Status Assessment Report for the rayed bean, *Villosa fabalis*, occurring in the Mississippi River and Great Lakes systems (U.S. Fish and Wildlife Service Regions 3, 4, and 5, and Canada)

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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 rayed bean (*Villosa fabalis*). 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: rayed bean

Scientific name: *Villosa fabalis*

Controversial or unsettled taxonomic issues: The rayed bean is a member of the mussel family Unionidae and was originally described as *Unio fabalis* Lea, 1831. The type locality is the Ohio River, probably in the vicinity of Cincinnati, Ohio. Parmalee and Bogan (1998) summarized the synonomy of the rayed bean. The specific epithet of this species has also been spelled *fabale* and ultimately as *fabalis.* Over the years, the rayed bean has been placed in the genera *Unio, Margarita, Margaron, Eurynia, Micromya,* and *Lemiox*. It was ultimately placed in the genus *Villosa* by Stein (1963), where it remains today (Turgeon et al. 1998). The Service recognizes *Unio capillus, U. lapillus,* and *U. donacopsis* as synonyms of *Villosa fabalis.*

Physical description of the taxon: The following description of the rayed bean is generally summarized from Cummings and Mayer (1992), Parmalee and Bogan (1998), and West et al. (2000). The rayed bean is a small mussel usually under 1.8 inches in length. Shell outline is elongate or ovate in males and elliptical in females, and moderately inflated in both sexes, but more so in females. The valves are thick and solid. The anterior end is rounded in females and bluntly pointed in males. Females apparently are generally smaller than males. Dorsally, the shell margin is straight, while the ventral margin is straight to slightly curved. The beaks are slightly elevated above the hingeline, with sculpture consisting of double loops with some nodules. No posterior ridge is evident. Surface texture is smooth and sub-shiny, and green, yellowish-green, or brown in color, with numerous wavy dark-green rays of various widths (sometimes obscure in older, blackened specimens). Internally, the left valve has two pseudocardinal teeth that are triangular, relatively heavy, and large, and two short, heavy lateral teeth. The right valve has a low triangular pseudocardinal tooth, with possibly smaller secondary teeth anteriorly and posteriorly, and a short, heavy, and somewhat elevated lateral tooth. The color of the nacre (mother-of-pearl) is silvery white or bluish and iridescent posteriorly. Some soft anatomy characters were described by Ortmann (1911). Key characters useful for distinguishing the rayed bean from other mussels is its small size, thick valves, unusually heavy teeth for a small mussel, and color pattern.

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, and then slow appreciably at sexual maturity (when energy is being diverted from growth to reproductive activities).

As a group, mussels are extremely long-lived, living from a couple to several decades, and possibly up to 100 to 200 years in extreme instances (Mutvei et al. 1994). Thick-shelled, large river forms are thought to live longer than other species (Stansbery 1961). However, the rayed bean's small size probably indicates a shorter life span. No quantitative longevity information on the rayed bean is available, although the age of some individuals has been estimated qualitatively (external growth ring counts) in the literature (e.g., Ecological Specialists, Inc. 1993, 2000). These limited data indicate that the rayed bean does not live very long, probably less than 20 years.

Most mussels, including the rayed bean, generally have separate sexes. Age at sexual maturity for the rayed bean is unknown, but in other species is estimated to occur after a few years. Males expel clouds of sperm into the water column, which are drawn in by females through their incurrent siphons. Hermaphroditism occurs in many species of mussel (van der Schalie 1966), but is not known for the rayed bean. 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.

Fertilization takes place internally, and the resulting zygotes develop into specialized larvae termed glochidia within the gills. The rayed bean utilizes only a discrete portion of the outer pair of gills as a marsupium for its glochidia. It is thought to be a long-term brooder; gravid females have been collected from May through October (Parmalee and Bogan 1998; Ecological Specialists, Inc. 2000; Woolnough 2002; P. Badra, Michigan Natural Features Inventory [MNFI], pers. comm., 2001). Observations in French Creek, Pennsylvania, indicate that females have numerous papillae arranged along the mantle edge (J.W. Jones, Virginia Polytechnic Institute and State University [VPI&SU], pers. comm., 2002). When displaying, females generally lay on their side and the mantle papillae "zip" rhythmically. The display usually involves a pause near the middle of the zip, when the mantle "quivers." Glochidia in these species are released when the lure is stimulated. The glochidia are subspatulate or rounded with a straight hinge (West et al. 2000), and medium in size. The length (0.008 inches) is slightly greater than the height (0.007 inches) (Hoggarth 1993). It is probably a gill parasite (West et al. 2000). Fecundity is positively related to body size and inversely related to glochidia size (Bauer 1994). Total fecundity (including glochidia and ova) per female rayed bean is probably in the thousands.

Glochidia must come into contact with a specific host fish(es) in order for their survival to be ensured. Without the proper host fish, the glochidia will perish. Little has been published regarding host fishes of the rayed bean (Parmalee and Bogan 1998, West et al. 2000). The only published research identifies the Tippecanoe darter (*Etheostoma tippecanoe*) as a host fish for the rayed bean (White et al. 1996). Other hosts are thought to include the greenside darter (*E. blennioide*s), rainbow darter (*E. caeruleum*), mottled sculpin (*Cottus bairdi*), and largemouth bass (*Micropterus salmoides*) (Woolnough 2002). Based on inference of closely related species (i.e., purple bean, *V. perpurpurea*; Cumberland bean, *V. trabalis*), additional hosts may be suitable, including species in the *Etheostoma* subgenus *Nothonotus* (e.g., bluebreast darter, *E. camurum*; spotted darter, *E. maculatum*), sculpins (*Cottus* spp.), and fantail darter (*E. flabellare*)

(J.W. Jones, VPI&SU, pers. comm., 2002). The method of host fish attractant reported above seems to be more appropriate for small predatory fishes like darters and sculpins.

In many species of mussels, a few weeks are spent parasitizing the fishes' gill tissues. Laboratory tests showed that the encysted rayed bean glochidia from Canada metamorphosed after 7-14 days (Woolnough 2002). Newly-metamorphosed juveniles drop off to begin a free-living existence on the stream bottom. Unless they drop off in suitable habitat, they will die. Thus, the complex life history of the rayed bean and other mussels has many weak links that may prevent successful reproduction and recruitment of juveniles into existing populations.

Habitat requirements: The following habitat requirements of the rayed bean are generally summarized from Watters (1988), Parmalee and Bogan (1998), and West et al. (2000). The rayed bean is generally known from smaller, headwater creeks, but records exist in larger rivers. They are usually found in or near shoal or riffle areas, and in the shallow, wave-washed areas of glacial lakes, including Lake Erie. In Lake Erie, it is generally associated with islands in the western portion of the lake. Substrates typically include gravel and sand. It is oftentimes associated with vegetation (e.g., water willow, *Justicia americana*; water milfoil, *Myriophyllum* sp.) in and adjacent to riffles and shoals. Specimens are typically buried among the roots of the vegetation. 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. Adult and juvenile specimens appear to produce byssal threads (Woolnough 2002), apparently to attach themselves to substrate particles.

Historical and current range: The distributional history of the rayed bean presented in this section is detailed in tabular form in Appendix I. Information in Appendix I is presented by major river drainage (i.e., upper, lower Great Lakes; Ohio, Tennessee 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 rayed bean occurred in parts of the upper (i.e., Lake Michigan drainage), lower Great Lakes system, and throughout most of the Ohio and Tennessee River systems (Appendix I). Interestingly, it was never recorded from the Cumberland River system (Parmalee and Bogan 1998) (Appendix I). The species was not known from the Lake Michigan drainage until 1996 (from a tributary of the St. Joseph River). The rayed bean was historically known from 106 streams, lakes, and some man-made canals in 10 states and 3 Service regions (Appendix II). In the order presented in Appendix I, these include by stream system (with tributaries) the following: upper Great Lakes system (Pigeon River); lower Great Lakes system (Black [Mill Creek], Pine, Belle, Clinton [North Fork Clinton River], Sydenham, South Branch Thames, Detroit, Rouge, Huron, Raisin [Macon Creek], Maumee [St. Joseph River (West Branch St. Joseph; Fish, Cedar Creeks; Feeder Canal to St. Joseph River), Auglaize (Ottawa, Blanchard Rivers)], Sandusky [Tymochtee, Wolf Creeks] Rivers; Lake Erie); Ohio River system (Ohio River [Allegheny River (Chautauqua Lake outlet; Chautauqua Lake; Olean, Cassadaga, Conewango, Oil, French [Cussewago Creek], Crooked Creeks), West Fork, Beaver (Shenango, Mahoning Rivers; Pymatuning Creek) Rivers; Middle Island Creek; Muskingum (Walhonding, Mohican Rivers), Elk, Scioto (Olentangy River; Mill, Alum, Whetstone, Big Walnut [Walnut Creek], Big Darby [Little Darby Creek], Deer, Sugar, Scioto Brush, Cedar Creeks; Buckeye Lake; Ohio and Erie Canal), Little Miami (East Fork Little Miami River), Stillwater, South Fork Licking, North Fork Elkhorn Creek, Eagle Creek, Brashears Creek, Green (Nolin, Barren Rivers), Wabash (Salamonie, Mississinewa, Tippecanoe Rivers [Tippecanoe, Winona Lakes; Lake Maxinkuckee], Vermilion [Salt Fork Vermilion, Middle Fork Vermilion, North Fork Vermilion Rivers], Embarras, Sugar Creek, White [West, East Forks White; Big Blue Rivers; Walnut, Mill, Fall, Sugar Creeks])] Rivers); and Tennessee River system [Tennessee River (Holston [North, South Forks Holston River], Nolichucky [Lick Creek], Clinch [North Fork Clinch, Powell Rivers], Elk [Richland Creek], Duck Rivers)]. The rayed bean historically occurred in Illinois, Indiana, Kentucky, Michigan, New York, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia. Alabama is not considered to be in the verified range of the rayed bean (*contra* West et al. 2000; Appendix I, Footnote 3). These states comprise Service regions 3 (Midwest), 4 (Southeast), and 5 (Northeast).

The rayed bean was last reported from some streams several decades ago (e.g., North Branch Clinton, Rouge, Auglaize, Ohio, West Fork, Beaver, Shenango, Mahoning, Mohican, Scioto, Green, Barren, Salamonie, White, Big Blue, Tennessee, Holston, North Fork Holston, South Fork Holston, Nolichucky, Clinch, North Fork Clinch, Powell, Elk Rivers; Wolf, Conewango, Oil, Crooked, Pymatuning, Mill, Alum, Whetstone, Deer, Lick, Richland Creeks; Buckeye, Tippecanoe, Winona Lakes) (Appendix I). The rayed bean population in Lake Erie was once considerable (Stansbery 1961, subsequent OSUM collections), but has been eliminated by the zebra mussel.

Current distribution: Populations of the rayed bean were generally considered extant if live or FD specimens have been collected since the mid-1980s. Extant populations of the rayed bean are known from 22 streams and a lake in 5 states and 2 Service regions (Appendix II). In the order presented in Appendix I, these include by stream system (with tributaries) the following: lower Great Lakes system (Black [Mill Creek], Pine, Belle, Clinton, Sydenham, St. Joseph [Fish Creek], Blanchard Rivers; Tymochtee Creek); and Ohio River system (Allegheny [Olean, Cassadaga, French, Cussewago Creeks], Walhonding, Scioto Brush Creek, Little Miami [East Fork Little Miami River], Stillwater, Tippecanoe [Lake Maxinkuckee] Rivers; Sugar Creek]).

The rayed bean appears to be declining rangewide (Strayer and Jirka 1997, West et al. 2000). The rayed bean has been eliminated from 78% of the total number of streams and other water bodies from which it was historically known (22 streams and a lake currently compared to 106 water bodies historically). This species has also been eliminated from long reaches of former habitat in hundreds of miles of the Maumee, Ohio, Wabash, and Tennessee Rivers and from numerous stream reaches in their tributaries. In addition, the species is no longer known from the States of Illinois, Kentucky, Tennessee, Virginia, and West Virginia, representing half of the states from which it was formerly known.

Current and historical populations, and population trends: During historical times, the rayed bean was fairly widespread (Appendix I) and locally common in many Ohio River system streams based on collections made over a several-decade period (see Appendix I). The species was once fairly common in the Belle, South Branch Thames, Detroit, Scioto, Wabash, and Duck Rivers, several tributaries in the Scioto system (e.g., Olentangy River; Big Darby, Alum Creeks), and Tippecanoe Lake based on literature and museum records (Call 1900, Watters 1994, West et al. 2000; P. Badra, MNFI; G.T. Watters, Ohio State University Museum of Biological Diversity [OSUM], pers. comm., 2001). Although eight FD shells were collected in Big Darby Creek in 1986, subsequent sampling has failed to find evidence of its persistence there, and it is now thought to be extirpated from the system (Watters 1994). Some researchers may maintain that because the rayed bean is a small species and buries in the substrate, it could be easily overlooked in sampling efforts (Ortmann 1918, Bogan and Parmalee 1983, Watters 1992, West et al. 2000). However, the fact that no specimens have been found in numerous streams for several decades indicates that a substantial loss in total range has occurred. In addition, remaining populations are generally isolated and fairly small with limited exceptions. Currently, the rayed bean is considered to be “very rare and/or in decline” rangewide (West et al. 2000).

