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Status of the Rayed Bean, *Villosa fabalis* (Bivalvia: Unionidae), in Ontario and Canada†

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The Rayed Bean, *Villosa fabalis*, is a very small freshwater mussel that lives in stable substrates of sand or gravel in shallow riffle areas of rivers and streams. Its host fish in Canada is unknown. Although population trends are difficult to quantify due to a lack of numerical data, the species is generally recognized to have significantly declined throughout its range in recent years. Its global rank was uplisted from G2 to G1G2 by The Nature Conservancy in 1997, and it is currently ranked S1 in most jurisdictions. In Canada, *Villosa fabalis* was historically known from the Thames, Sydenham and Detroit Rivers and western Lake Erie in southwestern Ontario. It is now restricted to the middle reach of the Sydenham River. Siltation and agricultural chemicals are likely the most significant threats to the continued existence of this species in Canada. Pollution from urban sources and livestock farming may have caused the extirpation of the species from the Thames River. As the Sydenham River population is one of only a few remaining populations in North America that still show signs of recruitment, preserving this population may be important for the global survival of the species.

Key Words: Rayed Bean, *Villosa fabalis*, Unionidae, freshwater mussels, endangered species, COSEWIC, Great Lakes.

The Rayed Bean, *Villosa fabalis*, is a small unionid belonging to the Subfamily Lampsilinae. It was originally described by Lea in 1831 as *Unio fabalis* (Simpson 1914), with the type locality being the Ohio River (LaRoque 1953; Simpson 1914). The authority for the current nomenclature is Turgeon et al. (1988). *Villosa fabalis* can be distinguished from other Canadian species of freshwater mussels by its very small size, elliptical shape, crowded wavy green rays, and hinge teeth that are unusually heavy for the size of the animal (Clarke 1981; Cummings and Mayer 1992). Clarke (1981) describes the shell as sub-elliptical, very small, and solid, with a mid-anterior shell wall thickness of 2.5 mm. Females tend to be more inflated and more broadly rounded posteriorly than males. The periostracum is normally light or dark green and covered with wide or narrow, wavy, darker green rays that are clearly apparent except on old, blackened specimens. The nacre is silvery white and iridescent. The beaks are narrow, slightly elevated above the hinge line and not excavated, and the beak sculpture is fine and composed of about five crowded double-looped ridges. The hinge teeth are relatively heavy with erect, pyramidal, serrated pseudocardinals, short laterals with diagonal serrations, and a thick interdentum. According to Cummings and Mayer (1992) and TNC (1987*), shells are normally 25–35 mm in length. However, specimens up to 38 mm long have been reported in Canada (Clarke 1981; Metcalfe-Smith et al. 1999). The Rayed Bean may be confused with the Rainbow Shell, *Villosa iris*, but the latter species grows about three times as large and has a thinner shell with more delicate hinge teeth and fewer rays. Young specimens of the Kidneyshell, *Ptychobranchus fasciolaris*, or the Spike, *Elliptio dilatata*, may also be mistaken for *V. fabalis*, although their beak sculptures differ. Figure 1 shows the right valves of a fresh male shell (left) and female shell (right) taken from the Sydenham River in southwestern Ontario.

Distribution

The Rayed Bean was historically known from Alabama, Illinois, Indiana, Kentucky, Michigan, New York, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia (TNC 1997*) and Ontario; see inset, Figure 2A. The historical distribution of the species is summarized here using information from Burch (1975), Clarke (1981), Bogan and Parmalee (1983) and Strayer and Jirka (1997). *Villosa fabalis* was once widely but discontinuously distributed throughout the Ohio and Tennessee River systems, including the Wabash, Monongahela, Elk, Allegheny, Green, Rouge, Clinch, Powell, North Fork Holston, and Duck Rivers. It also occurred in western Lake Erie and its tributaries, including the Maumee River, and in tributaries to the St. Clair River and Lake St. Clair

†Endangered status assigned by COSEWIC 19 April 1999.
*See Documents Cited section.

