that some mussel populations were fragmented by habitat degradation, primarily a result of channel instability from historical land-use practices. Stream sites with this type of unsuitable habitat were characterized by wide, shallow channels with shifting pea-sized gravel. Mid-channel substrates at most sites in the system were generally unstable and lacked mussels. Nutrient enrichment from expanding cattle production in the watershed, particularly evident downstream from the confluence of and in the Big Piney, was also deemed a major problem for mussel populations. Luxuriant growths of aquatic vegetation in this area were attributed to over-enrichment. Bruenderman et al. (2001) thought that cattle production in the system was expanding as evidenced by conversion of forests to pastures and by the increasing number of confined animal feeding operations (i.e., dairy, beef cattle; hogs; poultry) in the basin (Blanc 2001). Cattle were frequently observed on streambanks and in stream channels, sometimes directly on mussel beds. Excessive growths of filamentous algae were also a common sight, oftentimes associated with cleared riparian areas having unrestricted cattle access. Wastewater effluents from several municipal and industrial sources were also noted. Gravel dredging is also a problem in the Gasconade. Dozens of permitted sites have been documented in the system. Zebra mussels are not currently thought to be in the Gasconade. However, they are in the Missouri River, and their potential colonization should be closely monitored.

Big Piney River: The Big Piney River, a southern tributary of the Gasconade, harbors a small population of the spectaclecase, last collected in 1993 in the lower main stem (S.A. Bruenderman, Missouri Department of Conservation [MDC], pers. comm., 2002). The persistence of this population is questionable, since no sign of the spectaclecase was found during Bruenderman's (2001) survey work at ten stream sites. If viable, it may be dependent on the much larger source population in the Gasconade for sustainability (S.A. Bruenderman, MDC, pers. comm., 2002).

Bruenderman et al. (2001) summarized threats to mussel populations throughout the Gasconade, River system, and particularly noted that the Big Piney had unstable substrates from massive gravel bedloads associated with poor land-use practices in portions of the stream. They also stated that nutrient enrichment was a particular problem in the lower portion of the river where the only spectaclecase population occurs. Ft. Leonard Wood and other sources of wastewater effluents were thought to be a significant contributor of over-enrichment in this river.

Osage Fork: The Osage Fork is a southwestern headwater tributary of the Gasconade River. The spectaclecase is known from the lower portion of this Gasconade River tributary, specifically from a single site (RM 13.9). Sampling in the Osage Fork in 1999 yielded 26 specimens from this site (Bruenderman et al. 2001). Relative abundance in the Osage Fork was 3.9%, and CPUE was 1.3/person hour. This population is thought to be viable, but it may also be dependent on the much-larger source population in the Gasconade for long-term sustainability. In summarizing threats to mussels in the Gasconade River system, Bruenderman et al. (2001) noted the prevalence of unstable substrates from substantial gravel bedloads associated with poor landuse practices in the Osage Fork. The Gasconade River system, including the lower Big Piney, lower Osage Fork, and Gasconade main stems, can be considered a single spectaclecase metapopulation.

Ohio River system

Ohio River: The Ohio River in 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 spectaclecase was documented from the Ohio River from the vicinity of Cincinnati, Ohio, to its mouth. Although no specimens are known upstream of Cincinnati in the main stem, a single relic valve is known from a tributary, the Muskingum River (OSUM 1995:0241), located well upstream of Cincinnati. Nearly all spectaclecase records from the Ohio were made circa 1900 or before (Schuster 1988). The lone recent record is for a single live specimen found, paradoxically, in a balled-up gill net abandoned near the Illinois shore in 1994 (K.S. Cummings, INHS, pers. comm., 2001). If a population of the spectaclecase continues to occur in the Ohio River, its viability is extremely doubtful and continued existence seriously threatened by the zebra mussel.

Kanawha River: The Kanawha River is a major southern tributary of the Ohio River draining much of West Virginia. The spectaclecase was not known from this stream until 2002 when a single, very old specimen was discovered near Glasgow, Kanawha County (G. Zimmerman, EnviroScience, Inc., pers. comm., 2002). This site is approximately 20 miles downstream of Kanawha Falls, below which is the only significant mussel bed known from the Kanawha River. It is highly doubtful that a viable spectaclecase population occurs in the Kanawha. Threats to the spectaclecase include sedimentation, mine runoff, and developmental activities in the narrow band of bottomlands along the deeply entrenched Kanawha River. 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).

Green River: The Green River is a lower Ohio River tributary in west central Kentucky. The Green historically had the most mussel species known from a single site outside of the Tennessee River. The spectaclecase has been collected sparingly in the Green River. As evidence for the difficulty in finding specimens of the spectaclecase, it was not reported in early collections made in the system (Price 1900, Ortmann 1926, Clench and van der Schalie 1944). Stansbery (1965) was the first to find it in the mid-1960s at Munfordville, Hart County, where he reported an astonishing 47 species collected over a several-year period in the early 1960s. More recently, Cicerello and Hannan (1990) reported single FD specimens at six sites from 1987-89, and relic specimens from an additional five sites in Mammoth Cave National Park (MCNP). The only recent live record for this species was a single specimen from MCNP, Edmonson County, in 1995. Sampling conducted from 1996-98 located FD specimens at two sites above MCNP, with a relic shell at a third site further upstream (Cicerello 1999). At least one FD specimen was reported from MCNP in 2001, suggesting that the spectaclecase still occurs there (J.B. Layzer, USGS, pers. comm., 2002).

A small spectaclecase population remains in the upper Green River from below Lock and Dam 5 upstream through MCNP, Edmonson County, into western Hart County. Most recent specimens have been reported from the upstream portion of this reach, where it is generally distributed from MCNP upstream to western Hart County. Its distribution is much more sporadic and localized in the lower portion of this reach due to the two lock and dam pools (5 and 6). A concerted effort (~15 person/hours) to locate rare mussels below Lock and Dam 5 and at other sites downstream in 2001 failed to reveal a single spectaclecase shell. However, a FD shell was found ~2 miles downstream a week before this intensive effort. The occurrence of variable-sized individuals in the 1990s indicates different year classes, but not necessarily recent recruitment (R.R. Cicerello, Kentucky State Nature Preserves Commission, pers., comm., 2002). The long-term viability of the Green River population, primarily limited to an approximately 15 mile stretch of river, is therefore questionable.

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 agricultural runoff to 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.

Cumberland River system

With few exceptions, most records of the spectaclecase in the Cumberland River were made prior to the 1920s. It was historically known from the main stem and four tributaries. The spectaclecase was considered "not rare" in the Cumberland River by Hinkley and Marsh (1885), while Ortmann (1924) reported that rangewide it "seems to be most abundant in the Cumberland and Tennessee drainages." It was found at six sites by Wilson and Clark (1914) during their survey primarily for commercial species in the Cumberland River system. In a 1947-49 survey of the Kentucky portion of the upper Cumberland River, Neel and Allen (1964) reported live specimens only from one of six main stem sites they sampled below Cumberland Falls. They considered it to be "uncommon" in the lower Cumberland River (where they did not sample), a statement possibly based on its sporadic occurrence as reported by Wilson and Clark (1912). One of the last main stem records is that of a single live specimen found in the cold tailwaters of Wolf Creek Dam, Kentucky, near the Tennessee border in 1982 (Miller et al. 1984). This was one of only two live mussels found during a survey of the dewatered river reach below the huge dam. Sadly, the Caney Fork may have the only surviving spectaclecase population in the entire Cumberland River system.