Although quantitative historical abundance data for the rayed bean 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 rayed bean populations thought to be extant by stream system, as outlined in the “Current Distribution” above.

Lower Great Lakes System

Twenty-six of the total water bodies the rayed bean was recorded from historically are in the lower Great Lakes system. The species is thought to be extant in 10 streams, but historically significant populations have been eliminated from Lake Erie, and the South Branch Thames and Detroit Rivers. The percentage of stream and other water body population losses in this drainage system (16 of 26, 62%) is much lower than losses rangewide (83 of 106, 78%).

Black River: A tributary of the St. Clair River, linking Lakes Huron and St. Clair, the Black River is located in southeastern Michigan. Hoeh and Trdan (1985) surveyed 17 sites in the Black River system, including 12 main stem sites, but failed to find the rayed bean. The rayed bean was not discovered there until the summer of 2001. A single live specimen was found in the lower river in the Port Huron State Game Area (P. Badra, MNFI, pers. comm., 2001). The status of this newly discovered population cannot be accurately assessed at this time, but would appear to be small and of questionable viability.

Mill Creek: Mill Creek is a tributary of the Black River, St. Clair County, in southeastern Michigan. The rayed bean was not discovered in Mill Creek until August 2002. Five presumably FD specimens were found approximately 0.5 miles above its confluence with the Black in the Port Huron State Game Area (P. Badra, MNFI, pers. comm., 2001). Similar to the population in the Black, the status of this newly discovered population cannot be accurately assessed at this time.

Pine River: Another tributary of the St. Clair River, the Pine River is located in southeastern Michigan. The rayed bean was apparently not collected in the Pine until 1982 when specimens were found at three sites (Hoeh and Trdan 1985). These collections included 5 live, 18 whole FD, and 5 unmatched FD shells (P. Badra, MNFI, pers. comm., 2001). Hoeh and Trdan considered it to be "rare," semi-quantitatively defined as occurring at a rate of <1 specimen per person hour (PH) sampling effort. At one of the four known sites, notes in the MNFI database state that the 1984 sampling estimated rayed bean density at $0.7/\text{foot}^2$, or an estimated 350-500 specimens from the locality. In 1985 samples, 198 specimens of the rayed bean were found at this site, and the species was "common in pea gravel and sand" at another site sampled that same year. Another site had an estimated $1.1/\text{foot}^2$ in the 1984 sampling. Evidence of recruitment was found during the mid-1980s at three of the four sites. The last record for the rayed bean is from this site in 1997, when two live specimens were found. The species may have declined significantly since the 1980s, but is probably still viable. The Pine is located in a primarily agricultural watershed (Hoeh and Trdan 1985), and the rayed bean population is threatened by sedimentation and runoff.

Belle River: The Belle River is a third tributary of the St. Clair River harboring an extant population of the rayed bean. This species was first collected from the Belle in 1965, when 17 FD specimens were collected (OSUM 1965:0106). The same site (Wadhams Road Bridge) was revisited in 1978, but only one FD shell is represented in OSUM 1978:0013. Since that time, live or FD specimens have been found in 1983 and 1992, while only relic shells were found in 1994 (P. Badra, MNFI, pers. comm., 2001). In 1992, nine whole and two unmatched valves, all FD, were collected from the same site as those from 1965 and 1978 (J.B. Layzer, USGS, pers. comm., 2001). Owing to recent rains, turbid conditions prevented Layzer from actively searching for live specimens, but he noted that the shells were found on a bar immediately downstream of the bridge. During summer 2002 sampling, single live specimens were found at two new sites, with an additional four and two FD specimens also found from these sites (P. Badra, MNFI, pers. comm., 2001). The status of this population is still not well known, but would appear to be small. The Belle is located in a primarily agricultural watershed (Hoeh and Trdan 1985), and the rayed bean population is threatened by sedimentation and agricultural runoff.

Clinton River: The rayed bean was first recorded from the Clinton River by H. van der Schalie in 1933 (P. Badra, MNFI, pers. comm., 2001). Van der Schalie found the rayed bean at 4 of 11 sites surveyed, including 3 sites on the main stem Clinton and 1 in the lower North Branch Clinton River (Strayer 1980). Main stem sites were widely distributed with one on the lowermost Clinton (Mt. Clemons) and two in the river from Pontiac upstream in the headwaters of the Clinton. In 1977-78, Strayer (1980) surveyed 76 sites in the drainage and found the rayed bean to be "uncommon" at four main stem sites, all in areas that are now highly developed west of Pontiac. He located no live specimens, but FD shells were found at three of his sites. Eight live specimens were found at a single site in 1991, and the species was recorded there in 1995 (P. Badra, MNFI, pers. comm., 2001). In 1992, Trdan and Hoeh (1993) found 26 live specimens using a suction dredge from a bridge site slated for widening where Strayer (1980) found only relic shells. They represented 1.2% relative abundance of the 10 species collected at the site. Interestingly, the globally imperiled snuffbox (*Epioblasma triquetra*) was the most common mussel collected from the site (804 live specimens, 38.1% relative abundance). The rayed bean population is probably viable. However, given that it appears to be currently restricted to about three miles of stream in the western suburbs of Pontiac, its long-term status would appear to be highly precarious.

The mussel fauna in the entire main stem of the Clinton River downstream of Pontiac was apparently wiped out by pollution between 1933 and 1977 (Strayer 1980). The tenuous rayed bean population in the Clinton is highly threatened by municipal pollution and the negative effects of developmental activities.

Sydenham River: The only extant population of the rayed bean located outside the United States resides in the Sydenham River, southwestern Ontario, Canada. It also represents one of the largest rayed bean populations remaining. West et al. (2000) presented a highly detailed collection history of the rayed bean in the Sydenham. The rayed bean was first collected there by H.D. Athearn in 1963, with subsequent collections in the 1960s from other sites in the stream. However, surveys in 1971 (11 sites) and 1985 (20 sites) failed to find the rayed bean. Time efforts at individual sites were limited to approximately 1 PH/site during these surveys, much shorter than time spent in the 1960s records. Not until a 1991 survey (16 sites) was the rayed bean rediscovered in the system, represented by a single specimen near Alvinston (Clarke 1992).

West et al. (2000) reported sampling conducted by Metcalfe-Smith et al. (1998, 1999) during 1997-98. They sampled 4.5 PH/site from at least 17 sites, including all 5 sites where the rayed bean had previously been recorded. Live or FD shells were found at 9 sites, including 15 live specimens from 5 sites. Average numbers of live or whole FD specimens per site (n = 8) were 3.6/site (the 37 single FD valves they reported would increase this number considerably). The sex ratio was skewed towards females (62:38), and size ranged from 0.6-1.5 inches. Additional sampling in 2001 resurveyed sites reported by West et al. (2000), plus several addition localities (Woolnough 2002). The rayed bean was located live from 15 sites, including most of the sites where West et al. (2000) reported it as live or FD, in addition to several previously unsampled sites. A total of 522 specimens were found live, with many more FD shells discovered. Average densities per site in the 2001 survey for live specimens were 34.8/site. More than 100 live specimens were located at 2 sites. Sampling effort averaged approximately 6.4 PH/site. Size range was from 0.5-1.8 inches. The data gathered from the two surveys clearly indicates the importance of very intensive sampling efforts for this diminutive species.

The rayed bean is currently thought to exist in an approximately 75-mile reach of the middle Sydenham, from the general vicinity of Napier downstream to Dawn Mills. The species appears to be most abundant in the lower half of this river reach. Although the range has remained relatively consistent over time, abundance data at repeatedly sampled sites from the 1960s to the late 1990s indicate a general decline of the rayed bean. Based on the range of sizes and roughly even number of specimens in various size classes of the live and FD material they gathered, West et al. (2000) considered the population to be "healthy" and "reproducing" (recruiting). The 2001 sampling showed evidence of recruitment and variable size classes for both sexes from most all sites. Based on Woolnough's (2002) data, the rayed bean population in the Sydenham is doing considerably better than West et al. (2000) suggested.

West et al. (2000) summarized threats to the rayed bean in the Sydenham, which are also addressed at a web site (www.sydenhamriver.on.ca). An estimated 80-85% of the watershed is in agriculture. They surmised that siltation, over-enrichment, and exposure to agricultural pesticides and fertilizers were the most obvious threats to the rayed bean in the Sydenham. Clarke (1992) noted that silt covered most of the riffles he sampled, and surmised that there may be a relationship between several riffle species being lost from the system and sedimentation. Highway runoff and municipal and industrial runoff were probably also factors limiting the occurrence of the rayed bean in Canada (West et al. 2000). They thought that the rayed bean may be sensitive to chemical toxicants (see "A. The present or threatened destruction, modification, or curtailment of its habitat or range; Chemical Contaminants"). West et al. (2000) surmised that threats from the zebra mussel should be minimal due to its burrowing habits. However, the fact that zebra mussels have eliminated once-extensive rayed bean populations in the Detroit River, western Lake Erie, and elsewhere refutes this claim. Presumably, zebra mussels do not currently occur in the Sydenham reach harboring the extant rayed bean population, but they do occur in the lowermost main stem near Lake St. Clair (D.A. Woolnough, Iowa State University (ISU), pers. comm., 2002) and bear close monitoring (see "Past, current, and anticipated conservation activities undertaken for the benefit of the species or its habitat").

Maumee River system: The Maumee River system, which flows into the western end of Lake Erie, was once a major center of distribution of the rayed bean. It was historically known from eight streams in the system in addition to the main stem Maumee.

St. Joseph River: The St. Joseph River is one of the two major headwater tributaries to the Maumee, with a drainage area in southeastern Michigan, northwestern Ohio, and northeastern Indiana. The main stem flows in a southwesterly direction to its confluence with the St. Marys River to form the Maumee in Ft. Wayne, Indiana. It was historically known from numerous sites on the river. Watters (1988) reported it from eight sites in the 1980s and 1990s, but FD at only two of them. After sampling at 85 sites in the entire St. Joseph River system 1988, he considered the rayed bean to be "very uncommon" and of "sporadic occurrence" in the drainage.

The rayed bean apparently persists only at a couple of sites in the lower St. Joseph in Allen and DeKalb Counties, Indiana (Watters 1988, 1998). A few FD specimens were found in both studies. Watters (1988) reported it FD from 4.6% and as relics from 10.3% of the sites he sampled in the St. Joseph River system. He calculated a reduction of range in the St. Joseph system of 55.5%. Relative abundance was 0.1% in the entire system. Based on the limited recent information for the rayed bean, the viability and status of this population appears uncertain.

Watters (1988) outlined threats to the system, which included heavy metals and other chemicals (e.g., cyanide, chromium, cadmium, copper) from Edgerton, Ohio, and sewage, phenols, oil, cyanide, zinc, and other heavy metals from Montpelier, Ohio. Quarries located near the river are potential sources of sedimentation. Cedarville Reservoir, Indiana, impounded approximately 5 miles of the St. Joseph north of Ft. Wayne, isolating the only extant populations known in the river. Only relic shells were found below the reservoir in Watters' (1988) study. However, the site near Ft. Wayne that is thought to still harbor the rayed bean is immediately below a low-head dam at Johnny Appleseed Memorial Park.

Fish Creek: A tributary of the St. Joseph River, Fish Creek drains primarily Indiana, but eventually flows eastward into Ohio before joining the St. Joseph at Edgerton. Overlooked by Clark (1977), Hoggarth (1987) reported the rayed bean from one site in Ohio. It persists in Williams County, Ohio, and possibly DeKalb County, Indiana. Based on the appearance of FD shells, it inhabits the lower 10 miles or less of the stream (Watters 1988), but the viability and status of this population is uncertain (B. E. Fisher, Indiana Department of Natural Resources [IDNR], pers. comm., 2001).

Watters (1988) considered Fish Creek to be "the most pristine tributary of the St. Joseph system." Fish Creek is apparently the last stream harboring an extant population of the federally endangered white catspaw (*E. obliquata perobliqua*). The stream was not as prone to drought as are other area streams, he surmised, due to a prevalence of springs and a canopied channel. The watershed is sparsely populated and mostly in agriculture. A mussel kill at a site well upstream of the extant rayed bean reach was possibly the result of manure runoff from a hog farm (Watters 1998). A swamp-like area around river mile (RM) 12 separates the highly imperiled faunal elements found only in the lower creek from the upper system. A major diesel fuel spill from a ruptured pipeline in DeKalb County in 1993 resulted in a mussel kill in the lower portion of the stream (Sparks et al. 1999). It is not known if any rayed bean were affected by the spill.