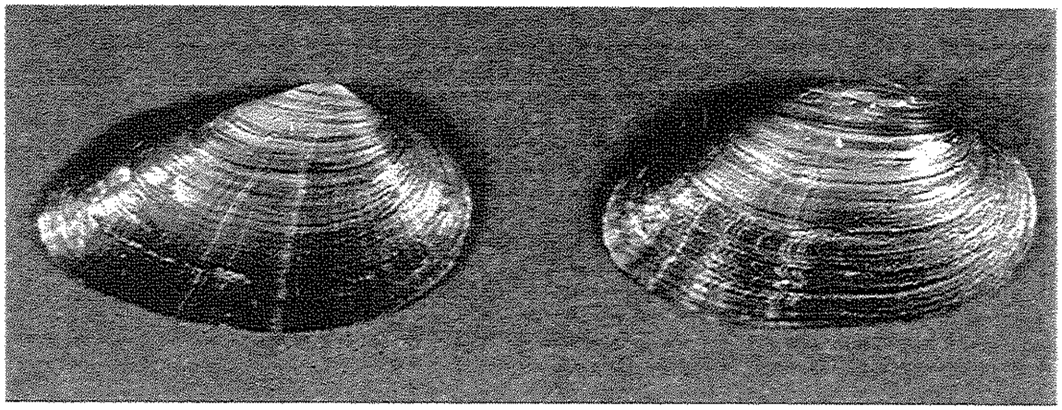

FIGURE 1. External shell morphology of a male (left) and female (right) specimen of *V. fabalis* collected as spent shells from the Sydenham River near Shetland, Ontario in August 1998. Right valves are shown for both sexes.

such as the Pine River (Hoeh and Trdan 1985) and the Clinton River (Strayer 1980). A previously unknown population was recently discovered in the Belle River, Michigan (J. B. Layzer, U.S. Geological Survey, Tennessee Cooperative Fishery Research Unit, Tennessee Tech University, Cookeville, Tennessee, personal communication, April 1999). The easternmost records for this species are those from western New York (Strayer et al. 1991). In Canada, *V. fabalis* was known from the Detroit River, the Sydenham and Thames Rivers in the Lake St. Clair drainage, and western Lake Erie (LaRoque 1953; Clarke 1981; museum records described below).

Figure 2A illustrates the historical distribution of *V. fabalis* in Ontario (and Canada) based on occurrence records from the National Water Research Institute's Lower Great Lakes Unionid Database. The database and its data sources are described in detail in Metcalfe-Smith et al. (1998a). At present, the database consists of over 5000 records for 40 species of mussels collected from the Canadian waters of the lower Great Lakes drainage basin between 1860 and 1998. A total of 20 historical records for *V. fabalis* were available from the holdings of the Ohio State University Museum of Biological Diversity (OSUM), the Royal Ontario Museum (ROM) and the University of Michigan Museum of Zoology (UMMZ); the personal records of Carol B. Stein (retired from the OSUM) and Michael J. Oldham (Natural Heritage Information Centre, Ontario Ministry of Natural Resources); the private collections of Herbert D. Athearn (Emeritus, Tennessee Academy of Science); and Clarke (1992).

Protection

Canada does not have federal endangered species legislation at this time. However, Ontario is one of five provinces that have stand-alone Endangered Species Acts (Aniskowicz 1997; and B. T. Fowler [nee Aniskowicz], personal communication, September 1999). Species classified as provincially Endangered, and their habitats, are protected from willful destruction under these provincial acts, but in Ontario there is currently no protection for Threatened or Vulnerable species. The Provincial Policy Statement under Section 3 of Ontario's Planning Act prohibits development and site alteration in the habitats of Threatened and Endangered species. The Rayed Bean is currently being considered for Endangered status in Ontario by the Committee On the Status of Species At Risk in Ontario (COSSARO) and, if approved, would receive provincial protection. Other mechanisms for protecting mussel habitat in Ontario include the Ontario Lakes and Rivers Improvement Act, which prohibits the impoundment or diversion of a watercourse if it would cause siltation; and the voluntary Land Stewardship II program of the Ontario Ministry of Agriculture, Food and Rural Affairs, which is designed to reduce the erosion of agricultural lands. Stream-side development in Ontario is managed through flood plain regulations enforced by local conservation authorities. Most land along the reach of the Sydenham River where *V. fabalis* presently occurs is privately owned and in agricultural use. Two small properties, the 7-ha Shetland Conservation Area and the 20-ha Mosa Township forest, are publicly owned (Muriel Andreae, St. Clair Region Conservation Authority, personal communication, March 1998).