Caney Fork: The Caney Fork is a major tributary of the middle Cumberland River in central Tennessee. The only recent spectaclecase record from the entire Cumberland River system is limited to a single specimen located in the lower Caney Fork below Center Hill Dam, a coldwater release. Layzer et al. (1993) surmised that the size and condition of the specimen possibly indicates that the spectaclecase recruited "albeit limitedly" since the time the dam was closed in 1948. However, it is possible that the species recruited from the population that persisted in the nearby main stem Cumberland until the 1980s. No other information on the spectaclecase in the system is known. If a population remains in the Caney Fork, it s highly threatened by widely fluctuating water levels, bank scouring, and cold water releases from the high wall Center Hill dam. The viability of the spectaclecase in the Caney Fork is therefore very questionable.

Tennessee River system

The spectaclecase was originally known from the Tennessee River and eight of its stream systems. Ortmann (1924) reported that the spectaclecase "seems to be most abundant in the Cumberland and Tennessee drainages, including the upper Tennessee," while acknowledging its presence elsewhere in its range (e.g., upper Mississippi, Ohio, lower Wabash, lower Illinois, Osage, Ouachita Rivers). In an earlier paper, Ortmann (1918) reported the spectaclecase as being "locally abundant" in parts of the upper Tennessee River system, but noted that it was "generally regarded as a rare species."

Hundreds of miles of large river habitat on the Tennessee main stem has 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 spectaclecase rangewide. Today, at least one stream population of the four remaining appears to be viable, while another has shown evidence of recent recruitment.

Tennessee River main stem: 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). The spectaclecase population in historical times must have been phenomenal given the amount of historical habitat that was apparently available and literature accounts of the period. Hinkley (1906) in 1904 considered it "plentiful," noting 200 specimens under a single slab boulder. Twenty years later, Ortmann (1924) stated that "this species must be, or have been, abundant" at Muscle Shoals based on the "considerable number of dead shells" he observed. In these quotes he prophesied the demise of the spectaclecase. The construction of three dams (i.e., Wilson in 1925, Wheeler in 1930, and Pickwick Landing in 1940) inundated most of the historical habitat, leaving small habitat remnants (Garner and McGregor 2001). The largest remnant habitat remaining is the Wilson Dam tailwaters, a several-mile reach adjacent to, and downstream from, Florence, Alabama.

Interestingly, with the exception of 1976-78 when it was "collected infrequently" from below Wilson Dam (Gooch et al. 1979), no collections of the spectaclecase were reported at Muscle Shoals from 1931 until 1995 (this despite surveys conducted in 1956-57, 1963-64, and 1991; Garner and McGregor 2001). A juvenile specimen has recently been observed (J.T. Garner, Alabama Department of Natural Resources [ADNR], pers. comm., 2002), indicating some, probably low level of population viability.

Elsewhere along the Tennessee main stem, a specimen has recently been reported from the Guntersville Dam tailwaters in northern Alabama. From 1997-99, 10 live, 1 FD, and 4 relic spectaclecase specimens have been reported from 3 sites in this river reach based on OSUM records. The species is found only occasionally in the lower Tennessee River below Pickwick Landing Dam in southeastern Tennessee. Unreported in various surveys (e.g., van der Schalie 1939, Scruggs 1960, Bates and Dennis 1981), Yokley (1972) considered it "rare," having only found fresh-dead specimens in his three-year study. Hubbs and Jones (2000) reported two live specimens found in 1998 at RM 170, Hardin County. The viability status of these small populations is uncertain (J.T. Garner, ADNR; D.W. Hubbs, Tennessee Wildlife Resources Agency [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 spectaclecase population. Other threats include gravel mining and navigational channel maintenance activities

(D.W. Hubbs, TWRA, pers. comm., 2002).

Clinch River: The Clinch River is a major tributary of the upper Tennessee River in southwestern Virginia and northeastern Tennessee. Böpple and Coker (1912) noted the occurrence of numbers of spectaclecase shells in muskrat middens in a portion of the Clinch now inundated by Norris Reservoir. Ortmann (1918) reported the spectaclecase as being "locally abundant" in the lower Clinch, again in an area mostly flooded by the reservoir. Oddly, he failed to find this species above Claiborne County (upstream of Hancock County, Tennessee). Yet, in later years, the spectaclecase's fourth largest known population occurs in the reach of river from Hancock County, Tennessee, upstream. Scores of records are known. The species was locally common at sites in the upper Clinch, according to OSUM records from the 1960s. Ahlstedt (1991a) considered this species to be "relatively rare" in the Clinch based on survey work conducted during 1978-83. He recorded 78 live specimens from 22 sites between RMs 151-223, for an average of 3.5/site. The spectaclecase population reported by Ahlstedt (1991a) from the lower Clinch between Melton Hill and Norris Dams (11 specimens from 4 sites between RMs 45-73) was considered to be "small but viable" at least at the upstream site he sampled circa 1980. Once considered abundant in the Clinch at Speers Ferry, Scott County, Virginia (Bates and Dennis 1978), the species is now "extremely rare" at this site (Neves 1991).

Currently, the species is locally common in the Tennessee River system only in the upper Clinch River, and populations are primarily restricted to the Tennessee portion of that stream. Despite extremely low numbers (0.02/foot^2) detected in quantitative sampling (428, 2.7^2 foot quadrats) in 1994 (Ahlstedt and Tuberville 1997), slab boulders in the upper Clinch in Tennessee may still yield two to three dozen specimens. The upper Clinch population is considered viable, with fairly young juveniles occasionally being found (S.A. Ahlstedt USGS, pers. comm., 2001). The continued occurrence of a disjunct population from the lower Clinch River was recently verified, separated from the upper Clinch population by Norris Reservoir. The specimens sampled appear to have recruited since the closing of Norris Dam in the mid-1930s (S.J. Fraley, North Carolina Wildlife Resources Commission [NCWRC], pers. comm., 2001), despite the cold tailwaters that destroyed the vast majority of the mussel fauna in this once incredibly diverse river reach.

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 River (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).