Blanchard River: The Blanchard River is a tributary of the Auglaize River in the Maumee River system, in northwestern Ohio. First discovered in 1946, this population is one of the largest for the rayed bean rangewide. The rayed bean in the Blanchard is restricted to ~25-30 RMs in the upper portion of the stream in Hardin and Hancock Counties upstream of Findley (Hoggarth et al. 2000). They sampled 11 sites in 1994 and 1996, and found 250 live/FD specimens from 4 sites, and relic shells from 2 other sites Hoggarth et al. 2000; M.A. Hoggarth, Otterbein College (OC), pers. comm., 2002). Three sites yielded 55, 59, and 131 specimens. Amazingly, the rayed bean represented the fourth most common species in the drainage with a relative abundance of 11.5%. Much, but not all, of the FD shell material was sent to OSUM (M.A. Hoggarth, OC, pers. comm., 2002). This population is viable.

Threats to the rayed bean in the Blanchard include agricultural runoff and sedimentation. A "channel improvement" plan to remove gravel bars and channelize portions of the stream in the 1990s was thwarted by M.A Hoggarth (OC, pers. comm., 2002), who convinced the would-be perpetrators into limiting channel disturbance activities to some log jam removal work (Hoggarth et al. 2000).

Tymochtee Creek: Tymochtee Creek is a tributary to the upper Sandusky River, north central Ohio, which flows into the southwestern portion of Lake Erie. The rayed bean is known from three sites in a reach of stream in Wyandot County and was first collected in 1970 (OSUM 1970:0340). All collections of the rayed bean have been small, with not more than five FD shells (OSUM 1971:0287) in any collection. The last record was from 1996 (Museum of Fluviatile Mollusks [MFM] 19338), when a pair and three unpaired valves were collected. The condition of at least one of the valves indicated that the rayed bean is probably still extant in the stream, although no surveys for live individuals were conducted (H.D. Athearn, MFM, pers. comm., 2002). The rayed bean status in Tymochtee Creek is therefore currently unknown.

Ohio River system

The rayed bean was historically known from the Ohio River in the vicinity of Cincinnati, Ohio, downstream to the Illinois portion of the river. It undoubtedly occurred elsewhere in the upper main stem. Few historical records are known (mostly circa 1900), indicating that it became extirpated there decades ago. It was historically known from 67 streams, canals, and lakes in the system, representing roughly two-thirds of its total range. Ortmann (1925) considered the rayed bean to be "abundant in small streams" in the Ohio River system. Currently, only 12 streams and a lake are thought to have extant rayed bean populations in the system. The percentage of stream and other water body population losses in this river system (54 of 67, 81%) closely mirrors losses rangewide (83 of 106, 78%).

Allegheny River system: Ortmann (1909a) considered the rayed bean to be "nowhere abundant" in western Pennsylvania, referring primarily to the Allegheny River system. Nine streams and Chautauqua Lake historically harbored rayed bean populations. Currently, the rayed bean is found in half of these water bodies, but in good numbers in two streams in this drainage.

Allegheny River: The Allegheny River drains northwestern Pennsylvania and joins the Monongahela River at Pittsburgh to form the Ohio River. The population of rayed bean in the Allegheny is one of the largest known rangewide. Ortmann (1909a, 1919) was the first to report the rayed bean from the Allegheny. The population once stretched from Cataraugus County, New York, to Armstrong County, Pennsylvania.

Population information collected from 1998-2001 at four sites associated with a bridge replacement project at Kennerdell, Vanango County (i.e., two control, two relocation sites) yield quantitative data (R. Villella Bumgardner, USGS, pers. comm., 2002). Data at the relocation sites includes animals relocated from the bridge sites. Densities at these sites were as follows: control site 1 ranged from 0.25/foot^2 in 1998, 0.11/foot^2 in 1999, and 0.26/foot^2 in 2001; control site 2 ranged from 0.69/foot^2 in 1998, 0.35/foot^2 in 1999, and 0.41/foot^2 in 2001; relocation site 1 ranged from 0.05/foot^2 in 1998, 0.03/foot^2 in 1999, and 0.13/foot^2 in 2001; and relocation site 2 ranged from 0.41/foot^2 in 1998, 0.24/foot^2 in 1999, and 0.35/foot^2 in 2001. Counts for live specimens ranged from 61-191 at control site 1, 231-551 at control site 2, 27-327 for relocation site 1, and 172-473 for relocation site 2. Relative abundance at control sites ranged from 5.5-20.0% and at relocation sites from 2.8-12.4% over these years. Trend data over the four years was not as apparent at it was for French Creek (see account below). However, additional sampling effort at the direct impact area (DIA) under the Kennerdell bridge and in adjacent indirect impact areas upstream (UP) and two downstream (DOWN) in 2001 after bridge replacement completion resulted in the following densities: DIA 0.07/foot^2, UP 0.19/foot^2, proximal DOWN 0.08/foot^2, and distal DOWN 0.19/foot^2. These data indicate that rayed bean densities have not recovered to pre-construction levels in the DIA, which may have resulted from a combination of both construction and relocation effects (R. Villella Bumgardner, USGS, pers. comm., 2002).

Data from additional sampling efforts in the Allegheny upstream in Forest County were also made available (R. Villella Bumgardner, USGS, pers. comm., 2002). At Hunter in 2001, she reported eight live individuals, for an estimated density of 0.004/foot^2 and a relative abundance of 0.03%. During sampling at two closely located sites at West Hickory in 1999, she recorded no rayed beans in quadrats at the bridge site, but a total of seven live specimens were found in qualitative sampling (relative abundance 0.07%). At a site a short distance downstream from the bridge, four specimens were found in qualitative sampling for a relative abundance of 0.04%, and a density of 0.003/foot^2 was determined from quadrat work. Smith et al. (2001) reported a relative abundance from timed searches of 0.16% for the rayed bean at the West Hickory bridge replacement site.

Based on historical collections, it would appear that the rayed bean is more abundant now than it was historically. This trend may indicate that the rayed bean population in the Allegheny has indeed expanded in the past 100 years. Many streams in western Pennsylvania have improved water quality since Ortmann's time when he reported on the wholesale destruction of the fauna in several streams (Ortmann 1909b). However, it may also be an artifact of sampling, with limited access in historical times. Many older collections may have been made before a more thorough knowledge of the species' habitat was known. Regardless, the population in the Allegheny is one of the most important remaining rangewide today. It currently occurs from downstream of Allegheny (Kinzua) Reservoir in Warren County to the pool of Lock and Dam 8 in northern Armstrong County, a distance of over 100 RMs.

Nine locks and dams were constructed on the lower Allegheny River (72 RMs) from Armstrong County to Pittsburgh, which disrupted extensive historical riverine habitat for the rayed bean. However, it is currently found in pools 8 and 9. The construction of Kinzua Dam on the main stem (forming Allegheny Reservoir) destroyed habitat for the rayed bean on both sides of the Pennsylvania-New York border. Stream populations are now isolated on both sides of the reservoir (see following two accounts). Current threats to the rayed bean in the Allegheny River include channel maintenance activities, sedimentation, additional bridge replacement projects, and silvicultural activities (T. Proch, Pennsylvania Department of Environmental Protection [PDEP], pers. comm., 2002). Oil and gas extraction is accelerating in the watershed (R.M. Anderson, Service, pers. comm., 2002). Pollutants from these activities include brines and organics. Zebra mussels are dense in Chautauqua Lake, New York (S.A. Ahlstedt, USGS, pers. comm., 2002), where an historical population of the rayed bean occurred. There is a distinct possibility that they will move down the system, or upstream through the navigation channel into rayed bean populations in pools 8 and 9. Their potential expansion in the river bears monitoring. A large refinery in Warren is a potential source for pollutants in the Allegheny (R.M. Anderson, Service, pers. comm., 2002).

Olean Creek: Olean Creek is a tributary of the Allegheny River in western New York. A small population of the rayed bean is known from the lower portions of the stream. Strayer et al. (1991) reported the rayed bean from three sites during 1987-90 sampling, although just one live specimen was located with relic shells from the other two sites. At the live site for the rayed bean, 4 PH were expended. Only relic shells were found in Olean in 1994, but three live specimens were found in 2000 at the proposed construction site of the City of Olean Water Treatment Plant (Ecological Specialists, Inc. 2000). Age was qualitatively estimated to be between four and six years, while shell lengths were 1.1 to 1.3 inches. Collected only during their quantitative sampling (20, 2.7 foot^2 quadrats) effort, the rayed bean represented a relative abundance of 11.5% of the 7 live species sampled. Overall rayed bean density in the three sites sampled was estimated to be 0.06/foot^2. One of the specimens was a gravid female, perhaps indicating successful reproduction (Ecological Specialists, Inc. 2000). The age distribution of these specimens would also indicate recent recruitment into population. The current status of this population in Olean Creek is largely unknown, but it's apparently very tenuous considering current population levels. Relic specimens are now known from an eight mile reach of stream, with live individuals known from less than 1.5 miles of the lower creek.

Observations by D.L. Strayer (Institute of Ecosystem Studies [IES], pers. comm., 2002) notes that agricultural activities oftentimes are conducted without adequate stream buffers and cattle may have ready access to many Allegheny River system streams in western New York. Therefore, agricultural runoff and nutrient enrichment are concerns. The town of Olean provides sources of urban and suburban runoff into Olean Creek, in addition to the impacts from the water treatment plant construction, which were outlined by Ecological Specialists, Inc. (2000). Highway improvements are a threat to the rayed bean, as is an oil pipeline that is planned to cross the stream upstream of the rayed bean reach (Kathy O'Brien, New York Department of Environmental Conservation (NYDEC), pers. comm., 2002)

Cassadaga Creek: Cassadaga Creek is a tributary of Conewango Creek in the Allegheny River system, in western New York. A small population of the rayed bean is known from a single riffle (Ross Mills) in the lower creek north of Jamestown. Four live specimens were found in

1994 (Strayer 1995). Muskrat middens collected during the winter of 2002 produced 38 FD specimens with a size range of 0.8-1.7 inches (M. Clapsadl, State University of New York at Fredonia, pers. comm., 2002). Quadrat data at this site indicates a rayed bean density of 0.07/foot^2. Although the rayed bean is not known from other sites in the stream, its population status would appear to fairly healthy at this site. However, the highly restricted extent of the population makes it extremely susceptible to a stochastic event (e.g., toxic chemical spill).

Threats to this population include construction activities, agricultural practices, and nutrification (see Olean Creek account). Riparian lands are oftentimes farmed up to the stream bank, and cattle have been observed in the stream (D.L. Strayer, IES, pers. comm., 2002). The stream is therefore constantly turbid, even at low-flow conditions. Highway improvements are a threat to the rayed bean, as is an oil pipeline that is planned to cross the stream (Kathy O'Brien, NYDEC, pers. comm., 2002).

French Creek: French Creek is a major tributary of the middle Allegheny River in western New York and northwestern Pennsylvania. One of the largest rayed bean populations known is found in much of the lower portions of the stream in four Pennsylvania counties (the species is not known from the New York portion of stream). Ortmann (1909a, 1919) reported it from two counties, Crawford and Vanango. Not until circa 1970 did the population become more thoroughly known, with museum lot sizes indicating sizable populations at several sites, particularly in the lower reaches of the stream.

Recent collections indicate that population levels remain high. Population information collected from 1998-2001 at four sites associated with a bridge replacement project at Utica, Vanango County (i.e., two control, two relocation sites), yield quantitative data (R. Villella Bumgardner, USGS, pers. comm., 2002). Data at the relocation sites includes animals relocated from the bridge sites. Densities at these sites were as follows: control site 1 ranged from 0.35/foot^2 in 1998, 0.21/foot^2 in 1999, and 0.20/foot^2 in 2001; control site 2 ranged from 0.48/foot^2 in 1998, 0.29/foot^2 in 1999, and 0.40/foot^2 in 2001; relocation site 1 ranged from 0.54/foot^2 in 1998, 0.45/foot^2 in 1999, and 0.18/foot^2 in 2001; and relocation site 2 ranged from 0.31/foot^2 in 1998, 0.17/foot^2 in 1999, and 0.15/foot^2 in 2001. Counts for live specimens ranged from 126-238 at control site 1, 79-135 at control site 2, 138-407 for relocation site 1, and 124-368 for relocation site 2. Relative abundance at control sites ranged from 14.6-25.2% and at relocation sites from 11.5-18.2% over the four-year period. These data show a decline in rayed bean density, particularly noticeable at relocation sites (R. Villella Bumgardner, USGS, pers. comm., 2002). A negative effect of relocating animals may be apparent from these numbers.