The federal Fisheries Act may represent the most important legislation protecting the habitat of the Rayed Bean in Canada. Under this Act, freshwater mussels are considered to be shellfish, which are included in the definition of "fish" and therefore afforded protection in theory. In practice, the Fisheries Act is mainly applied to habitats that sup-

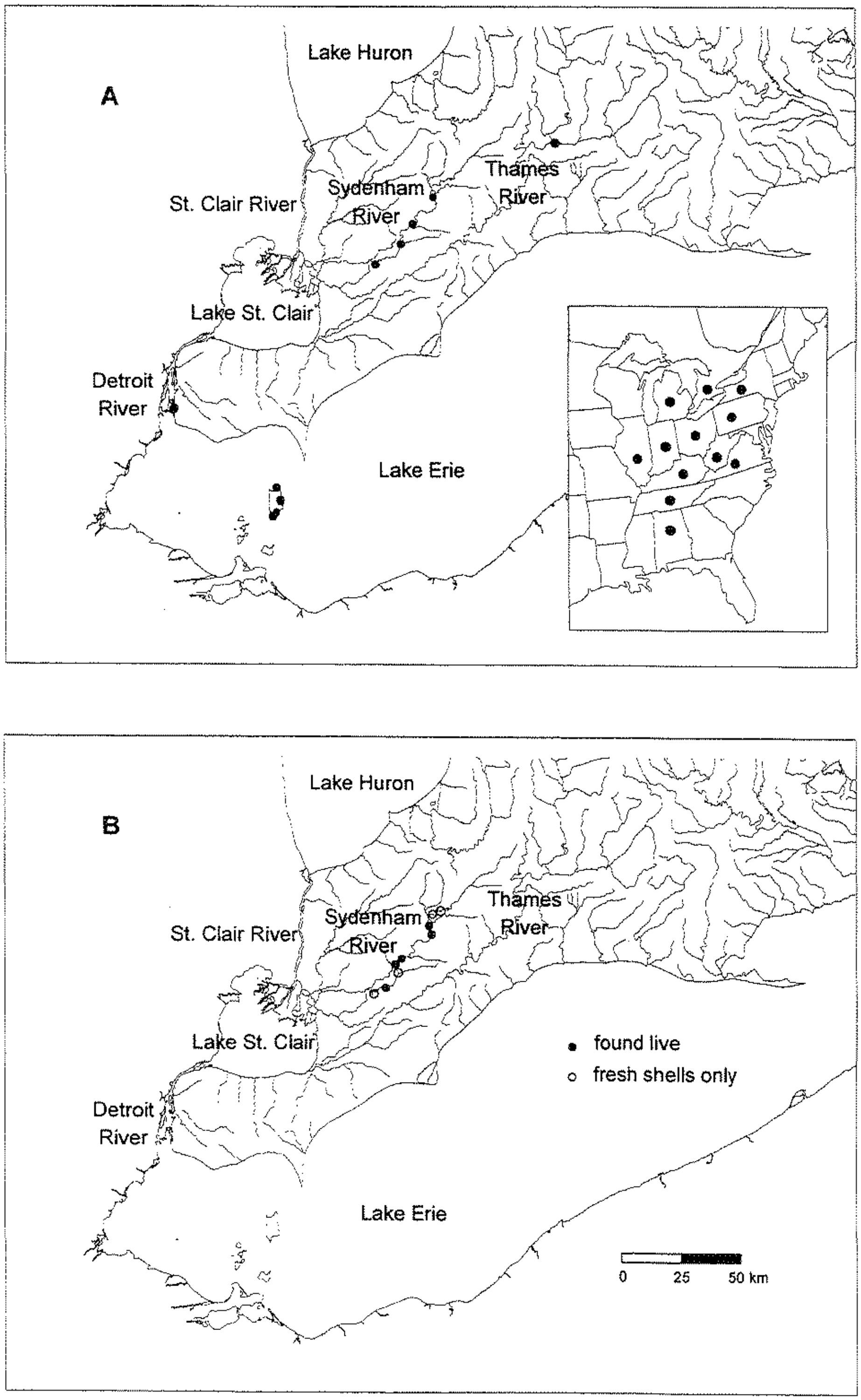

FIGURE 2. Distribution of *Villosa fabalis* in Ontario: A. Historical distribution (inset shows historical North American distribution). B. Presumed current distribution, based on the results of 1997–1998 surveys.

port recreational or commercial fisheries. As *V. fabalis* presently occurs in a river that supports a recreational fishery, its habitat should be indirectly protected by the Fisheries Act.

Villosa fabalis was previously listed as a Category 2 Federal Candidate under the U.S. Endangered Species Act (Cummings and Mayer 1992); however, maintenance of this list was discontinued in 1996 (Roth 1997*). Category 2 species were defined as those species for which there was some evidence for vulnerability, but not enough data for them to be listed as Endangered or Threatened (Cummings and Mayer 1992). Because state and local governments are no longer asked to take Category 2 candidates into account in their environmental planning, this change in listing procedures will significantly weaken the protection of species such as *V. fabalis* in the United States (Roth 1997*). The Rayed Bean is afforded state protection in Alabama, Indiana, Kentucky, Michigan and Ohio, where it is currently listed as endangered or of special