Nolichucky River: The Nolichucky River is a tributary of the lower French Broad River, in the upper Tennessee River system in Tennessee. The spectaclecase was discovered in this river by H.D. Athearn in 1954. The population was once sizable, judging from museum lots (e.g., 23 FD, OSUM 1971:0372). Sampling at 41 Nolichucky sites in 1980, Ahlstedt (1991a) reported 8 live specimens from 6 sites from RM 11.4-31.9. A small population of the spectaclecase persists in a relatively short reach of the lower Nolichucky River, Tennessee (S.A. Ahlstedt, USGS, pers. comm., 2002). This population is highly isolated from others in the Tennessee River system, and its viability is questionable. It appears to be threatened by reduced habitat in the form of a significant sedimentation load embedding the boulders and ledges preferred by this species (S.A. Ahlstedt, USGS, pers. comm., 2002) and nutrient enrichment, manifested in dense growths of aquatic vegetation..

Duck River: The Duck River is the downstream-most significant tributary of the Tennessee River, joining it in the headwaters of Kentucky Reservoir. A single specimen of the spectaclecase, representing a new drainage record, was found live in the lower Duck in 1999 (Hubbs 1999). Since then, relic specimens have been found at several other sites in the lower Duck (D.W. Hubbs, TWRA; J.R. Powell, USGS, pers. comm., 2002). These records stretch over an approximately 20-mile reach of river, with the live specimen reported from the lower end of this reach. The species is also known from the nearby Tennessee River in the headwaters of Kentucky Reservoir below Pickwick Landing Dam (see account above). The spectaclecase must be considered extremely rare in the Duck, and its viability status is unknown. Excessive sedimentation is a concern in the lower Duck River.

Lower Mississippi River system

The spectaclecase was apparently never widely distributed in the lower Mississippi River system. Only two stream records are known, both from Arkansas.

Ouachita River: The Ouachita River is a major western tributary of the lower Mississippi in Arkansas and Louisiana. This species was first reported in this portion of its range from the Ouachita River, southwestern Arkansas, in the early 1900s (Wheeler 1918). Spectaclecase records in the Ouachita span a three-county reach of river. Only two live specimens have been found in the mid-1990s, both in the lower portion of the spectaclecase reach in Ouachita County. Relic shells were also found in Montgomery County, at the upper end of its Ouachita range in 2000 (S. Rogers, Service, pers. comm., 2001). Threats include bauxite and barium sulfate mining activities and sedimentation. The population is considered very small and non-viable (J.L. Harris, Arkansas Highway and Transportation Department [AHTD], pers. comm., 2001).

Mulberry River: The Mulberry River is a tributary of the Arkansas River in northwestern Arkansas. The only other record of the spectaclecase in the lower Mississippi River system is a single specimen found in the mid-1990s in the Mulberry. There is some uncertainty regarding the validity of this record, as the collectors were not experienced malacologists, and no specimen nor photograph are available to substantiate the record. However, J.L. Harris (AHTD, pers. comm., 2001), a long time Arkansas malacologist, has accepted this record as valid. The status of the spectaclecase in the Mulberry is unknown.

Summary of Extant Populations: The spectaclecase appears to be declining rangewide, with the possible exception of a few significant populations. Its occurrence in the St. Croix, Meramec, Gasconade, and Clinch Rivers represent the only sizable viable populations remaining rangewide. Recent recruitment has also been documented in the Tennessee River below Wilson Dam in Alabama. The spectaclecase has been eliminated from three-fifths of the total number of streams from which it was historically known from (20 streams currently compared to 45 streams historically). This species has also been eliminated from long reaches of former habitat in hundreds of miles of the Illinois, Ohio, Cumberland, and other rivers, and from several reaches of the Mississippi and Tennessee Rivers. In addition, the species is no longer known from the States of Ohio, Indiana, Kansas, and Nebraska (see Appendix II, Footnote 1). The extirpation of this species from numerous streams within its historical range indicates that substantial population losses have occurred. Given this compilation of current distribution, abundance, and trend information, the relative imperilment of the spectaclecase is clear.

Summary of status and threats:
A. The present or threatened destruction, modification, or curtailment of its habitat or range. The decline of the spectaclecase 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 spectaclecase 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; and decreasing stability due to subsequent sedimentation. The reproductive process of riverine mussels is generally disrupted by impoundments making the spectaclecase unable to successfully reproduce and recruit under reservoir conditions. Limited recruitment, however, is thought to be occurring in large river pools behind locks and dams.

In addition, dams can also seriously alter downstream water quality and riverine habitat, and negatively impact tailwater mussel populations (Allan and Flecker 1993, Layzer et al. 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 silt 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). There is some evidence that the spectaclecase may experience low levels of recruitment in hypolimnetic tailwater conditions (Gordon and Layzer 1989); however, such habitat is far from optimal for this species.

Population losses due to impoundments have probably contributed more to the decline and imperilment of the spectaclecase and other Mississippi River system mussels than has any other single factor. Large river habitat throughout nearly all of the range of the spectaclecase 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 are now impounded; these reaches were once strongholds for the spectaclecase (Ortmann 1924). 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 the Tennessee Valley Authority (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 adversely affected by coldwater releases. Other major U.S. Army Corps of Engineers (Corps) impoundments on Cumberland River tributaries (e.g., Stones River, Caney Fork) have inundated over 100 miles of additional potential riverine habitat for the spectaclecase. 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 spectaclecase. One-third of the streams that the spectaclecase 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. 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, Green, Muskingum Rivers), many low-head dams (e.g., St. Croix, Chippewa Rivers), and some high-wall dams (e.g., Kaskaskia, Osage Rivers), that have contributed to the loss of spectaclecase habitat. Sediment accumulations behind dams of all sizes generally preclude the occurrence of the spectaclecase.
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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 events 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, which may smother benthic organisms.

Channel maintenance operations for barge navigation have impacted habitat for the spectaclecase in many large rivers rangewide. Periodic maintenance may continue to adversely affect this species in the upper Mississippi River, lower Ohio River, and Tennessee River. 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 spectaclecase 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). Bogan and Parmalee (1983) considered the spectaclecase “apparently...unable to survive even minimal amounts of organic pollution or chemical waste.”

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 spectaclecase 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 spectaclecase.

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 spectaclecase 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 spectaclecase 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 1991a), 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, which were 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 two federally listed species, were estimated lost (B. Tolin, Service, pers. comm., 2002). Chemical spills will invariably continue to occur and have the potential to completely eliminate spectaclecase 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 spectaclecase. 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, 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).

Various mining activities take place in other systems that potentially impact current spectaclecase populations. For instance, bauxite and barium sulfate are extracted in the Ouachita River system. 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, which 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). The spectaclecase population in the Big is restricted the lowermost portion of the river. These impacts may have contributed to a reduction of spectaclecase range in the Big River.

In-stream 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). Gravel mining activities may be a localized threat in some large rivers with extant spectaclecase populations. For instance, in the lower Tennessee River where a spectaclecase population survives, gravel mining is permitted at 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 species in recent years. These activities have the potential to impact the river's precarious spectaclecase 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, Markings 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, which 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 spectaclecase, appear to be experiencing recruitment failures.