Threats to the rayed bean in French Creek include sedimentation and municipal runoff and effluents. Oil and gas development wastes (e.g., brines, organics) are a concern in parts of the watershed (T. Proch, PDEP, pers. comm., 2002). The zebra mussel is known from a headwater impoundment, Edinboro Reservoir, and three zebra mussels have been found in the middle portion of French Creek near Vanango (R.M. Anderson, Service, pers. comm., 2002). If these populations expand rapidly like they have in so many systems, one of the very best rayed bean populations known will be at risk. Close monitoring of the zebra mussel distribution in the stream is highly recommended. Also at risk in French Creek are abundant populations of two federally endangered mussels, northern riffleshell (*E. torulosa rangiana*) and clubshell (*Pleurobema clava*).

Cussewago Creek: Cussewago Creek is a tributary of lower French Creek, with its confluence at Meadville, Crawford County, Pennsylvania. A small population was reported in 1991 from Cussewago Creek (T. Proch, PDEP, pers. comm., 2001). The rayed bean is thought to persist in the stream, but its current status is unknown.

Walhonding River: The Walhonding River is a tributary of the upper Muskingum River system, in central Ohio, forming the latter river at its confluence with the Tuscarawas River at Coschocton. Small numbers are represented in OSUM collections from the 1960s and 1970s. During 1991-93, Hoggarth (1995-96) discovered a single live and single FD specimens at his site 16, and 4 relic specimens were found at sites 7, 17, and 19. Relative abundance was ~0.01%. A small rayed bean population is thought to remain in the Walhonding currently. Its status is unknown, but must be deemed highly tenuous given the population size and the reduction in habitat over the past few decades (see below). The population is probably on its way towards extirpation (M.A Hoggarth, OC, pers. comm., 2002).

A major impoundment has severely curtailed potential habitat for the rayed bean population in the Walhonding River. The construction of Mohawk Dam on the main stem Walhonding ~30 RMs above its mouth destroyed many miles of potential habitat. Four OSUM collections were made in the reach of river now flooded behind Mohawk Dam. Between 1961 and 1977, an additional six OSUM collections of the rayed bean were made from the lower Mohican River, a Walhonding tributary that is now flooded by the reservoir. Current threats to the rayed bean in this system are sedimentation, agricultural runoff, and flow releases from Mohawk Dam.

Scioto River system: The Scioto River system, central and south central Ohio, is a major northern tributary of the Ohio River. A once large meta-population of the rayed bean occupied 11 streams, the Ohio and Erie Canal, and Buckeye Lake. At least 17 sites yielded OSUM specimens in the Olentangy River alone, although the rayed bean is thought to be extirpated from this river today. Sizable populations were noted in at least the Olentangy River and Alum and Big Darby Creeks, based on OSUM collections primarily from the 1960s. A series of system reservoirs mostly north of Columbus reduced habitat and contributed to the elimination of some populations in several streams (e.g., Alum, Big Walnut, Deer Creeks; Olentangy, Scioto Rivers). The location of the Columbus Metropolitan Area in the heart of the watershed has also taken a major toll on the species. The Scioto rayed bean meta-population has accordingly been decimated by anthropogenic factors. Currently, a remnant population remains only in Scioto Brush Creek.

Scioto Brush Creek: Scioto Brush Creek is a small western tributary of the lower Scioto River in Scioto County, south-central Ohio. Watters (1992) discovered the rayed bean in this stream in 1987, reporting two FD and 2 relic specimens from one site and a relic specimen from a second site. He collected 20 sites in the system. This is apparently the only rayed bean population remaining in the entire Scioto River system, but its status is uncertain. Threats are probably agricultural runoff and sedimentation.

Little Miami River: The Little Miami River is a northern tributary of the Ohio River in southwestern Ohio, flowing into the latter at the eastern fringe of Greater Metropolitan Cincinnati. Hoggarth (1992) surveyed over 100 sites in the entire system. He found one live specimen at a site in Warren County and possibly (contradictory data in his paper) a subfossil shell at another site. The latter site may have been the same as that reported for a pre-1863 record (Hoggarth 1992). Relative abundance for the rayed bean in the Little Miami River was 0.1% based on these two specimens. The rayed bean appears to be very rare in the Little Miami; it has been found extant at only 1 of 46 main stem sites. Its status in the river is uncertain, but apparently very tenuous and probably on its way out (M.A Hoggarth, OC, pers. comm., 2002). Hoggarth (1992) highlighted the “fragile nature” of the extant unionid community in the system, while noting that localized reaches of the Little Miami were “severely impacted.” He suggested that water quality improvements were needed to protect the mussel fauna. Sedimentation, agricultural runoff, and developmental impacts from metropolitan Cincinnati threaten the population.

East Fork Little Miami River: The East Fork is an eastern tributary of the lower Little Miami River, with its confluence at the eastern fringe of Greater Metropolitan Cincinnati. According to OSUM records, eight FD specimens were reported from a site in eastern Clermont County in 1973. Hoggarth (1992) reported one live, three FD, and one relic rayed bean from three sites in an ~7 RM stretch of the East Fork in western Clermont and adjacent Brown County (including the 1973 site). He sampled a total of 27 sites on the East Fork. Relative abundance for the rayed bean was 0.2%. The status of the rayed bean in the East Fork is uncertain, but probably of doubtful persistence (M.A Hoggarth, OC, pers. comm., 2002). Harsha Reservoir on the East Fork destroyed several miles of potential stream habitat for the rayed bean a few miles downstream of the extant population. Current threats include sedimentation and agricultural runoff.

Stillwater River: Stillwater River is a western tributary of the middle Great Miami River in southwestern Ohio. The rayed bean is known from two specimens, one FD and a relic, collected in 1987 at two sites a short distance apart upstream and downstream of the Miami-Montgomery County line (OSUM records). The FD specimen was found at the downstream site in northern Montgomery County. Both sites occur in the footprint of Englewood Reservoir (constructed circa 1920), a retarding basin designed to hold back flood waters to be slowly released through the dam (D. Johnson, Miami Conservancy District, pers. comm., 2002). As such, the “reservoir” is normally a free-flowing river except in times of flood, therefore providing riverine habitat that is oftentimes destroyed by permanently impounded reservoirs. Five such structures have been created in the upper Great Miami River system. The rayed bean in the Stillwater may be extant, but its status is currently unknown and in significant peril. The population may also be on its way out (M.A Hoggarth, OC, pers. comm., 2002), similar to the other Ohio River tributary populations in southwestern Ohio.

The rayed bean is threatened by sedimentation. A borrow pit above the Englewood Dam has nearly filled with sediment, creating a marsh-like area just a mile downstream from the site yielding the FD shell in 1987 (D. Johnson, Miami Conservancy District, pers. comm., 2002). The location of the population in the northwestern fringes of the Greater Dayton Metropolitan area is also a concern.

Tippecanoe River: The Tippecanoe River is a large northern tributary of the middle Wabash River in north-central Indiana. The first records for the rayed bean date to circa 1900 (Daniels 1903). Historically, this species was known from numerous sites in six counties in the Tippecanoe. Cummings and Berlocher (1990) recorded it from three sites in Fulton, Pulaski, and Carroll Counties, but all shells were relic.

Survey work in the early 1990s (Ecological Specialists, Inc. 1993) indicated very high diversity in the Tippecanoe River. Collectively, 48 mussel species were found live or FD at 30 sites. They reported 36 rayed bean specimens from 15 sites, but most of them were relic. A total of 12 FD specimens were found at 5 sites sampled in 1992 in Pulaski (7 specimens), Carroll (2), and Tippecanoe (3) Counties. Live specimens have been observed at a site in Pulaski County in 1991 and from at least one site in Tippecanoe County in both 1991 and 1995 (Ecological Specialists, Inc. 1993; B.E. Fisher, IDNR, pers. comm., 2001). The lone Tippecanoe County specimen collected in 1991 by Ecological Specialists, Inc. (1993) was 1.5 inches long and qualitatively estimated to be 7 years old. Two live individuals were found in Carroll County in 2001 during the County Route 150 North bridge replacement survey, where three live federally endangered fanshell (*Cyprogenia stegaria*) were also found (B.E. Fisher, IDNR, pers. comm., 2001). The rayed bean "is apparently on the decline" in the river according to Ecological Specialists, Inc. (1993), who thought that "[t]he only viable population may be at French Creek." However, the Tippecanoe rayed bean population was thought to be recruiting by B.E. Fisher (IDNR, pers. comm., 2001), but the population appears tenuous and its long-term viability questionable.

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

Lake Maxinkuckee: Lake Maxinkuckee is a glacial lake in the headwaters of the Tippecanoe River, north central Indiana. The rayed bean has been known from the lake for a century (Blatchley 1901), with several other records in the early 1900s. A 1997 OSUM record for the lake noted 7 FD specimens collected at its outlet to the Tippecanoe River. This population is thought to persist, but massive numbers of zebra mussels are an imminent threat to mussel populations in the lake and may currently be impacting the rayed bean (B.E. Fisher, IDNR, pers. comm., 2002). Fisher, who made the 1997 OSUM collection, noted that many native mussels had zebra mussels attached to them; the zebra mussels were apparently contributing to native mussel mortality. The status of the rayed bean in Lake Maxinkuckee is therefore highly tenuous, and its long-term health extremely imperiled.

Sugar Creek: Sugar Creek is a tributary of the East Fork White River in the lower Wabash River system in south-central Indiana. A population was first reported there in 1930. Harmon (1992) extensively sampled Sugar Creek, conducting surveys at 27 main stem and 16 tributary sites. He found FD specimens at three main stem sites and relic specimens from two other sites. These sites were consecutive, with the sites with FD material found in the lowermost six miles of stream (from County Route 400 South downstream to Camp Atterbury in Johnson County). The status and viability of this tenuous population is uncertain (B.E. Fisher, IDNR, pers. comm., 2001). Threats to the Sugar Creek rayed bean population are sedimentation and agricultural runoff. A small mill dam at Camp Atterbury has been breached, but is thought to have a minimal effect on stream flows (Harmon 1992).

Tennessee River system

Historically, the rayed bean was known from the Tennessee River and 11 of its tributary streams. Ortmann (1924) reported that the rayed bean was a "rather rare" species. However, museum lots show that it was fairly common in some streams (e.g., North Fork Clinch, Duck Rivers). The last live rayed bean records in the system, with the exception of the Duck River, were from the 1960s. The species held on in the Duck until the early 1980s. Recent intensive sampling in the Duck watershed has failed to locate even a relic shell of the rayed bean (S.A. Ahlstedt, USGS, pers. comm., 2002). Tributaries in this system have been extensively sampled over the past 25 years. It is highly probable that this species is extirpated from the entire Tennessee River system.

The rayed bean population in the Tennessee River system was conspicuously disjunct from other populations, particularly considering its absence from the adjacent Cumberland River system. Unlike many northern populations, the rayed bean in the Tennessee system was generally found in larger creeks and rivers. It is possible that the Tennessee population was a different taxon from the rayed bean in the remainder of the Ohio River system and elsewhere. Numerous endemic mussels, fishes, and other aquatic organisms are known from this system, which has been geologically stable for eons longer than glaciated streams in much of the remainder of the rayed bean range. Although much shell material is available in museums, material suitable to conduct genetic and anatomical studies on its identity may be largely unavailable. We may never know the true taxonomic status of the rayed bean in the Tennessee River system.

Summary of Extant Populations: A status review was conducted by the Service in 1989 (W.A. Tolin, Service, pers. comm., 2002), but the rayed bean was not deemed to warrant Federal listing at that time. However, the information presented herein indicates that its status has changed. According to Strayer and Jirka (1997), "[t]ypically an uncommon species, *V. fabalis* has declined or disappeared over most of its range". The rayed bean has experienced a significant reduction in range and most of its populations are disjunct, isolated, and with few exceptions appear to be declining (West et al. 2000). The extirpation of this species from over 80 streams and other water bodies within its historical range indicates that substantial population losses have occurred. Relatively few streams are thought to harbor long-term viable populations (e.g., Sydenham, Blanchard, Allegheny Rivers; French Creek). Interestingly, the best remaining populations are found in the far northern portions of its range. The rayed bean appears to be extirpated from the southern unglaciated portion of its range. Small population size and restricted stream reaches of current occurrence are a real threat to the rayed bean due to the negative aspects of genetics of small geographically isolated populations (see "Factor E. Other natural or manmade factors affecting its continued existence" below). Given this compilation of current distribution, abundance, and trend information, the relative imperilment of the rayed bean 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 rayed bean in the Great Lakes drainages and the Ohio and Tennessee River systems 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 of the factors in this section will continue to impact extant rayed bean populations.