concern (TNC 1997*; TVA 1996*). In Michigan, for example, the Natural Resources and Environmental Protection Act provides for the possible acquisition of land or aquatic habitat, and the establishment of programs necessary for the conservation, protection, restoration and propagation of listed species (Michigan DNR 1998*). *Villosa fabalis* has also been proposed for endangered status in New York (D. L. Strayer, Institute of Ecosystem Studies, Millbrook, New York, personal communication, June 1998).

Population Sizes and Trends

The Rayed Bean is considered to be a rare species (Clarke 1981; Strayer and Jirka 1997), but it has been suggested that its rarity may be more apparent than real because it is a small species that burrows deeply into the substrate and could be easily overlooked (TNC 1987*). Abundant populations have been seen on occasion. For example, Hoggarth et al. (1998*) recently found it to be the third most common species of unionid in a stretch of the upper Blanchard River in northwestern Ohio. It also ranked third in abundance (21% of 3452 mussels) among 17 species relocated from the impact zone of a bridge replacement project on the upper Allegheny River in Pennsylvania in 1998, and second in abundance (9% of 15 737 mussels) among 19 species moved from a site on French Creek, Pennsylvania for the same reason (G. F. Zimmerman, EnviroScience, Inc, Cuyahoga Falls, Ohio, personal communication, April 1999). Densities of *V. fabalis* at these two sites were 0.261 and 0.73 individuals/m^2, respectively, whereas densities as high as 5.5 individuals/m^2 have been seen elsewhere in these systems.