Many Midwestern and Southeastern streams have increased turbidity levels due to siltation. The spectaclecase 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 spectaclecase 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 to an increase in cattle grazing and loss of riparian vegetation along the stream, among other factors. These impacts may potentially affect the spectaclecase 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, which threatens its spectaclecase population. Despite the level of protection provided to the St. Croix River by the St. Croix National Scenic Riverway (SCNSR), the spectaclecase 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 spectaclecase and other mussel populations susceptible to depressed stream levels.

B. Overutilization for commercial, recreational, scientific, or educational purposes.
Native Americans consumed large quantities of mussels (Morrison 1942, Bogan 1990). However the spectaclecase, due to its habitat preferences, represents insignificant portions of their shell middens. Although not included in a list of the most actively sought species for pearls constructed by Anthony and Downing (2001), the spectaclecase was probably sacrificed for this purpose during several decades circa 1900. 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. They even document a decline in the spectaclecase population at a site where fisherman used them for bait. 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. 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 therefore unlikely that exploitation activities have eliminated any spectaclecase populations.

The spectaclecase is not a commercially valuable species, but may be increasingly sought by collectors with its increasing rarity. 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 over-collecting, 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. Böpple and Coker (1912) noted the occurrence of "large piles of shells made by the muskrats" on an island in the Clinch River, Tennessee, composed of "about one-third" spectaclecase shells. Predation by muskrats may represent a seasonal and localized, but probably not a significant threat to the spectaclecase. 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 spectaclecase is not thought to be significant.

D. The inadequacy of existing regulatory mechanisms. Most states with extant spectaclecase 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.

Existing authorities available to protect riverine ecosystems may not have been utilized, such as the Clean Water Act (CWA), administered by the Environmental Protection Agency and the Corps. This may have contributed to the general habitat degradation apparent in riverine ecosystems and loss of populations of aquatic species in the Midwest and Southeast. Although the spectaclecase coexists with other federally listed mussels and fishes throughout most 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 spectaclecase 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. 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 spectaclecase 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 spectaclecase populations rangewide, a potential condition exacerbated by its reduced range and increasingly isolated populations. If these trends continue, further significant declines in total spectaclecase population size and consequent reduction in long-term viability may soon become apparent. The present distribution and status of the spectaclecase 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 spectaclecase 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 spectaclecase (see "Description, Biology, and Life History" section above), would potentially take decades to expire post-impoundment. Given the occasional occurrence of relatively young specimens of this species between certain impoundments (e.g., lower Clinch River), limited post-impoundment recruitment is thought to be occurring. However, the level of recruitment in these cases indicates that these small populations are probably not long-term viable. 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 spectaclecase. The fact that only 20 of 45 streams of historical occurrence continue to harbor populations of the spectaclecase may be testimony to this phenomenon.

Alien Species

Various alien or nonnative species of aquatic organisms are firmly established in the range of the spectaclecase. The alien species that poses the most significant threat to the spectaclecase 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 in which zebra mussels impact native mussels. The primary means of impact is direct fouling of the shells of live native mussels; zebra mussels attach 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 in which zebra mussels 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 spectaclecase, zebra mussels are thoroughly established in the upper Mississippi, St. Croix, Ohio, and Tennessee Rivers. 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 extent to which they will impact the spectaclecase in most areas is largely unknown. The greatest potential for present zebra mussel impacts to the spectaclecase 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 undoubtedly reduced spectaclecase 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, spectaclecase 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 spectaclecase 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 non-sterile black carp are 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 spectaclecase was first given conservation status by Stansbery (1970, 1971) before the Endangered Species Act (Act) was legislated. The Nature Conservancy has given it a global rank of G2G3. Although sub-national ranks vary from S1-S3, the majority are S1. This species is State-listed in 8 of the 10 states that are thought to harbor extant populations. Only in Missouri and Tennessee is this species not assigned conservation status. The level of protection it receives from State-listing varies from state to state. The American Malacological Society and American Fisheries Society consider the spectaclecase 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 spectaclecase or in their respective watersheds. However, vast tracts of riparian lands in spectaclecase streams are privately owned. The spectaclecase 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 land-use 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 spectaclecase populations.

The St. Croix River population of the spectaclecase receives protection by being located in the SCNSR, Minnesota and Wisconsin. The SCNSR completely overlaps the range of the spectaclecase in the St. Croix. 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 (e.g., Chengwatana, Governor Knowles, St. Croix State Forests; Minnesota Interstate, St.

Croix, St. Croix Wild River, William O'Brien, Wisconsin Interstate State Parks; St. Croix Islands Wildlife Area; Rock Creek Wildlife Management Area) lie adjacent to some sections of the SCNSR providing additional buffering lands along the St. Croix. Numerous other public lands occur in the St. Croix watershed.

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 Muscatine, Iowa. Between Muscatine and Keithsburgs, 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.

Parts of the lower Big Piney River and significant reaches of the upper Gasconade River flow adjacent or through the Mark Twain National Forest; the lower Big Piney also flows through Ft. Leonard Wood Military Reservation. 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.

The Nature Conservancy (TNC) has created bioreserves along two stream systems harboring extant populations of the spectaclecase: the upper Clinch/Powell River, Tennessee and Virginia; and upper Green River, Kentucky. 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 spectaclecase, 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 spectaclecase 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:
Conservation activities that would benefit the species include Funding Programs, Research and Surveys, Management, Outreach, and Habitat Improvements and Conservation.

< Funding Programs:
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 spectaclecase populations. For instance, specific watershed level projects that have benefited habitat for the spectaclecase 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 spectaclecase 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 spectaclecase population.

Several settlements from large chemical spills are currently being negotiated (J. Schmerfeld, Service, pers. comm., 2002). Money from these court cases has the potential to fund significant recovery-type projects benefiting a suite of imperiled species like the spectaclecase. 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.

< Research and Surveys:
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 large spectaclecase population. Participants annually present their research, which are regularly 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 has 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 in-stream habitat in the Green. These efforts may pay dividends in improving conditions for the spectaclecase and a host of other imperiled aquatic organisms in the upper Green River.

Survey work continues in many portions of the range of the spectaclecase. Information gathered from these surveys will help determine its population status, and generates other data useful for conservation management and recovery efforts.

A project has been funded in 2002 by the Service to study the genetics of the large extant populations of spectaclecase. With funding from Service Regions 3, 4, and 5, this project represents a coordinated efforts among three Service ecosystems (i.e., Lower Tennessee Cumberland, ORVE, Southern Appalachian). The work is being conducted at Miami University of Ohio, D. Berg, principal investigator. Information gathered from this study will aid managers in selecting source populations for potential reintroduction efforts and determine the genetic variability between and within populations of this species.

< Management:

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, which further species recovery goals. Species of concern and candidate species, such as the spectaclecase, 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 spectaclecase have made imperiled mussels a high priority resource for conservation. The Ohio River Valley Ecosystem (ORVE), Mollusk Subgroup, put the spectaclecase 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 spectaclecase.

< Outreach/Education:

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, which comprises 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.

Habitat Improvements and Conservation:

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 spectaclecase 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.

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 spectaclecase:

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

< **Prioritize streams & watersheds:** 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 accessibility; likelihood for success; and low resilience to disturbance.