Impoundments

Impoundments result in the dramatic modification of riffle and shoal habitats and the resulting loss of mussel resources, especially in larger rivers. Neves et al. (1997) and Watters (2000) reviewed the specific effects of impoundments on freshwater mollusks. Dams interrupt most of a river's ecological processes by modifying flood pulses; controlling impounded water elevations; altering water flow, sediments, nutrients, and energy inputs and outputs; increasing depth; decreasing habitat heterogeneity; decreasing stability due to subsequent sedimentation; blocking host fish passage; and isolating mussel populations from fish hosts. Even small low-head dams can have some of these effects on mussels. The reproductive process of riverine mussels is generally disrupted by impoundments making the rayed bean unable to successfully reproduce and recruit under reservoir conditions. The rayed bean, however, historically occurred in the wave-washed shallows of several glacial lakes, an environment very different from that found in impoundments.

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 sediment loads from bank sloughing; and altered host fish communities. Coldwater releases from large non-navigational dams and scouring of the river bed from highly fluctuating, turbulent tailwater flows have also been implicated in the demise of mussel faunas (Layzer et al. 1993). There is no evidence that the rayed bean may persist in hypolimnetic tailwater conditions. Cold tailwaters below Tims Ford Dam on the Elk River and Norris Dam on the Clinch River, Tennessee, may have helped eliminate the rayed bean in those streams.

Population losses due to impoundments have probably contributed more to the decline and imperilment of the rayed bean and other Ohio River system mussels than has any other single factor. Stream habitat throughout significant portions of the range of the rayed bean has been impounded. The majority of the Tennessee River main stem and many of its largest tributaries are now impounded. For example, over 2,300 river miles (about 20 percent) of the Tennessee River and its tributaries with drainage areas of 25 square miles or greater were impounded by TVA by 1971 (Tennessee Valley Authority 1971). A total of 36 major dams are located in the Tennessee River system. Watters (2000) summarizes the tremendous loss of mussel species from various portions of the Tennessee River system. The rayed bean has been eliminated from the Tennessee River system (see account under "Current and historical populations, and population trends" above). This impoundment scenario is all to familiar in many other parts of its range, and include numerous navigational locks and dams (e.g., Ohio, Allegheny, Muskingum, Green Rivers), some high-wall dams (e.g., Walhonding, Tippecanoe Rivers), and many low-head dams (e.g., Duck River) that have contributed to the loss of rayed bean habitat. Sediment accumulations behind dams of all sizes generally preclude the occurrence of the rayed bean.

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. The only known rayed bean populations that remain in navigation channels are in the upper two navigation pools of the Allegheny River. These activities may have contributed to the elimination of the rayed bean from the Ohio, lower Allegheny, and Muskingum Rivers, and potentially others.

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 (Havlik and Marking 1987, Keller and Zam 1991), 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 (Keller and Zam 1991, Naimo 1995, Jacobson et al. 1997, Keller and Lydy 1997).

Among pollutants, ammonia has been shown to be lethal to mussels at concentrations of 5.0 ppm (Havlik and Marking 1987). Ammonia is oftentimes associated with animal feedlots, nitrogenous fertilizers, and the effluents of out-dated municipal wastewater treatment plants (Goodreau et al. 1993). In stream systems, ammonia is most prevalent at the substrate/water interface (Frazier et al. 1996). Due to its high level of toxicity and the fact that the highest concentrations occur in the microhabitat where mussels live, ammonia should be considered among the factors potentially limiting survival and recovery of mussels at some locations (Augspurger et al. in prep.). A congener of the rayed bean, the rainbow (*Villosa iris*), is very sensitive to common toxicants, such as ammonia and monochloramine (Goodreau et al. 1993) and copper (Jacobson et al. 1997). If the rayed bean is also sensitive to pollution, this data suggests that contaminants are at least partially responsible for the demise of the rayed bean rangewide (West et al. 2000).

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 rayed bean populations, providing ample opportunities for some pollutants to enter streams.

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 oxygen levels resulting from over-enrichment (Sparks and Strayer 1998). Because interstitial habitats are also the typical habitat of adult rayed beans, oxygen reductions may also negatively affect them. 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 rayed bean.

Numerous streams throughout the range of the rayed bean have experienced mussel and fish kills from toxic chemical spills (Sparks et al. 1999), particularly in the upper Tennessee River system in Virginia where several major spills have been documented (Neves 1986, 1991). Catastrophic pollution events, coupled with pervasive sources of contaminants (e.g. municipal and industrial pollution, coal-processing wastes), probably contributed to the elimination of the rayed bean in the Clinch River several decades ago (Neves 1991). An alkaline fly ash pond spill in 1967 and a sulfuric acid spill in 1970 on the Clinch 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). The timing of this single event roughly coincides with the demise of the rayed bean in the Clinch River. A major diesel fuel spill from a ruptured pipeline in Fish Creek, DeKalb County, Indiana, in 1993 resulted in a mussel kill in the lower portion of the stream (Sparks et al. 1999). Chemical spills will invariably continue to occur and have the potential to completely eliminate rayed bean 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 historical rayed bean habitat in the Allegheny River system in western Pennsylvania (Ortmann 1909b) and the upper Tennessee River system, Virginia (Kitchel et al. 1981). The low pH commonly associated with mine runoff can reduce glochidial encystment rates (Huebner and Pynnönen 1992). Residual acid mine runoff may thus impact mussel recruitment. No rayed bean populations are thought to remain in drainages with current coal mining activities. However, if coal mining activities are reinitiated in western Pennsylvania, they could become a threat to populations in lower French Creek and the Allegheny River. Oil and gas exploration is accelerating in western Pennsylvania. Pollutants from these activities include brines and organics. These activities are also a threat to rayed bean populations in these streams.

Instream gravel mining has been implicated in the destruction of mussel populations (Hartfield 1993). Negative impacts associated with gravel mining include stream channel modifications (e.g., altered habitat, disrupted flow patterns, sediment transport), water quality modifications (e.g., increased turbidity, reduced light penetration, increased temperature), macroinvertebrate population changes (e.g., elimination, habitat disruption, increased sedimentation), and changes in fish populations (e.g., impacts to spawning and nursery habitat, food web disruptions) (Kanehl and Lyons 1992, Roell 1999). Gravel mining activities may be a localized threat in some streams with extant rayed bean populations. Gravel mining has been a long-term problem in the Elk River, Tennessee, and may have contributed to the demise of its rayed bean population.

Sedimentation

Siltation and general sedimentation runoff is a pervasive problem in streams and has been implicated in the decline of stream mussel populations (Ellis 1936, Marking and Bills 1979, Vannote and Minshall 1982, Dennis 1985, Brim Box 1999, Fraley and Ahlstedt 2000). Sources, biological effects, and the control of sediment in streams were thoroughly reviewed by Waters (1995), while Brim Box and Mossa (1999) reviewed how mussels are specifically affected by sediment and discussed land-use practices that may impact mussels. Specific biological impacts on mussels from excessive sediment include reduced feeding and respiratory efficiency from clogged gills, disrupted metabolic processes, reduced growth rates, increased substrate instability, limited burrowing activity, and physical smothering (Ellis 1936, Stansbery 1971, Marking and Bills 1979, Vannote and Minshall 1982, Waters 1995). Studies tend to indicate that the primary impacts of excess sediment on mussels are sublethal, with detrimental effects not immediately apparent (Brim Box and Mossa 1999). The physical effects of sediment on mussels appear to be multifold, and include changes in suspended and bed material load; bed sediment composition associated with increased sediment production and run-off in the watershed; channel changes in form, position, and degree of stability; changes in depth or the width/depth ratio, 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. The habit of the rayed bean in burrowing deep into interstitial substrates makes it more susceptible to degradation of this 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 rayed bean, appear to be experiencing recruitment failure. Many Midwestern, Northeastern, and Southeastern streams have increased turbidity levels due to siltation. 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).

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 % 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 and increase run-off and trampling increases the probability of erosion (Armour et al. 1991, Trimble and Mendel 1995, Brim Box and Mossa 1999).

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 Greater Metropolitan Columbus area, the once substantial population in the middle Scioto River system has been decimated. Extant populations still occur in the Greater Metropolitan Detroit and Fort Wayne areas, but are probably declining. Developmental activities may threaten isolated rayed bean populations in some other regions (e.g., western New York, northwestern Pennsylvania). 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 rayed bean and other mussel populations susceptible to depressed stream levels.

B. Overutilization for commercial, recreational, scientific, or educational purposes. Native Americans were known to have harvested the rayed bean for food, but because of its size utilization rates were very low (Bogan 1990). Commercial endeavors, such as pearling and the pearl button industry, resulted in the destruction of millions of mussels in much of the country (Anthony and Downing 2001). Again, due to its size, it is unlikely that the rayed bean was collected by pearlers and other commercial interests in later times. 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).

The rayed bean is not a commercially valuable species. An increasingly rare species like the rayed bean may increasingly be sought by lay and experienced collectors. Most stream reaches inhabited by this species are restricted, and its populations are generally 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).

Muskrats are a perceived localized threat to mussel populations, according to Neves and Odum (1989). They concluded that this activity could limit the recovery potential of endangered mussel species or contribute to the local extirpation of already depleted mussel populations. However, muskrats were not thought to be a threat to the rayed bean by West et al. (2000), due to their general selection of mussels larger than 1.4-1.6 inches long (Convey et al. 1989, Hanson et al. 1989). Neves and Odum (1989) also noted that muskrats did not select for small unionids (e.g., moccasinshell, *Medionidus conradicus*). Nevertheless, some muskrat predation on the rayed bean has recently been documented (e.g., Cassadaga Creek, NY; see "Current and historical populations, and population trends"), but is generally considered insignificant.

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 rayed bean is not thought to be significant.

D. The inadequacy of existing regulatory mechanisms.

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

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

E. Other natural or manmade factors affecting its continued existence.

Population Fragmentation and Isolation

The majority of the remaining populations of the rayed bean are generally small and geographically isolated. The patchy distributional pattern of populations in short river reaches makes them much more susceptible to extirpation from single catastrophic events, such as toxic chemical spills (Watters and Dunn 1993-94). Furthermore, this level of isolation makes natural repopulation of any extirpated population impossible without human intervention. Population isolation prohibits the natural interchange of genetic material between populations, and small population size reduces the reservoir of genetic diversity within populations, which can lead to inbreeding depression (Avise and Hambrick 1996).

Genetic Considerations

The likelihood is high that some populations of the rayed bean 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 rayed bean populations rangewide, a potential condition exacerbated by its reduced range and increasingly isolated populations. If these trends continue, further significant declines in total rayed bean population size and consequent reduction in long-term viability may soon become apparent. The present distribution and status of the rayed bean 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 Great Lakes drainages and the Ohio and Tennessee River systems. Historically, there were presumably no absolute barriers preventing genetic interchange among its tributary sub-populations that occurred in various streams and lakes. With the completion of numerous dams, some main stem rayed bean populations were lost, and tributary 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 rayed bean (see "Description, Biology, and Life History" section above) would potentially take many years to expire post-impoundment. Without the level of genetic interchange the species experienced historically (i.e., without barriers such as reservoirs), small isolated populations that may now be comprised predominantly of adult specimens could be slowly dying out. Even given the improbable absence of the impacts addressed in "Factors A through D" above, we may lose smaller isolated populations of this species to the devastating consequences of below-threshold effective population size. In reality, degradation of these isolated stream reaches resulting in ever decreasing patches of suitable habitat is contributing to the decline of the rayed bean. The fact that only 22 streams and a lake continue to harbor populations of the rayed bean compared to 106 water bodies of historical occurrence may be mute testimony to this phenomenon.

Alien Species

Various alien or nonnative species of aquatic organisms are firmly established in the range of the rayed bean. The alien species that poses the most significant threat to the rayed bean 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 have attached in large numbers to the shells of live native mussels and have been implicated in the loss of mussel beds. Fouling impacts include impeding locomotion (both laterally and vertically), interfering normal valve movements, deforming valve margins, and locally depleting food resources and increasing waste products. Heavy infestations of zebra mussels on mussels may overly stress the animals by reducing their energy stores. They may also reduce food concentrations to levels too low to support reproduction or even survival in extreme cases. Other ways in which zebras may impact native mussels is potentially through filtering their sperm and possibly even their tiny glochidia from the water column. Habitat for native mussels may also be degraded by large deposits of zebra mussel pseudofeces (Vaughan 1997).

Overlapping much of the current range of the rayed bean, zebra mussels are thoroughly established in the Great Lakes drainages and much of the Ohio River system. Populations of the rayed bean have been eliminated by the zebra mussel in Lakes Erie and Tippecanoe and the Detroit River. The greatest current potential for present zebra mussel impacts to the rayed bean appears to be in the Lake St. Clair drainages, Allegheny and Tippecanoe Rivers, French Creek, and Lake Maxinkuckee. In addition, there is long-term potential for zebra mussel invasions into other systems that currently harbor rayed bean populations.

The Asian clam (*Corbicula fluminea*) has spread throughout the range of the rayed bean since its introduction 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 (Yeager et al. 2001).

Current protective status under state/provincial/tribal/Federal laws and regulations.
The rayed bean was first given conservation status by the Service in the late 1980s as a category 2 candidate. The Nature Conservancy considers it to be a G1G2 species; the vast majority of sub-national ranks are S1.The American Malacological Society and American Fisheries Society consider the rayed bean to be threatened (Williams et al. 1993).