It is difficult to quantify population trends for *V. fabalis*, as many studies note only its presence or absence (e.g.. Clarke 1973), or indicate that it was "rare". However, several studies provide evidence that the species is now very rare and/or in decline. For example, Strayer (1980) found *V. fabalis* to be represented by spent shells at just four of 76 sites surveyed on the Clinton River, Michigan, in 1977–1978, whereas it had been found (presumably alive) at four of 26 sites prior to 1935. The species was also represented by spent shells only at just two of 24 sites on the Raisin River in southeast Michigan in 1976–1977 (Strayer 1979), and it was one of nine species found to be rare (defined as < 1 mussel found per person-hour of collecting) in three small tributaries to the St. Clair River, Michigan, in 1982–1983 (Hoeh and Trdan 1985). In New York, *V. fabalis* is described as "rare in the State and gone from some historic sites" (Schneider 1998*). According to Strayer and Jirka (1997), small populations of *V. fabalis* still persist at two of several sites where it previously occurred in the Allegheny River basin in New York. It was represented by one live specimen at one site and spent shells at two other sites in a short stretch of Olean Creek during a survey of 26 sites in the Allegheny River system between 1987 and 1990 (Strayer et al. 1991). In a subsequent survey of 10 sites in the Allegheny basin, Strayer (1995*) observed four live specimens at one site on Cassadaga Creek. A total of 226 mussels of 13 species were found at this site; thus, *V. fabalis* constituted less than 2% of the community. In the Tennessee River system, the current range of this species is restricted to a few locations in the Duck and Clinch rivers (TNC 1987*). As noted by Bogan and Parmalee (1983), the majority of previously known populations in the state of Tennessee are now inundated by reservoirs. In the United States, *V. fabalis* is now found most frequently (1970 to present) in the Ohio drainage, including French Creek (tributary of the Allegheny River), Elk River (tributary of the Kanawha River), Eagle Creek (tributary of the Kentucky River), Muskingum River, Little Miami River and three tributaries (Big Darby Creek, Deer Creek and Olentangy River) of the Scioto River (TNC 1987*).

The earliest records for *V. fabalis* in Canada date back to the 1930s. It was reported from the Detroit River at Bois Blanc Isle by Bryant Walker in 1934 (UMMZ Catalogue # 92807), and it was collected by C. Goodrich at nearby Amherstberg in 1935 (UMMZ Catalogue # 92823). Bryant Walker also collected the species from a site near Pelee Island in western Lake Erie in 1934 (UMMZ Catalogue # 928822). It was found several more times near Pelee Island between 1958 and 1967 (fresh shells only), but a survey of 17 sites throughout the western basin of Lake Erie in 1991 (Schloesser and Nalepa 1994) failed to reveal any trace of *V. fabalis*. It was not found during surveys of 29 sites in Lake St. Clair in 1986, 1990, 1992 or 1994 (Nalepa et al. 1996); however, there are no historical records for the species from Lake St. Clair, so it may never have occurred there.

Sydenham River

The Rayed Bean was first collected alive from the Sydenham River ixn 1963 by H. D. Athearn near the town of Shetland (Clarke 1973). It was subsequently found alive in 1965 and 1967 near Florence and Alvinston, respectively (C. B. Stein, personal communication, September 1997). Athearn reported it from another site near Shetland in 1967, but did not say if it was found alive. Stein surveyed two sites in 1973, namely, her 1965 site and a new site at Dawn Mills, and found only one fresh valve at each location. The first extensive survey of the Sydenham River was conducted in 1971 by Clarke (1973), who visited 11 sites. Although he did not find *V. fabalis*, it should be noted that he used a smaller sampling effort than previous collectors (Clarke averaged 1h per site, whereas Athearn conducted a 4h survey and Stein searched for 3–6h). Mackie and Topping (1988) surveyed 20 sites on the Sydenham River in 1985 using a sampling effort of 1h per site, and found no trace of *V. fabalis*. Clarke (1992) revisited the river in 1991, and surveyed 16 sites. He spent between 0.4 and 8.0 person-hours (p-h) at each site and found many more live species than Mackie and Topping (1988), including a single specimen of *V. fabalis* at a site near Alvinston. A few weathered valves were also collected from this site by Oldham (personal records) in 1991 and 1992.

In 1997 and 1998, Metcalfe-Smith et al. (1998b, 1999) surveyed 66 sites on the Grand, Thames, Sydenham, Ausable and Maitland Rivers in the Lake Erie, Lake St. Clair and lower Lake Huron drainages to assess the current conservation status of rare species of freshwater mussels in southwestern Ontario. They used the timed-search sampling method, which is particularly effective for detecting rare species (Strayer et al. 1997), and an intensive sampling effort of 4.5 p-h/site. Sites that were known to support these species in the past were targeted, including five sites on the Sydenham River where live specimens or shells of *V. fabalis* had been found between 1963 and 1991. The data for all survey sites that produced live animals and/or shells in 1997–1998 are presented in Table 1. Based on the presence of live specimens, the current range of *V. fabalis* in the Sydenham River extends over a distance of approximately 45 km between Alvinston and Croton (see Figure 2B). A total of 15 live animals numbering 1–6 individuals/site were encountered at five of seven sites within this reach, and a few fresh shells were found at a sixth site. Several fresh shells were also taken from two sites above and one site below the reach. If fresh shells are taken to indicate the presence of live animals at perhaps lower densities, the range of *V. fabalis* expands to 65 km. As only one of the 12 sites surveyed for mussels on the main branch of the Sydenham River was outside of this reach, it is possible that the species may occur further upstream. However, there is no mussel habitat below Dawn Mills, where water levels fluctuate with the levels in Lake St. Clair.