< **Involve local communities:** 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 spectaclecase 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.

< **Seek funding:** Seeking funding from various sources will be crucial in the recovery of the spectaclecase. 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 spectaclecase and other mussels.

< **Implement Best Management Practices on riparian lands:** 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 spectaclecase.

< **Initiate more habitat restoration programs:** More watershed level, community-based riparian habitat restoration projects should be initiated in high biodiversity streams harboring the spectaclecase (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.

< **Adjust numerical criteria for pollutants:** Where current numerical criteria of certain pollutants may not be protective of the spectaclecase and other mussels, these standards should be adjusted to better conserve mussel resources.

< **Monitor population & habitat conditions:** 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 spectaclecase populations.

< **Reduce impacts of mining:** 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 spectaclecase habitat.

< **Increase public outreach & education:** 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 spectaclecase populations or in unoccupied habitat essential for its recovery.

< **Conduct stress analyses**: Stress analyses should be undertaken in at least those watersheds with significant extant spectaclecase populations. The purpose of a stress analysis is to determine the entire suite of stressors to the spectaclecase 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.

< **Establish a GIS database:** 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 (a) to complete the status assessment and allow for an informal listing decision and (b) to bring about recovery:

(a) to complete the status assessment and allow for an informal listing decision
Additional survey work may be warranted in some river systems. 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 spectaclecase for consideration for candidate status.

(b) to bring about recovery

< **Determine host organisms:** Foremost among the recovery needs for the spectaclecase is to determine its host organism. Dozens of fishes have been tested over the past several years (see "Summary of biology and natural history"). Without knowing its host, laboratory propagation efforts will be futile, thus reducing our options for reintroducing populations into historical habitats.

< **Develop propagation technology:** Once the host has been determined for the spectaclecase, propagation technology 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.

< **Research species life history & habitat needs:** Some information is available with regard to the life history of the spectaclecase. However, much additional life history information in addition to determining its host species will be needed in order to successfully implement the recovery tasks. In addition, spectaclecase habitats (e.g., relevant physical, biological, chemical components) for all life history stages need to be elucidated. The sensitivity of each life history stage to contaminants and general threats to the species also need investigating.

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

< **Develop parameters for species augmentations:** A set of biological, ecological, and habitat parameters will need to be developed to determine if an extant spectaclecase population will be suitable for species augmentation. This is particularly important in habitats that may be considered marginal (e.g., where the spectaclecase 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.

< **Develop parameters for species reintroductions:** A set of biological, ecological, and habitat characterization parameters will need to be developed to determine if a site will be suitable for spectaclecase 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.

< **Survey for additional populations:** The loss of much of its historical habitat, coupled with past and ongoing threats, clearly indicates the heightened level of imperilment of the spectaclecase. However, survey work to search for potentially new spectaclecase 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. Optimal habitat (e.g., under large slab boulders, rock shelves) may need to be searched more extensively to assess its population status for recovery purposes. These streams should be prioritized in order of importance to achieve this recovery goal with limited funding resources.

< **Determine potential taxonomic distinction of populations:** A rangewide phylogenetic study on the spectaclecase 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 or the Ouachita River, represent undescribed taxa. Endemic aquatic organisms, particularly among fishes, are known from these two systems. The population genetics project mentioned above (see "Past, current, and anticipated conservation activities undertaken for the benefit of the species or its habitat") would need to be expanded to answer these types of questions.

< **Develop & implement cryogenic techniques:** Developing and implementing cryogenic techniques to preserve spectaclecase 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.

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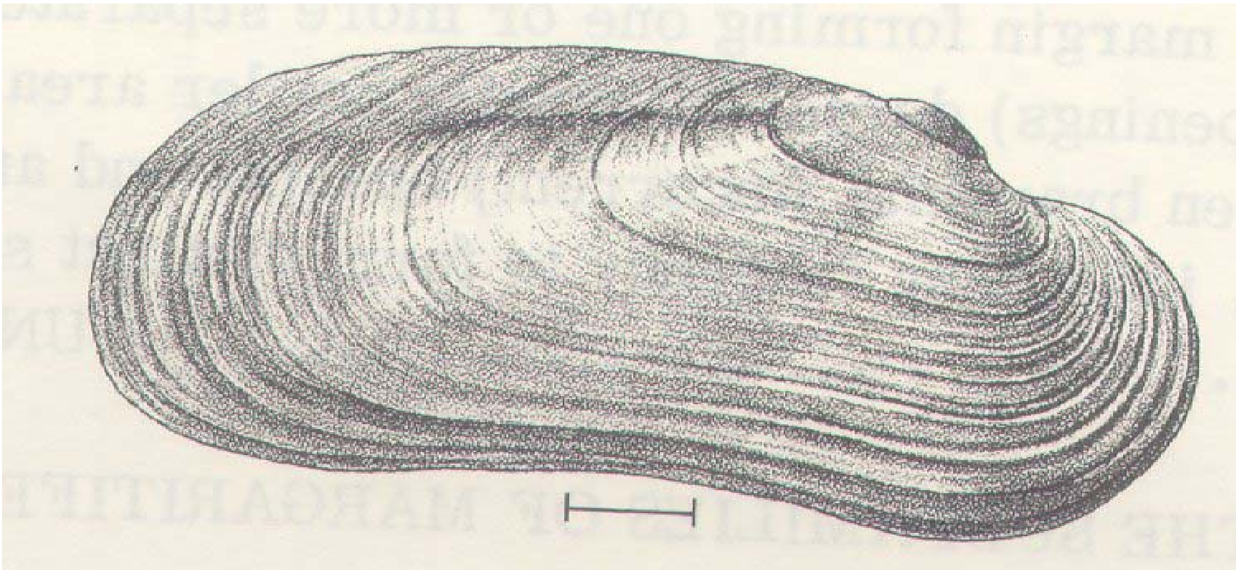
List of primary individuals contacted: See Appendix IV.

APPENDIX I

***Cumberlandia monodonta* (Say, 1829) Line Drawing (Burch 1975).**
The bar is one centimeter.



APPENDIX II

Cumberlandia monodonta (Say, 1829) 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, Alembic, Clayton Counties, IA; Crawford, Vernon Counties, WI	OSUM 1981:0284, 0310, 0338 D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001) Thiel (1981) OSUM 1978:0344 Chemic (1921) & Baker (1928) [in Havlik & Stansbery (1978)] Baker (1905) [in Havlik & Stansbery (1978)]	1981 >1980 1977-79 R 1978 1920-22 1904
Mississippi River, Clayton, Dubuque counties, IA; Grant County, WI	OSUM 1981:0314, 0315, 0323, 0425 D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2001) Thiel (1981)	1981 >1980 1977-79 R
Mississippi River, Rock Island County, IL; Muscatine, Scott Counties, IA	INHS 21355, 22881, 24307 Whitney et al. (1995) INHS 17382 INHS 11716 INHS 4625 INHS 9431 Nelson (1982) OSUM 1978:0143, 0281; UMA 1426 OSUM 1977:0131, 0144 OSUM 1976:0160 OSUM 19--:0352 FMNH 21448 USNM 504892 FSM 20665 USNM 504819, 504893 ANSP 41291 INHS 1538 MCZ 150176, 220590; UMMZ 150635; USNM 504890	1996-98 1996 1994 1989 1987 1979 1978-79 1978 1977 1976 <1973 <1958 <1957 1911 1890-99 1860-69 1837 ?
Mississippi River, Mercer County, IL; Louisa County, IA	INHS 9460 OSUM 1978:0280 OSUM 1977:0117, 0178 MCZ 5624 UMMZ 107651	1979 1978 1977 <1918 1885
Mississippi River, Henderson County, IL; Des Moines County, IA	INHS15928	1979
Mississippi River, Hancock County, IL; Lee County, IA	INHS 2989	1987
Mississippi River, Adams County, IL; Marion County, MO	INHS 14271, 14794	1987