This species is state-listed in all five of the states that are thought to harbor extant populations. The level of protection it receives from state-listing varies from state to state. The Little Miami River is an Ohio Scenic River. Such designation provides basic protection for the river and its small rayed bean population, but does little to curb activities in the watershed that might threaten this species (e.g., sedimentation, agricultural runoff, developmental activities). State and provincial levels of protection status are outlined by West et al. (2000).

In Canada, the Committee on the Status of Endangered Wildlife in Canada designated the rayed bean an endangered species in 1999 (J.L. Smith-Metcalfe, Environment Canada [EC], pers.

comm., 2002). However, because Canada does not currently have endangered species legislation, the rayed bean receives no protection at the national level. The Province of Ontario has legislated an Endangered Species Act, but it has not regulated mussels, which precludes legal protection for the rayed bean (J.L. Smith-Metcalfe, EC, pers. comm., 2002).

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 rayed bean or in their respective watersheds. However, vast tracts of riparian lands in rayed bean streams are privately owned. The rayed bean is a riverine species. The prevalence of privately held riparian lands in streams with extant populations somewhat diminishes the level of importance afforded by public lands that may implement various landuse restrictions. Riparian activities that occur outside or upstream of public lands may be pervasive and have a profound impact on their populations. Habitat protection benefits on public lands may therefore easily be negated by detrimental activities upstream in the watershed. Following are some of the more significant public lands associated with important rayed bean populations.

The Nature Conservancy has made at least two streams harboring extant populations of the rayed bean bioreserves: Fish Creek, Indiana and Ohio; and French Creek, Pennsylvania and New York. 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 the lower Great Lakes basin, the Port Huron State Game Area is located on the Black River and lower Mill Creek. Johnny Appleseed Memorial Park is located on the lower St. Joseph River and is thought to harbor an extant rayed bean population. In the Ohio River system, Clear Creek State Forest and State Game Lands No. 86 are located on the Allegheny River. Parcels of Allegheny National Forest occur in some small tributaries of the Allegheny. The Miami Conservancy District owns lands associated with the rayed bean population in the Stillwater River.

Several parcels of public lands are known in the Wabash River system. Along the Tippecanoe River these include Winamac City Park (which harbors an extant rayed bean population), Potawatomi Wildlife Park, Winnamac Fish and Wildlife Area, Tippecanoe River State Park, and Tippecanoe River and Sandhill Nature Preserves. The lower main stem of Sugar Creek, Indiana, occurs in Camp Atterbury Maneuver Training Center and Atterbury Fish and Wildlife Area.

Past, current, and anticipated conservation activities undertaken for the benefit of the species or its habitat:

- Funding Programs & Settlements

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 rayed bean populations.

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), Landowners Incentives Program, National Fish and Wildlife Foundation (NFWF) habitat programs, and numerous other Federal programs are potential sources of money for rayed bean habitat restoration and conservation.

Settlements from large chemical spills have been negotiated and restoration plans written to help mitigate for spill impacts. Sparks et al. (1999) outlined the Fish Creek Restoration Plan, which was written for a diesel fuel spill in northeastern Indiana in 1993. The plan focused on five primary objectives: 1) enhancing mussel recovery, 2) improving water quality, 3) protecting the riparian corridor, 4) conducting public outreach efforts, and 5) monitoring restoration plan success. Approximately $2.5 million of settlement money is going towards these goals in Fish Creek. 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.

- 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 rayed bean, receive no regulatory protection under the federal Endangered Species 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 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 rayed bean have made imperiled mussels a high priority resource for conservation. The Ohio River Valley Ecosystem (ORVE), Mollusk Subgroup determined the need for this status review. Ecosystem teams will be a source for identifying future funding needs for the rayed bean.

- 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, comprising the headwaters of the Tennessee River system (among other drainages), aquatic issues form a major part of the outreach efforts in the ecosystem among Service representatives and partners. Representative projects have included posters and videos highlighting aquatic faunal groups, a riparian restoration and conservation video for streamside landowners, endangered species pamphlets, and mussel trunks (outreach/education kits) for educators

The spread of the zebra mussel threatens many rayed bean populations (see "Current and historical populations, and population trends" and "Factor E. Other natural or manmade factors affecting its continued existence"). Public outreach efforts to stem the spread of this invader, such as signs at boat ramps, are in place in many areas (e.g., Sydenham River; D.A. Woolnough, ISU, pers. comm., 2002). A web site (www.sydenhamriver.on.ca) provides a recovery strategy for rare mussels in the Sydenham while outlining perceived threats to native mussel species in that stream.

- Research & Surveys

Survey work continues in many portions of the range of the rayed bean. For instance, intensive sampling is currently planned for portions of the lower Allegheny River (R. Villella Bumgardner, USGS, pers. comm., 2002) and southeastern Michigan streams (P. Badra, MNFI, pers. comm., 2001). Information gathered from these surveys will help determine its population status and generates other data useful for conservation management and recovery efforts.

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

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

Prioritize Streams & Watersheds: Streams, stream reaches, lakes, 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 rayed bean 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 rayed bean. 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 rayed bean 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 rayed bean.

Initiate more habitat restoration programs: More watershed-level, community-based riparian habitat restoration projects should be initiated in high biodiversity streams harboring the rayed bean (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 rayed bean and other mussels, these standards should be adjusted to better conserve mussel resources.

Monitor populations & habitat conditions: A monitoring program should be developed and implemented to evaluate efforts, monitor population levels and habitat conditions, and assess the long-term viability of extant, newly discovered, augmented, and reintroduced rayed bean 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 rayed bean 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 rayed bean 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 rayed bean populations. The purpose of a stress analysis is to determine the entire suite of stressors to the rayed bean 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 informed listing decision; Additional survey work may be warranted in some river systems (e.g., upper Allegheny River system in western New York). 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 rayed bean for consideration for candidate status.

b. to bring about recovery

Determine additional hosts: Several darters apparently serve as host fishes for the rayed bean (see "Summary of biology and natural history"). Other fishes potentially serve as host for this species. Knowing all its host fishes rangewide will facilitate rayed bean recovery.

Develop propagation technology: Propagation technology for the rayed bean 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: Very little information is available with regard to the life history of the rayed bean. Additional biological information will be needed in order to successfully implement the recovery tasks. In addition, the species habitats (e.g., relevant physical, biological, chemical components) for all life history stages needs to be elucidated. The sensitivity of each life stage to contaminants and general threats to the species also need investigating.

Monitor zebra mussel populations: Monitoring existing populations of the zebra mussel and its spread into new systems should be implemented in the most at-risk systems. These include, among others, the lower Great Lakes drainages, and the Allegheny and Tippecanoe River systems.

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

Develop parameters for species augmentation: A set of biological, ecological, and habitat parameters will need to be developed to determine if an extant rayed bean population will be suitable for species augmentation. This is particularly important in habitats that may be considered marginal (e.g., where the rayed bean 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 reintroduction: A set of biological, ecological, and habitat characterization parameters will need to be developed to determine if a site will be suitable for rayed bean 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 rayed bean. However, survey work to search for potentially new rayed bean populations, thought to be extirpated populations, and to assess the status of presumably small populations would be beneficial in several rivers for recovery and conservation purposes. These streams should be prioritized in order of importance to achieve this recovery goal with limited funding resources.

Investigate reasons for rangewide differences in survival: A research project should be designed to determine why the rayed bean is doing relatively well in some glaciated northern streams and why it has disappeared from the southern, unglaciated portion of its range.

Investigate possible taxonomic distinction of populations: A rangewide phylogenetic study on the rayed bean should be conducted to determine if there are any populations that may be taxonomically distinct. There is a possibility that the disjunct population in the upper Tennessee River system was a unique population. Unfortunately, the rayed bean is now extirpated from this system.

Develop & implement cryogenic techniques: Developing and implementing cryogenic techniques to preserve rayed bean 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 III.

APPENDIX I

Rayed Bean (*Villosa fabalis*) 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 Great Lakes System		
Pigeon River, Lagrange County, IN	Watters (1996)	1996 R
Lower Great Lakes System		
Black River, St. Clair County, MI	P. Badra (Michigan Natural Features Inventory, pers. comm., 2001)	2001
Mill Creek, St. Clair County, MI	P. Badra (Michigan Natural Features Inventory, pers. comm., 2001)	2002 R
Pine River, St. Clair County, MI	P. Badra (Michigan Natural Features Inventory, pers. comm., 2001) Hoeh & Trdan (1985)	1997, 1982-85 1982
Belle River, St. Clair County, MI	P. Badra (Michigan Natural Features Inventory, pers. comm., 2001) J.B. Layzer, (USGS, pers. comm., 1999) OSUM 1978:0013 OSUM 1965:0106	2002, 1994 R, 1983, 1978 R, 1965 R 1992 1978 1965
Clinton River, Oakland County, MI	P. Badra (Michigan Natural Features Inventory, pers. comm., 2001) Trdan & Hoeh (1993) Strayer (1980)	1991, 1984 R, 1981, 1978, 1933 1991 1977-78, 1933
Clinton River, Macomb County, MI	Strayer (1980)	1933
North Branch Clinton River, Macomb County, MI	Strayer (1980)	1933
Sydenham River, ONT	Woolnough 2002 Metcalfe-Smith et al. (1998, 1999) West et al (2000) Clarke (1992) West et al. (2000) OSUM 1967:0217; MFM 15864 OSUM 1965:0105 Clarke (1973)	2001 1997-98 1991-92 R 1991 1973 1967 1965 1963
South Branch Thames River, ONT	Metcalfe-Smith et al. (1998, 1999) ROM:M3470	1997-98 R 1934
Detroit River, Wayne County, MI	OSUM 1983:0027 OSUM 1982:0346 West et al. (2000), UMMZ ? Goodrich & van der Schalie (1932) Walker (1913)	1983 1982 1934-35 <1932 <1913

Rouge River, Wayne County, MI	Simpson (1914)	<1914
Huron River, Wayne County, MI	P. Badra (Michigan Natural Features Inventory, pers. comm., 2001)	1995 R, 1931-32
Raisin River, Lenawee County, MI	P. Badra (Michigan Natural Features Inventory, pers. comm., 2001)	1941, <1930
Raisin River, Monroe County, MI	P. Badra (Michigan Natural Features Inventory, pers. comm., 2001) Strayer (1979), OSUM 1976:0211 OSUM 1964:0134	1984 R, 1976 R, 1964 R, <1930 1976 R 1964 R
Macon Creek, Monroe County, MI	Strayer (1979)	1976-78 R
Maumee River, Allen County, IN	Watters (1988) MFM 16047 CM 61.6858	1988 R 1967 R 1913
Maumee River, ? County, OH	West et al. (2000)	?
St. Joseph River, Williams County, OH	Watters (1988), OSUM1988:0146, 0161 OSUM 1971:0055 OSUM 1967:0067 OSUM 1966:0128 C.F. Clark (pers. comm., 1989 [with W.A. Tolin, Service])	1988 R 1971 R 1967 R 1966 1939-1975
St. Joseph River, Defiance County, OH	OSUM 1936:0022	1936
St. Joseph River, DeKalb County, IN	Watters (1998) Watters (1988) MFM 15954, 16015 OSUM 1964:0043, 0052 OSUM 1963:0177 OSUM 1962:0084, 0086	1998 1988 1967 1964 1963 1962
St. Joseph River, Allen County, IN	Watters (1998) Watters (1988) OSUM 1962:0082, 0083 UMMZ ? (K.S. Cummings, INHS, pers. comm., 2001)	1998 1988 1962 1941 R
West Branch West Fork St. Joseph River, Hillsdale County, MI	P. Badra (Michigan Natural Features Inventory, pers. comm., 2001)	1997 R
Fish Creek, DeKalb County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2000) M. Henschen (Indiana Department of Natural Resources, pers. comm, 1989 [with W.A. Tolin, Service])	1990s 1985-86
Fish Creek, Williams County, OH	OSUM 1991:0042, 0044, 0047, 0094, 0095 Watters (1988), OSUM 1988:0142, 0166, 0167 Hoggarth (1987), OSUM 1986:0193, 0204, 0218	1991 1988 1986