A comparison of Figures 2A and 2B suggests that the current range of *V. fabalis* in the Sydenham River has changed little over time; however, there is some evidence to indicate that abundance may have declined. Four of the sites surveyed by Metcalfe-Smith et al. (1998b, 1999) in 1997–1998 had been sampled 24 to 34 years earlier by Athearn or Stein, using similar sampling efforts. Comparisons of the historical and current data show a decline over time in the numbers of live specimens and/or fresh shells found at most sites (Table 2).

TABLE 1. Numbers of live specimens and spent shells of *V. fabalis* found in the Sydenham River (SR) and Thames River (TR) in 1997–1998*. Sites ordered in an upstream to downstream direction for each river.

Site number	Nearest urban centre	Live specimens	Fresh shells		Weathered shells	
			Whole	Valves	Whole	Valves
SR-11	Alvinston	0	1	0	0	0
SR-1	Alvinston	0	0	0	0	7
SR-10	Alvinston	0	2	0	0	0
SR-2	Alvinston	1	0	1	0	1
SR-3	Alvinston	1	0	2	3	0
SR-7	Shetland	5	0	20	0	0
SR-17	Florence	6	4	0	0	0
SR-5	Florence	0	1	2	0	0
SR-6	Croton	2	6	11	0	0
SR-12	Dawn Mills	0	0	1	0	0
TR-2	Dorchester	0	0	0	0	4
TR-3	London	0	0	0	0	26
TR-5	Oneida Reserve	0	0	0	0	10
TR-8	Kent Bridge	0	0	0	0	1

*data taken from Metcalfe-Smith et al. (1998b, 1999); a total of 17 sites were surveyed on the Sydenham River and 16 sites on the Thames River.

TABLE 2. Comparison of historical (1963-1973) and current (1997–1998) data on numbers of live specimens and fresh spent shells of *V. fabalis* collected from four sites on the Sydenham River.

Site number	Collector, date	Historical data Live	Whole shells	Valves	Current data* Live	Whole shells	Valves
SR-2	Stein 1967	2	16	3	1	0	1
SR-4	Athearn 1963	1	0	0	0	0	0
SR-5	Stein 1965	1	9	2	0	1	2
	Stein 1973	0	0	1	"	"	"
SR-12	Stein 1973	0	0	1	0	0	1

*data taken from Metcalfe-Smith et al. (1998b, 1999).

Live specimens of *V. fabalis* collected from the Sydenham River in 1997–1998 measured 20 to 38 mm in length, while spent shells ranged from 15–36 mm. As 90% of the shells were fresh, i.e., probably left by animals that died within the past year, data for live specimens and shells were combined to generate an overall size class distribution (Figure 3) for the species in this river. The broad range of sizes and fairly even distribution of individuals for both live specimens and shells is indicative of a healthy, reproducing population. The sex ratio could not be determined for live animals, as the specimens found in 1997 were not sexed. However, the sex ratio for the 64 shells was somewhat skewed towards females (62% females: 38% males), with female shells being smaller (23 mm) on average than male shells (28 mm). There is no information in the literature on normal sex ratios for this species.