	INHS 1539	<1919
Mississippi River, Pike County, IL; Pike, Ralls Counties, MO	INHS 21446 INHS 14800 INHS14762 Utterback (1917) [map in Oesch (1984)]	1996 1987 1986 <1917
Mississippi River, Calhoun County, IL; Lincoln County, MO	INHS 2667	1984
Upper Mississippi River System		
St. Croix River, Pine County, MN; Burnett County, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2002)	~2000
St. Croix River, Chisago County, MN; Polk County, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2002) Havlik (1994) OSUM 1990:0048, 0142, 0154	~2000 1992 1990
St. Croix River, Washington County, MN; St. Croix County, WI	D.J. Heath (Wisconsin Department of Natural Resources, pers. comm., 2002) Dunn (1998)	~2000 1994-97
Rush Creek, Chisago County, MN	JFBMNH 6690, D.L. Graf (ANSP, pers. comm., 2001)	late 1980s
Chippewa River, Chippewa County, WI	Balding & Balding (1996) OSUM 1989:0067	1989-94 1989
Rock River, ? Counties, IL	Cummings & Mayer (1997a), FSM 64205	<1970
Salt River, Pike County, MO	Oesch (1984)	1965 to 1980
Illinois River, Fulton, Mason Counties, IL	Danglade (1914) Baker (1906)	<1914 <1906
Illinois River, Calhoun, Greene Counties, IL	Danglade (1914) [in Starrett (1971)], USNM 678486	1912
Des Plaines River, Will County, IL	INHS 20441 UMMZ 107641	<1921 ~1900
Kankakee River, Grundy County, IL	UMMZ 107655	~1900
Kankakee River, Will County, IL	INHS 12604 Stinson et al. (2000)	1991 R 1906
Meramec River, Crawford County, MO	Baird (2000) Roberts & Bruenderman (2000) MFM 16070 Buchanan (1980)	1998-99 1997 1981 R 1977-78
Meramec River, Franklin County, MO	Baird (2000) Roberts & Bruenderman (2000) INHS 2318 S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001)	1998-99 1997 1985 1979

	Buchanan (1980)	1977-78
Meramec River, Jefferson, St. Louis Counties, MO	Baird (2000) Roberts & Bruenderman (2000) OSUM 1985:0190 S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001) UMA 1425 Buchanan (1980), OSUM 1977:0050, 0142, 0179 OSUM 1972:0412, FSM 30960	1998-99 1997 1985 1983, 1980-81 1982 1977-78 1972
Bourbeuse River, Franklin County, MO	Roberts & Bruenderman (2000) Buchanan (1980)	1997 1977-78 R
Big River, Jefferson County, MO	Roberts & Bruenderman (2000) Buchanan (1980), OSUM 1977:0051	1997 1977-78
Joachim Creek, Jefferson County, MO	Oesch (1984)	>1965
Kaskaskia River, ? Counties, IL	Cummings & Mayer (1997a) FMNH 67949	<1970 <1960
Lower Missouri River Main Stem		
[1] Missouri River, Nebraska?	Simpson (1914)	<1914
Lower Missouri River System		
"Northwest Missouri Lakes," ? County, MO	Utterback (1917)	<1917
Platte River, Platte? County, MO	Utterback (1917)	<1917
River Aux Vases, St. Genevieve County, MO	Oesch (1974a) [in Buchanan (1980)]	<1974
Osage River, St. Clair County, MO	map in Oesch (1984)	>1965
Osage River, Camden, Morgan Counties, MO	Utterback (1917)	<1917
Osage River, Miller County, MO	Grace & Buchanan (1981) OSUM 1972:0451 map in Oesch (1984) Utterback (1917?)	1980 1972 >1965 <1917
Osage River, Cole, Osage Counties, MO	Grace & Buchanan (1980) S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001)	1980 1978 R
Sac River, Cedar County, MO	S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001)	1978
Marais des Cygnes River, Linn County, KS	Obermeyer (2000)	1998 R
Gasconade River, Laclede County, MO	Baird (2000), Bruenderman et al. (2001)	1998-99
Gasconade River, Pulaski County, MO	Baird (2000), Bruenderman et al.	1998-99

	(2001) INHS 24141 map in Oesch (1984)	 1996 >1965
Gasconade River, Phelps County, MO	Bruenderman et al. (2001) S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001)	1998-99 1983
Gasconade River, Maries County, MO	Baird (2000), Bruenderman et al. (2001) S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001) map in Oesch (1984) OSUM 1964:0242; FSM18883; MFM 13318 OSUM 1963:0205 MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001)	1998-99 1994, 1981 >1965, <1920 1964 1963 ?
Gasconade River, Osage County, MO	Baird (2000) S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001)	1998-99 1994, 1983
Gasconade River, Gasconade County, MO	S.A. Bruenderman (Missouri Department of Conservation, pers. comm., 2001) INHS 6577 INHS 14389 map in Oesch (1984) OSUM 1964:0158, UMA 1106; FSM 18930; MFM 13311; MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001) OSUM 1962:0108	1994 1988 R 1978 >1965, <1920 1964 1962
Osage Fork Gasconade River, Laclede County, MO	Bruenderman et al. (2001)	1998-99
Big Piney River, Phelps County, MO	OSUM 1993:0147	1993
Big Piney River, Pulaski County, MO	OSUM 1993:0136, 0144, 0145, 0147 OSUM 1981:0586 OSUM 1965:0240	1993 1981 R 1965
Ohio River Main Stem		
Ohio River, Boone, Kenton counties, KY; Hamilton County, OH	OSUM 1909:0046 Schuster (1988) OSUM 18--:0491, 0494; MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001)	1909 1895, ? <1900
Ohio River, Jefferson County, KY; Clark, Floyd Counties, IN [Type Locality]	AMNH 30444, Call (1900) Say (1829) [in Parmalee & Bogan (1998)]	<1900 <1829