	OSUM 1985:0036, 0037, 0042	1985
Cedar Creek, Allen County, IN	Watters (1988)	1988 R
Feeder Canal to St. Joseph River, Allen County, IN	M. Henschen (Indiana Department of Natural Resources, pers. comm, 1989 [with W.A. Tolin, Service]) Clark & Wilson (1912), USNM 678261	1916 1909
Auglaize River, Auglaize County, OH	OSUM 1964:0084	1964
Auglaize River, Defiance County, OH	OSUM 1913:0008	1913
Ottawa River, Putnam County, OH	OSUM 1998:0142	1998 R
Blanchard River, Hardin County, OH	Hoggarth et al. (2000) OSUM 1995:0206, 0248 C.F. Clark (pers. comm., 1989 [with W.A. Tolin, Service])	1998, 1995 1995 1964, 1946
Blanchard River, Hancock County, OH	Hoggarth et al. (2000) OSUM 1996:0164 OSUM 1995:0205, 0207 OSUM 1994:0125 C.F. Clark (pers. comm., 1989 [with W.A. Tolin, Service])	1998, 1995 1996 1995 1994 1964, 1946
Sandusky River, Wyandot County, OH	OSUM 1978:0142 OSUM 1971:0289 OSUM 1970:0306	1978 1971 1970
Sandusky River, Seneca County, OH	OSUM 1971:0320, 0333, 0334	1971 R
Tymochtee Creek, Wyandot County, OH	MFM 19338 Service, State College, PA (in litt. 1990 [TNC Element Occurrence Record]) OSUM 1979:0002, 0161 OSUM 1971:0287 OSUM1970:0340	1996 1977-87 1979 1971 1970
Wolf Creek, Sandusky County, OH	OSUM 1971:0336	1971 R
Lake Erie, Monroe County, MI	P. Badra (Michigan Natural Features Inventory, pers. comm., 2001)	1941, <1930
Lake Erie, Essex County, ONT	Service, State College, PA (in litt. 1990) [TNC Element Occur. Record] West et al. (2000) [UMMZ in part] OSUM 1967:0089, 0090 OSUM 1966:0444 OSUM 1960:0074 OSUM 1958:0034	1977-87 1958-67 1967 1966 1960 1934
Lake Erie, Ottawa County, OH	OSUM 1977:0508, 0545 OSUM 1969:0036 OSUM 1967:0542, 0557 OSUM 1966:0119, 0462, 0468 OSUM 1964:0012, 0579, 0581, 0582 OSUM 1961:0166, 0177, 0183, 0184 OSUM 1960:0026, 0027, 0028, 0033,	1977 R 1969 1967 1966 1964 1961 1960

	0070, 0101, 0104, 0130 OSUM 1958:0035, 0037 OSUM 1957:0054 OSUM 1956:0054, 0067 OSUM 1955:0004, 0005, 0026 OSUM 1954;0024, 0037, 0038, 0039, 0053 OSUM 1953:0037, 0038	1958 1957 1956 1955 1954 1953
Ohio River Main Stem		
[1] Ohio River, Kenton County, KY; Hamilton County, OH [probable Type Locality]	Schuster (1988) Lea (1870) [in Cicerello et al. (1991)]	~1900 <1870
Ohio River, ? Counties, IN; ? Counties, KY	Call (1894) Stein (1881)	<1894 <1880
Ohio River, ? Counties, IL; ? Counties, KY	FMNH 68113	<1960
Ohio River System		
Allegheny River, Cattaraugus County, NY	ANSP 323375	?
Allegheny River, Warren County, PA	S.A. Ahlstedt (USGS, pers. comm., 2002)	2002 R
Allegheny River, Forest County, PA	Smith et al. (2001)	1999
Allegheny River, Clarion County, PA	T. Proch (Pennsylvania Department of Natural Resources, pers. comm., 2001)	1991
Allegheny River, Venango County, PA	OSUM 1998:0103 T. Proch (Pennsylvania Department of Natural Resources, pers. comm., 2001) Ortmann (1909a, 1919)	1998 1991 ~1909
Allegheny River, Armstrong County, PA	P. Morrison (Service, pers. comm., 2001)	1999-2000
Chautauqua Lake, Chautauqua County, NY	Ortmann (1919)	<1919
Chautauqua Lake outlet, Chatauqua County, NY	Ortmann (1919)	<1919
Olean Creek, Cattaraugus County, NY	K.M. O.Brien (New York State Department of Environmental Protection, pers. comm., 2002) Strayer (1995) Strayer et al. (1991)	2002 1994 R 1987-90
Cassadaga Creek, Chautauqua County, NY	K.M. O.Brien (New York State Department of Environmental Protection, pers. comm., 2002) Strayer (1995)	2002 1994
Conewango Creek, Warren County, PA	Ortmann (1909a, 1919)	~1908
Oil Creek, Crawford? Venango? County, PA	Dennis (1985)	<1970
French Creek, Erie County, PA	OSUM 1992:0038 T. Proch (Pennsylvania Department of Natural Resources, pers. comm., 2001)	1992 1991

French Creek, Crawford County, PA	OSUM 1997:0208 T. Proch (Pennsylvania Department of Natural Resources, pers. comm., 2001) OSUM 1977:0176 OSUM 1975:0113 Bates (1970), Dennis (1985) Ortmann (1909a, 1919)	1997 R 1991 1977 1975 1968-69 ~1908
French Creek, Mercer County, PA	T. Proch (Pennsylvania Department of Natural Resources, pers. comm., 2001)	1991
French Creek, Venango County, PA	OSUM 1994:0048 T. Proch (Pennsylvania Department of Natural Resources, pers. comm., 2001) OSUM 1975:0237 OSUM 1972:0287 OSUM 19--:0054 OSUM 1970:0241, 0346 Ortmann (1909a, 1919)	1994 1991 1975 R 1972 <1971 1970 ~1908
Cussewago Creek, Crawford County, PA	T. Proch (Pennsylvania Department of Natural Resources, pers. comm., 2001)	1991
Crooked Creek, Armstrong County, PA	Ortmann (1909a, 1913, 1919)	~1908
West Fork River, Harrison, Lewis Counties, WV	Ortmann (1913)	<1913
Beaver River, Lawrence County, PA	Ortmann (1919) Rhoads (1899) [in Ortmann (1909a)]	~1910 1898
Shenango River, Mercer County, PA	Ortmann (1909a, 1919)	~1908
Pymatuning Creek, Mercer County, PA	Ortmann (1909a)	~1908
Mahoning River, Trumbull County, OH	INHS 20915	<1921
Mahoning River, ? County, OH	MFM 1308	~1890
Mahoning River, Lawrence County, PA	Ortmann (1909a, 1919)	~1908
Middle Island Creek, Tyler County, WV	Taylor & Spurlock (1981), MUMC 1905	1980 R
Muskingum River, Muskingum County, OH	OSUM 1980:0028 OSUM 1979:0076	1980 R 1979 R
Walhonding River, Coshocton County, OH	Hoggarth (1995-96) OSUM 1991:0017, 0131 OSUM 1989:0190 0SUM 1971:0112 OSUM 1967:0126, 0127 OSUM 1964:0277	1991-93 1991 R 1989 R 1971 1967 1964
Mohican River, Coshocton County, OH	OSUM 1969:0172 OSUM 1967:0038, 0044, 0105, 0178 OSUM 1965:0250	1969 1967 1965
Elk River, Clay, Kanawha Counties, WV	J.L. Clayton (West Virginia Division of Natural Resources, pers. comm., 2001) OSUM 1970:0036, 0037, 0047 OSUM 1963:0039	1991-92 R 1970 1963

	Ortmann (1913)	<1913
Scioto River, Franklin County, OH	OSUM 1965:0001 OSUM 1964:0217 OSUM 1962:0004 OSUM 1961:0034, 0043 OSUM 1960:0030 OSUM 1959:0001, 0060	1965 R 1964 1962 R 1961 1960 1959
Scioto River, Pickaway County, OH	OSUM 1986:0081 OSUM 1962:0003 OSUM 1961:0074 OSUM 1960:0001, 0046	1986 R 1962 R 1961 R 1960
Mill Creek, Union County, OH	OSUM 1971:0212, 0222	1971 R
Alum Creek, Delaware County, OH	OSUM 1970:0123 OSUM 1969:0188, 0210 OSUM 1967:0032, 0102, 0357 OSUM 1965:0010 OSUM 1962:0006 OSUM 1961:0014, 0067 OSUM 1960:0012 OSUM 1959:0017, 0053, 0058, 0109	1970 1969 1967 1965 R 1962 1961 1960 1959
Olentangy River, Marion County, OH	OSUM 1989:0225, 0227, 0233, 0240 OSUM 1977:0042 OSUM 1962:0116 OSUM 1961:0170 OSUM 1960:0075, 0092, 0094 OSUM 1927:0012	1989 R 1977 R 1962 R 1961 1960 1927
Olentangy River, Delaware County, OH	OSUM 1989:0228, 0238 OSUM 1974:0104 OSUM 1962:0136 OSUM 1961:0158, 0159 OSUM 1960:0065, 0075, 0076 OSUM 18-B:0506 West et al. (2000)	1989 R 1974 R 1962 1961 1960 <1900 ?
Olentangy River, Franklin County, OH	OSUM 1995:0038 OSUM 1975:0008 OSUM 1961:0144 OSUM 1959:0042	1995 R 1975 R 1961 1959
Whetstone Creek, Morrow County, OH	OSUM 1961:0145	1961
Big Walnut Creek, Franklin County, OH	OSUM 1991:0023 OSUM 1961:0016, 0031	1991 R 1961
Walnut Creek, Pickaway County, OH	OSUM 1994:0066, 0067, 0069, 0070, 0078, 0147	1994 R
Buckeye Lake, Fairfield or Licking or Perry County, OH	OSUM 1880:0009	1880
Big Darby Creek, Union County, OH	Watters (1994) OSUM 1986:0163, 0164 OSUM 1963:0031, 0101 OSUM 1960:0008, 0009, 0048 MFM 2181	1990 R, 1986 1986 R 1963 1960 1951 R

Big Darby Creek, Franklin, Madison counties, OH	OSUM 2000:0067 Watters (1994) OSUM 1986:0153, 0154, 0161 OSUM 1976:0304 OSUM 1965:0109 OSUM 1963:0051 OSUM 1961:0029 OSUM 1957:0010	2000 R 1990 R, 1986 1986 R 1976 R 1965 R 1963 1961 1957
Big Darby Creek, Pickaway County, OH	OSUM 2000:0103 OSUM 1993:0088 OSUM 1986:0137 OSUM 1973:0001 OSUM 1964:0002 OSUM 1963:0034 OSUM 1962:0090 OSUM 1961:0023, 0038 OSUM 1960:0002, 0006, 0053 OSUM 1959:0016 OSUM 1958:0004, 0005, 0006, 0010, 0011, 0033 OSUM 1957:0001, 0020 OSUM 1956:0001	2000 R 1993 R 1986 R 1973 1964 1963 1962 1961 1960 1959 1958 1957 1956
Little Darby Creek, Madison County, OH	Watters (1994)	1990 R or 1986 R
Ohio and Erie Canal, Pickaway County, OH	OSUM 1999:0088	1999 R
Deer Creek, Ross County, OH	OSUM 1975:0020	1975
Deer Creek, Madison County, OH	OSUM 1968:0059	1968 R
Deer Creek, Fayette County, OH	MFM 12698 OSUM 1961:0036	1965 1961
Deer Creek, Pickaway County, OH	OSUM 1981:0165 OSUM 1978:0038 OSUM 1975:0067, 0069 OSUM 1969:0017	1981 1978 1975 1969 R
Sugar Creek, Fayette County, OH	OSUM 18-B:0508	<1900
Scioto Brush Creek, Scioto County, OH	Watters (1992), OSUM 1987:0312, 0348	1987
Cedar Creek, ? County, OH	?	?
Little Miami River, Warren County, OH	Hoggarth (1992) Whiteaves (1863) [in Hoggarth (1992)]	1990-91 <1863
East Fork Little Miami River, Brown, Clermont Counties, OH	Hoggarth (1992), OSUM 1990:0292, 0293, 0294 OSUM 1973:0028, 0031	1990-91 1973
Stillwater River, Miami County, OH	Watters (1988a) [in Watters (1994)], OSUM 1987:0353	1987 R
Stillwater River, Montgomery County, OH	Watters (1988a) [in Watters (1994)], OSUM 1987:0351	1987