Thames River

Only one historical record exists for *V. fabalis* from the Thames River. A single fresh whole shell was collected by J. C. Medcof in 1934 (ROM Catalogue # M3470) from the south branch of the Thames River at a location described only as being in the "east part of London". Metcalfe-Smith et al. (1998b, 1999) surveyed 16 sites throughout the Thames River watershed in 1997–1998, including one site in the vicinity of Medcof's site. No live specimens or fresh shells were found at any site; however, a total of 41 weathered valves were found at four sites, including 26 from the site located near Medcof's historical site (see Table 1). These data prove that *V. fabalis* once occurred in the Thames River; however, it has apparently now been lost.

Habitat

Villosa fabalis tends to inhabit the headwaters and smaller tributaries of river systems, where it is found in or near riffle areas (TNC 1987*). Cummings and Mayer (1992) describe its habitat as "Lakes and small to large streams in sand or gravel". It is occasionally reported from shallow water areas of lakes (TNC 1996*) and large rivers. For example, historical records show that it has been found along the edges of islands in Lake Erie and the Detroit River. In southeastern Michigan, Strayer (1983) found it to be scattered in the lower courses of rivers and medium-sized streams on the outwash plains. Such streams are characterized by low gradients, clear water, steady flows, and substrates of sand and gravel. All shells and live animals found by Strayer et al. (1991) in the New York waters of the Allegheny drainage were on "...shallow gravelly riffles among *Myriophyllum*, apparently the typical habitat for this species...". The Rayed Bean is usually found deeply buried in the substrate, among the roots of aquatic vegetation. As a result, this species may not be as sensitive to flow rate fluctuations in its habitat as some other mussel species (TNC 1987*). Live specimens encountered in the Sydenham River during recent surveys (Metcalfe-Smith et al. 1998b, 1999) were found buried in stable substrates of sand or fine gravel, generally in low flow areas along the margins of the river or the edges of small islands.

General Biology

Although specific information regarding the biology and ecology of *V. fabalis* is limited, general unionid biology is applicable (USFWS 1994). During spawning, males release sperm into the water and females living downstream take in the sperm through their incurrent siphons. Female mussels brood their young from the egg to the larval stage in their gills, using the posterior portions of their outer gills as marsupia. Once expelled into the water by the female, the larval mussels, or glochidia, must attach to the gills or fins of an appropriate fish host in order to complete their metamorphosis. *Villosa fabalis* is reported to be a long term brooder (bradytictic) that holds its glochidia over winter for spring release (Ortmann 1909, as cited in TNC 1987*). The glochidia have been described as subspatulate in shape (Bogan and Parmalee 1983), or as rounded but with a straight hinge line (Clarke 1981). They are 200 μm high and 170 μm long (Hoggarth 1993). Glochidia that are higher than long are mostly gill parasites. This morphological feature tends to maximize the chance of a successful encounter, while sacrificing adductor muscle strength that may be less important for maintaining attachment to this protect-

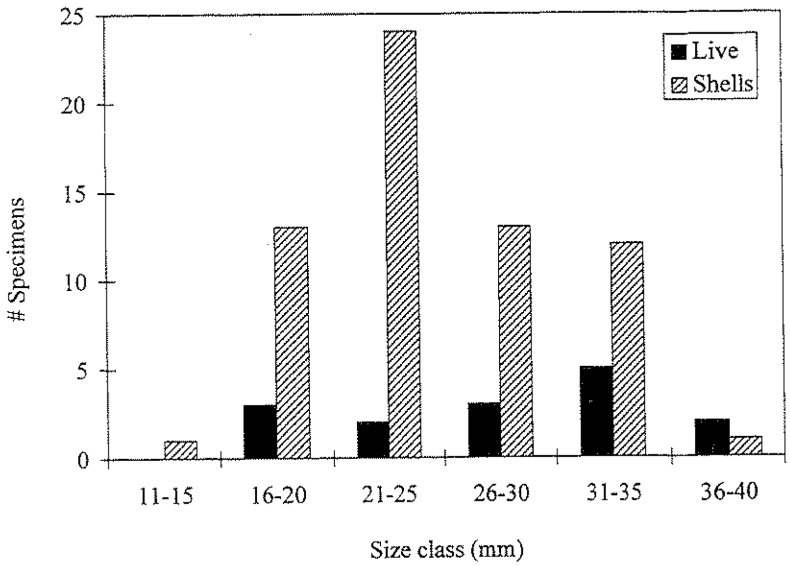

FIGURE 3. Size class distributions for live specimens and spent shells of *V. fabalis* found in the Sydenham River in 1997–1998.

ed internal surface. As *Villosa iris* is known to be a gill parasite (Jacobson et al. 1997), this is probably also true for *V. fabalis*. Most, but not all, lampsilines are gill parasites. The Northern Riffleshell, *Epioblasma torulosa rangiana*, is an example of a lampsiline that is a fin parasite (Hoggarth 1993).