Ohio River, Perry County, IN; Breckinridge County, KY	USNM 677235	1908
Ohio River, Massac County, IL; McCracken County, KY	INHS 16269	1994
Ohio River System		
Muskingum River, Washington County, OH	OSUM 1995:0241	1995 R
Kanawha River, Kanawha County, WV	G. Zimmerman (EnviroScience, Inc., pers. comm., 2002)	2002
Green River, Hart County, KY	R.R. Cicerello (Kentucky State Nature Preserves Commission, pers. comm., 2001) INHS 12716 INHS 12967 MFM 16080 OSUM 1981:0069, 0073 OSUM 1966:0089 Stansbery (1965), OSUM 1964:0166 MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001)	1998, 1994, 1990 1990 1989 1982 R 1981 1966 1960-64 1964
Green River, Edmonson County, KY	J.B. Layzer, (USGS, pers. comm., 2002) R.R. Cicerello (Kentucky State Nature Preserves Commission, pers. comm., 2001) Cicerello & Hannan (1990)	2001 1995, 1982-84 1987-89
Green River, Butler, Warren Counties, KY	R.R. Cicerello (Kentucky State Nature Preserves Commission, pers. comm., 2001) INHS 7445 OSUM 1980:0209	2001 R, 1993 1987 1980
Wabash River, Wabash County, IL; Gibson, Knox Counties, IN	INHS 12341 INHS 7324 Cummings et al. (1987), INHS 4251 INHS 6679	1991 R 1988 R 1987 R 1985 R
Wabash River, White County, IL; Posey County, IN [Type Locality]	INHS 19244 Cummings et al. (1987), INHS 4747 Cummings & Mayer (1997b) Goodrich & van der Schalie (1944) UMMZ 107653 MCZ 53983, 151739 USNM 86152, OSUM 18-B:0236, O590 Say (1829) [in Parmalee & Bogan (1998)]	1996 R 1987 R <1970 <1944 1903 <1900? <1887 <1829
Cumberland River Main Stem		
Cumberland River, McCreary, Pulaski, Wayne Counties, KY	Wilson & Clark (1914)	1911
Cumberland River, Clinton, Cumberland, Monroe, Russell Counties, KY	Miller et al. (1984) Schuster (1988), OSUM 1982:0276 Neel & Allen (1964)	1982 1982 R, 1925 1947-48

	Wilson & Clark (1914)	1919-11
Cumberland River, Smith County, TN	TVA (1976) Wilson & Clark (1914)	1976 R <1910
Cumberland River, Sumner, Trousdale, Wilson Counties, TN	Koch (1983) Wilson & Clark (1914)	1983 1910-11
Cumberland River, Davidson County, TN	Wilson & Clark (1914) MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001)	1910-11 <1900
Cumberland River, Cheatum County, TN	Wilson & Clark (1914)	1910-11
Cumberland River, Stewart County, TN	FSM3873 Wilson & Clark (1914)	1911 1910-11
Cumberland River, Livingston, Lyon Counties, KY	Cicerello et al. (1991)	A
Cumberland River System		
Big South Fork, Pulaski County, KY	UMMZ 107643	1911
Caney Fork River, Smith County, TN	Layzer et al. (1993), P.W. Shute (TVA, pers. comm., 2001) Miller (1984) MFM 8767	1988 1983 1961 R
Stones River, Davidson County, TN	Schmidt et al. (1989), OSUM 1965:0236, 0257 MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001) OSUM 1964:0234	1965-68 1965 1964
Red River, Robertson County, TN	OSUM 1966:0241	1966
Tennessee River Main Stem		
Tennessee River, Blount, Knox, Loudon Counties, TN	MCZ ? D.G. Smith [University of Massachusetts, pers. comm., 2001) Lewis (1870)	<1900? <1870
[2] Tennessee River, Meigs, Rhea Counties, TN	Ahlstedt & McDunough (1995-96)	<1918
Tennessee River, Morgan County, AL	OSUM 1999:0044 OSUM 1998:0005, 0016, 0032, 0035, 0037, 0039, 0046 OSUM 1997:0016, 0033, 0035, 0036, 0041	1999 1998 1997
Tennessee River, Limestone, Madison, Marshall, Morgan Counties, AL	P.W. Shute (TVA, pers. comm., 2001) Bowen et al. (1994) Ahlstedt & McDonough (1993) MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001)	1998 ~1993 ~1979 R <1900?
Tennessee River, Colbert, Lauderdale Counties, AL	J.T. Garner (Alabama Department of Natural Resources, pers. comm., 2001) McGregor et al. (1998) Garner & McGregor (2001)	2000 1998 R 1995

	Gooch et al. (1979) OSUM 1966:0043 0SUM 1965:0471 Morrison (1942) van der Schalie (1939) Ortmann (1925) INHS 20442 FSM 66121 Hinkley (1906), INHS 20444, FSM 64202 MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001) FSM 64203	1978 1966 1965 1937 1931 1924 <1921 1909 1904 <1900? ?
Tennessee River, Hardin County, TN	Hubbs & Jones (2000) Jenkinson (1994) INHS 14497, 14525 Yokley (1972), Dennis (1985) OSUM 1964:0285	1998 1993 1979 1969-72 1964
Tennessee River, Decatur, Perry Counties, TN	Hubbs (1995) OSUM 1991:0082 Yokley (1989) OSUM 1964:0292	1993 1991 1989 1964
Tennessee River, Benton, Humphries Counties, TN	Bates & Dennis (1983) Dennis (1985)	<1983 <1967
Tennessee River, Marshall, Livingston Counties, KY	J.B. Sickel (Murray State University, pers. comm., 1990 [with R.R. Cicerello, Kentucky State Nature Preserves Commission])	1990 R
Tennessee River System		
Holston River, Hawkins County, TN	Ortmann (1918)	1914
Holston River, Grainger, Jefferson, Knox Counties, TN	S.J.Fraley (North Carolina Wildlife Resources Commission, pers. comm., 2002) Ahlstedt (1991b) MFM 10528 Ortmann (1918) Böpple & Coker (1912) OSUM18-B:0235; MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001)	2002 R 1981 1963 R 1913-15 1909 <1900
Nolichucky River, Cocke, Greene, Hamblen Counties, TN	S.A. Ahlstedt (USGS, pers. comm., 2001) LACM 87-18.1, 18.2 Ahlstedt (1991b) OSUM1971:0372 OSUM 1968:0221; MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001) MFM 11883	2001 1987 1980 1971 1968 1964 R
Little River, Knox County, TN	Ortmann (1918), Walker (1911)	<1911