South Fork Licking River, Pendleton County, KY	Laudermilk (1993)	1982 R
North Fork Elkhorn Creek, Scott County, KY	R.R. Cicerello (Kentucky State Nature preserves Commission, pers. comm., 2001)	1982 R
Eagle Creek, Gallatin, Owen Counties, KY	Schuster (1988), OSUM 1981:0055	1981 R
Brashears Creek, Spencer County, KY	R.R. Cicerello (Kentucky State Nature preserves Commission, pers. comm., 2001)	1983 R
Green River, Green County, KY	MFM 11586	1964
Green River, Hart County, KY	Stansbery (1965)	1961-64
Nolin River, Grayson County, KY	R.R. Cicerello (Kentucky State Nature preserves Commission, pers. comm., 2001)	1983 R
Barren River, Warren County, KY	MCZ ?, ANSP ? [in Schuster (1988)]	<1900, ?
Wabash River, Mercer County, OH	OSUM 1962:0093	1962 R
Wabash River, Huntington County, IN	Cummings et al. (1988), INHS 5029	1988 R
Wabash River, Wabash County, IN	Cummings et al. (1988), INHS 6343	1988 R
Wabash River, Miami County, IN	Cummings et al. (1988), INHS 5341	1988 R
Wabash River, Carroll County, IN	INHS 8266 Cummings et al. (1988), INHS 5231, 5199, 6672	1989 R 1988 R
Wabash River, Tippecanoe County, IN	Cummings et al. (1992), INHS 6228, 6656 OSUM 1963:0332	1988 R 1963
Wabash River, Posey County, IN; White County, IL	USNM 85270	<1887
Wabash River, ? County, IL; ? County, IN?	Daniels (1903) Call (1900) Call (1896b) Stein (1881)	<1903 <1900 <1896 <1880
Salamonie River, Wabash County, IN	MFM 22676	1971
Mississinewa River, Miami County, IN	Ecological Specialists, Inc. (1995)	1994 R
Mississinewa River, Delaware County, IN	Ecological Specialists, Inc. (1995)	1993 R
Mississinewa River, Randolph County, IN	Ecological Specialists, Inc. (1995)	1993 R
Tippecanoe River, Kosciusko County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001)	1991 R
Tippecanoe River, Fulton County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) Cummings & Berlocher (1990), INHS 3665 Clark & Wilson (1920), USNM 677676	1991-92 R 1987 R 1908

	Daniels (1903) ?	<1903
Tippecanoe River, Pulaski County, IN	OSUM 1992:0136 B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) Cummings & Berlocher (1990), INHS 4188 Daniels (1903) ?	1992 1991-92 1987 R <1903
Tippecanoe River, White County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) Daniels (1903) ?	1991 R <1903
Tippecanoe River, Carroll County, IN	OSUM 1992:0115, 0116 B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) INHS 6605 INHS 3866	1992 1991 1988 R 1987 R
Tippecanoe River, Tippecanoe County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) OSUM 1992:0114	1995, 1991 1992
Tippecanoe Lake, Kosciusko County, IN	Clark & Wilson (1920) UMMZ 92826 Daniels (1903), INHS 20910? INSM 1037 Call (1900) [in Cummings & Berlocher (1990)] Call (1896a)	<1920 1907 <1903 1901 <1900 <1896
Winona Lake, Kosciusko County, IN	OSUM 1934:0006 Headlee & Simonton (1903) CHAS 18415	1934 <1903 ?
Walnut Creek, Kosciusko County, IN	OSUM 1992:0153; Ecological Specialists, Inc. (1993)	1992 R
Lake Maxinkuckee, Marshall County, IN	OSUM 1997:0206 MCZ 56043 Evermann & Clark (1920) UMMZ 92825; USNM 541901 FMNH 145000 Blatchley (1901)	1997 1924 1907 1904 <1901
Mill Creek, Fulton County, IN	Ecological Specialists, Inc. (1993)	1992 R
Vermilion River, Vermilion County, IL	INHS 24502	1999 R
Salt Fork Vermilion River, Champaign County, IL	Cummings et al. (1998), INHS 4882, 4885, 5285	1956-57
Salt Fork Vermilion River, Vermilion County, IL	Cummings et al. (1998), INHS 19989 Cummings et al. (1998), INHS 29908	1997 R 1920
Middle Fork Vermilion River, Vermillion County, IL	INHS 24677 INHS 12158	2000 R 1991
North Fork Vermilion River, Vermillion County, IL	Cummings et al. (1998), INHS 18611, 18125	1995 R

	Cummings et al. (1998), INHS 6976, 7003	1988 R
Sugar Creek, Parke County, IN	MFM 1622 M. Henschen (Indiana Department of Natural Resources, pers. comm, 1989 [with W.A. Tolin, Service]) USNM (2 uncatalogued lots)	1950 1930 1925
Embarras River, Douglas County, IL	INHS 16217	1994 R
Embarras River, Coles County, IL	INHS 2403	1956
White River, ? County, IN	Daniels (1903), USNM 25669 Stein (1881), INHS 20911 UMMZ 92929, ? (2 total lots); FMNH 14255	<1903 1881 ?
West Fork White River, Delaware County, IN	Cummings et al. (1992), INHS 8680	1989-91 R
West Fork White River, Madison County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001)	2000 R
West Fork White River, Hamilton County, IN	Cummings et al. (1992), INHS 8163	1989-91 R
West Fork White River, Marion County, IN	INHS 1170	1890-99
East Fork White River, Jackson County, IN	UMMZ 92824	?
Fall Creek, Hamilton, Henry, Madison, Marion Counties, IN	FMNH 9301	?
Big Blue River, Johnson County, IN	USNM 431427	1944
Big Blue River, Bartholomew County, IN	M. Henschen (Indiana Department of Natural Resources, pers. comm, 1989 [with W.A. Tolin, Service])	1944
Sugar Creek, Johnson County, IN	B.E. Fisher (Indiana Department of Natural Resources, pers. comm., 2001) Harmon (1992), INHS 11258, 11205, 11183, 11225 INHS 11247 M. Henschen (Indiana Department of Natural Resources, pers. comm, 1989 [with W.A. Tolin, Service])	1998 1990 1989 1930
Tennessee River Main Stem		
Tennessee River, Knox County, TN	Lewis (1870) Ortmann (1918)	<1870 <1918
[2] Tennessee River, Meigs, Rhea counties, TN	Ahlstedt & McDonough (1995-96)	<1918
Tennessee River, Jackson County, AL	Warren (1975) [S.A. Ahlstedt, USGS, pers. comm., 2001)	A
[3] Tennessee River, Colbert, Lauderdale counties, AL	van der Schalie (1939)	<1939
Tennessee River System		

Holston River, Hawkins County, TN	Ortmann (1918)	1914
Holston River, Grainger County, TN	Ortmann (1918)	1914
Holston River, Knox County, TN	Ortmann (1918)	1914-15
North Fork Holston River, Scott County, VA	Ortmann (1918)	1913
North Fork Holston River, Hawkins, Sullivan Counties, TN	Ortmann (1918)	1913
South Fork Holston River, Sullivan County, TN	Ortmann (1918)	1914
Nolichucky River, Greene County, TN	OSUM 1968:0221 Parmalee & Bogan (1998), OSUM 1964:0532; MFM 11885	1968 1964
Lick Creek, Greene County, TN	MFM 14874	1967 R
Clinch River, Russell County, VA	OSUM 1965:0222 OSUM 1963:0089 Ortmann (1918)	1965 1963 1913, 1899
Clinch River, Wise County, VA	OSUM 1963:0110 Ortmann (1918)	1963 1913
Clinch River, Scott County, VA	OSUM 1965:0225 OSUM 1963:0090 MFM 5487 MFM 3904 Ortmann (1918) OSUM 1909:0005 (Böpple)	1965 1963 1955 1953 1913 1909
Clinch River, Claiborne County, TN	Ortmann (1918)	1913
North Fork Clinch River, Hancock County, TN	INHS 20912	<1921
Powell River, Claiborne County, TN	Ortmann (1918)	1913-15
Powell River, Union County, TN	Ortmann (1918)	1899
Powell River, Campbell County, TN	Ortmann (1918)	1899
Elk River, Franklin County, TN	Isom et al. (1973), OSUM 1965:0290	1965
Elk River, Lincoln County, TN	Isom et al. (1973), OSUM 1965:0288 MFM 7334	1965 1957
Richland Creek, Giles County, TN	INHS 20914	1892
Duck River, Marshall County, TN	Ahlstedt (1991b), OSUM 1982:0162, 0167 OSUM 1972:0173 Isom & Yokley (1968), OSUM 1965:0301, 0302 OSUM 1964:0119, 0224, 0225 MFM 6924 MFM 4337 van der Schalie (1973) Ortmann (1924)	1982 1972 1965 1964 1956 1953 1931 1923
	Isom & Yokley (1968), OSUM	1965

Duck River, Maury County, TN	1965:0303, 0305	
	van der Schalie (1973)	1931
	INHS 20913	<1921
	Hinkley & Marsh (1885)	<1885

Footnotes:

[1] This is probably the type locality (stated simply as "Ohio River" by Lea [1829]) as it was the site of a major shoal and an historical locality for many other unionids, several of which are now extinct.

[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 *Villosa fabalis* from this Tennessee River reach, but did include it from just upstream in Knox County, Ahlstedt & McDonough (1995-96) may have assumed that it also must have occurred in the Meigs and Rhea counties reach.

[3] van der Schalie (1939), in his species list for Muscle Shoals, did not record *V. fabalis,* nor did Ortmann (1925) or anyone else before or since. However, in the text he lists species "generally confined to headwater and tributaries," but known from Muscle Shoals (presumably according to Ortmann 1925). In this textual list, he includes *V. fabalis*, which is the only species not recorded in Ortmann's list of taxa known from Muscle Shoals (pages 366-367). This record needs substantiation, as it appears that van der Schalie may have inadvertently included it among the species verified from this locality. The nearest known localities for *V. fabalis* are in the Elk River system, which flows into the upper end of the preimpoundment complex of shoals on the Tennessee River known collectively as Muscle Shoals. Historically, habitat undoubtably occurred at Muscle Shoals and this taxon may have occurred there. The TVA Heritage Program database includes a record for Muscle Shoals, presumably that of van der Schalie. Garner & McGregor (2001), however, omitted *V. fabalis* from their composite list of species known from Muscle Shoals. Based on this data, this species is not considered to have been part of the Alabama mussel fauna.

Codes:

< = collected before [date], > = collected after [date], ANSP = Academy of Natural Sciences Philadelphia, CHAS = Chicago Academy of Sciences, CM = Carnegie Museum, FMNH = Field Museum of Natural History, INHS = Illinois Natural History Survey, INSM = Indiana State Museum, MUMC = Marshall University Mollusk Collection, MFM = Museum of Fluviatile Mollusks, OSUM = Ohio State University Museum of Biological Diversity, R = relic shell(s) only, ROM = Royal Ontario Museum, TUR = Triannual Unionid Report, USNM = U.S. National Museum

Notes:

Ahlstedt (1991a) reported finding relic specimens in the upper Clinch River in 1978-83 without giving site specific information.

Call (1900) and Clark (1977) reported this species from the St. Joseph River, but I do not have a copy of their papers, and thus no county of occurrence(s) for their record(s).

Clark and Wilson (1912) reported this species from the Maumee River, but I do not have a copy of his paper, and thus no county of occurrence(s) for their record(s).

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

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

Marshall (1892) [in Ortmann (1909a)] reported this species in a list of shells without giving locality data, but "from localities within the limits of the state of New York, or from the Allegheny River at Warren [Warren County], Pa., just south of the New York boundary."

Ortmann (1913) reported this species from the Allegheny River, generally in Forest, Venango, and Warren Counties, Pennsylvania.

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

Strayer & Jirka (1997) mentioned a New York record for this species (UMMZ 92818) from the Chemung River of the upper Susquehanna River system, which lies directly east of the Allegheny River system. They considered the record as being "probably erroneous," but noted that it was "possible that [it] does live in the western tributaries of the Susquehanna." I consider this record to be erroneous and omit it from this table.

Walker (1898) reported this species from "Lake Erie, Detroit [R]iver and the streams tributary to them" without giving specific locality information.

APPENDIX II

Rayed bean (*Villosa fabalis*) extant populations*

Stream/Service Region	**State/Province**	**Last Observed**	**Recruiting?**
Region 3			
Black River	Michigan	2001	?
Pine River	Michigan	2002	Yes
Belle River	Michigan	1992	?
Clinton River	Michigan	1991	Yes
St. Joseph River	Indiana	1998	?
Fish Creek	Indiana, Ohio	1991	?
Tippecanoe River	Indiana	1995	Yes?
Lake Maxinkuckee	Indiana	1997	?
Sugar Creek	Indiana	1998	?
Blanchard River	Ohio	1998	Yes
Tymochtee Creek	Ohio	1977-87	?
Walhonding River	Ohio	1991-95	No?
Scioto Brush Creek	Ohio	1987	No?
Little Miami River	Ohio	1990-91	No?
East Fork Little Miami River	Ohio	1990-91	?
Stillwater River	Ohio	1987	No?
Region 4			
NO EXTANT OCCURRENCES			
Region 5			
Allegheny River	Pennsylvania	2001	Yes
French Creek	Pennsylvania	2001	Yes
Cussewago Creek	Pennsylvania	1991	?

Olean Creek	New York	2000	Yes
Cassadaga Creek	New York	1994	Yes
Canada			
Sydenham River	Ontario	2001	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 rayed bean was historically known from 106 streams, lakes, and canals in 10 states and 3 Service regions (3, 4, & 5) and Ontario, Canada. Currently, it is known from 22 streams and a lake in 5 states and Regions 3 and 5, and in Ontario. In the U.S., Region 3 has the most extant streams (and lake) of occurrence with 16, Region 5 has 5 occurrences, and 1 in Canada, but the species is extirpated from Region 4.