Little Tennessee River, Monroe County, TN	S.A. Ahlstedt (USGS, pers. comm., 2000) Bogan (1990)	~1980 R A
Clinch River, Tazewell County, VA	Church (1991)	1989-90
Clinch River, Wise County, VA	OSUM 1963:0110	1963
Clinch River, Russell County, VA	Church (1991) OSUM 1985:0119	1989-90 1985
Clinch River, Scott County, VA	P.W. Shute (TVA, pers. comm., 2001) Ahlstedt (1991a) OSUM 1981:0001, 0256 Bates & Dennis (1978) MFM 18237 MFM 20632 OSUM 1966:0033 OSUM 1965:0227, 0228; MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001) OSUM 1963:0093	1999, 1996, 1973 1978-83 1981 1973-75 1968 1969 1966 1965 1963
Clinch River, Hancock County, TN	S.A. Ahlstedt (USGS, pers. comm. 2001) Ahlstedt & Tuberville (1997) INHS 16641, 16656, 16694; FSM 195053 Barr et al. (1993-94) Ahlstedt (1991a), UMA 1143 OSUM 1978:0156, 0157; UMA 1873 OSUM 1977:0095 Bates & Dennis (1978) OSUM 1972:0039, 0179 OSUM 1970:0283; MFM 21036, 21781 OSUM 1969:0318, 0319 OSUM 1968:0133; MFM 1787E OSUM 1967:0143, 0144, 0164; MFM 16678 OSUM 1965:0234; MFM 1787D MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001) MFM 1787C MFM 1787 FSM 225963	2001 1994, 1988, 1979 1981 1978-83 1979 1978 1977 1973-75 1972 1970 1969 1968 1967 1965 1965, ? 1956 1950-51 ?
Clinch River, Claiborne, Grainger Counties, TN	Ahlstedt & Tuberville (1997) Ahlstedt (1991a) OSUM 1981:0168 OSUM 1978:0305, 0452 OSUM 1968:0222 MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001) MFM 992A, 16563 OSUM 1965:0235	1994 1978-83 1981 1978 1968 1968, 1965 1967 1965

	MFM 6946 MFM 992 Ortmann (1918)	1956 1949 1913
Clinch River, Campbell, Union Counties, TN	OSUM 1909:0008 (Böpple) Ortmann (1918)	1909 1899
Clinch River, Anderson, Knox Counties, TN	S.J.Fraley (North Carolina Wildlife Resources Commission, pers. comm., 2001) Ahlstedt (1991a) MFM 6115 Hickman (1937), INHS 20446 Cahn (1936) Ortmann (1918), FSM 64204	2001 1978-83 1956 ~1936 <1936 1914-15
Clinch River, Roane County, TN	MCZ ? D.G. Smith (University of Massachusetts, pers. comm., 2001)	<1900?
[3] Powell River, Hancock County, TN	S.A. Ahlstedt (USGS, pers. comm., 2001), Ahlstedt & Brown (1980)	1975-78
Powell River, Claiborne County, TN	S.A. Ahlstedt (USGS, pers. comm., 2001)	1999 R
Sequatchie River, Marion County, TN	Gordon (1991) Ortmann (1925)	1991 R <1925
Elk River, Limestone County, AL	McGregor et al. (1998) MFM 16225	1998 R 1974 R
Duck River, Humphries County, TN	Hubbs (1999)	1999
Lower Mississippi River System		
Mulberry River, Franklin County, AR	Harris et al. (1997)	~1995
Ouachita River, Montgomery County, AR	J.L. Harris (Arkansas Highway and Transportation Department, pers. comm., 2001)	2000 R
Ouachita River, Clark County, AR	Wheeler (1918) [in Harris et al. (1997)]	?, <1918
Ouachita River, Ouachita County, AR	Harris et al. (1997)	~1995

Footnotes:

[1] Simpson (1914) lists “Nebraska?” as possibly being in the range of *Cumberlandia*. Utterback (1917) reported it from “northwest Missouri lakes.” It is conceivable that the “lakes” Utterback referred to were oxbows of the Missouri River, which forms the boundary between southeastern Nebraska and northwestern Missouri. As far as is known, no records exist for Nebraska. However, it is not inconceivable that *Cumberlandia* once occurred in that state.

[2] Ahlstedt & McDonough (1995-96) do not specifically give a reference for the 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 *Cumberlandia* 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.

[3] Ahlstedt and Brown (1980) reported this species from the Powell River (both listing it in Table 2 and discussing it in the text), but inadvertently omitted the site of occurrence in Table 2. A personal communication with Ahlstedt in 2001 clarified its occurrence at McDowell's Ford in Hancock County during the survey.

Codes:
< = collected before [date], > = collected after [date], AMNH = American Museum of Natural History, ANSP = Academy of Natural Sciences Philadelphia, FMNH = Field Museum of Natural History, INHS = Illinois Natural History Survey, JFBMNH = J.F. Bell Museum of Natural History, LACM = Los Angeles County Museum, MFM = Museum of Fluviatile Mollusks, OSUM = Ohio State University Museum of Biological Diversity, R = relic shells only, TUR = Triannual Unionid Report, UMA = University of Massachusetts Museum of Invertebrate Zoology (Mollusks), UMMZ = University of Michigan Museum of Zoology, USNM = U.S. National Museum

Notes:
Citations used in Appendix II are in the Literature Cited section of the status review. Dennis (1985) reported this species in 1976-83 survey work from the Clinch River (RM 190-280) and the Cumberland River without giving site specific information. Grier (1915) and Utterback (1917) reported this species from the Meramec River without giving specific locality information.

APPENDIX III

Spectaclecase (*Cumberlandia monodonta*) extant populations*

Stream/Service Region	State/Province	Last Observed	Recruiting?
Region 3			
Mississippi River (a few reaches)	Minnesota, Wisconsin, Iowa, Illinois, Missouri	1996-98	No?
St. Croix River	Minnesota, Wisconsin	1992	Yes
Rush Creek	Minnesota	late 1980s	No
Chippewa River	Wisconsin	1989-94	No (1 spec.)
Meramec River	Missouri	1998-99	Yes
Bourbeuse River	Missouri	1997	Yes
Big River	Missouri	1997	Yes
Gasconade River	Missouri	1998-99	Yes
Osage Fork Gasconade River	Missouri	1998-99	Yes?
Big Piney River	Missouri	1993	No?
Ohio River	Illinois	1994	No (1 spec.)
Region 4 (see also Ohio River under Region 3)			
Green River	Kentucky	2001	?
Caney Fork	Tennessee	1988	No (1 spec.)
Tennessee River (3 tailwaters)	Alabama, Tennessee	2000	Yes (at least 1 tailwater)
Nolichucky River	Tennessee	2001	?
Clinch River (see also Region 5)	Tennessee	2001	Yes
Duck River	Tennessee	1999	No (1 spec.)
Mulberry River	Arkansas	~1995	No (1 spec.)
Ouachita River	Arkansas	~1995	No

Region 5			
Kanawha River	West Virginia	2002	No (1 spec.)
Clinch River (see also Region 5)	Virginia	1999	Yes

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

NOTE: The spectaclecase was historically known from 45 streams in 15 states and 4 Service regions (3, 4, 5, & 6). Currently, it is known from 20 streams in 11 states and 3 regions (3, 4, & 5). Region 3 has the most extant streams of occurrence (some streams may have multiple extant sites) with 11, while Region 4 has 7, and Region 5 has only 2 occurrences.

APPENDIX IV

List of primary individuals who provided status information on the spectaclecase

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