Only one fish host, the Tippecanoe Darter (*Etheostoma tippecanoe*), is known for *Villosa fabalis* (G.T. Watters, Ohio State University, personal communication, November 1997). As this species of fish is not found in Canada, the host fish for *V. fabalis* in this country is presently unknown. Assuming that darters are the most likely hosts, data on the distributions of darter species in the Sydenham and Thames rivers were obtained from the Royal Ontario Museum and the Ontario Ministry of Natural Resources' Ontario Fisheries Information System for comparison with the distribution of *V. fabalis* in these rivers. Nine species of darters have been found to inhabit the main stem of the Sydenham River: the Greenside Darter (*Etheostoma blenniodes*), Rainbow Darter (*Etheostoma caeruleum*), Logperch (*Percina caprodes*), Eastern Sand Darter (*Ammocrypta pellucida*), Fantail Darter (*Etheostoma flabellare*), Least Darter (*Etheostoma microperca*), Johnny Darter (*Etheostoma nigrum*), Blackside Darter (*Percina maculata*), and River Darter (*Percina shumardi*). All species except the Fantail Darter and River Darter were collected live in 1997 from the stretch of the river where *V. fabalis* presently occurs. The darter community of the Thames River is almost identical to that of the Sydenham River, except that it also includes the Iowa Darter (*Etheostoma exile*). It is likely that one or more of these fishes serve as hosts for *V. fabalis* in Canada. To confirm that a fish is a suitable host, it must be shown to facilitate the metamorphosis of glochidia in laboratory tests. Such tests have not yet been conducted in Canada.

The Rayed Bean, like all freshwater mussels, is a filter feeder. Although the exact food preferences of the adult form are unknown, they are probably similar to those of other freshwater mussels, i.e., suspended organic particles such as detritus, bacteria and algae (TNC 1986*).

Limiting Factors

Siltation, impoundments, pollutants from municipal, industrial and agricultural sources, and possibly Zebra Mussels, *Dreissena polymorpha*, have threatened *Villosa fabalis* across North America. Access to suitable fish hosts may also be a factor, but it cannot be assessed for Canadian populations until the host species have been identified. Siltation, urbanization and flood plain development have led to the deterioration of water and habitat quality for mussels in general (Biggins et al. 1995*). The historical distribution of *V. fabalis* in Ontario falls within one of the most heavily populated and intensively farmed regions of Canada. The main land use in the Thames and Sydenham River watersheds is agriculture, accounting for 80–85% of the total land area in both basins (WQB 1989, 1990). Factors limiting the occurrence of *V. fabalis* in Canada probably include siltation, due to poor agricultural practices; exposure to agricultural chemicals, such as fertilizers and pesticides; highway runoff (Mackie 1996); and municipal and industrial discharges, particularly in the upper portion of the Thames River basin.

The sensitivity of *V. fabalis* to specific environmental pollutants is not known, because this species has never been subjected to toxicity testing. According to Orton-Palmer and Keller (1997), "No studies have been published, nor is any data available, on toxic effects to threatened or endangered unionid species." However, newly-released glochidia of the related species, *Villosa iris*, have been tested for their response to several common river pollutants. Goudreau et al. (1993) found that the glochidia of *V. iris* were more sensitive to ammonia (24-hour LC50 = 0.284 mg/L) and monochloramine (24-hour LC50 = 0.084 mg/L) than many other species of invertebrates, including other molluscs. Jacobson et al. (1997) determined the toxicity of aqueous copper to the released glochidia of five species of unionids, and found that *V. iris* was the second most sensitive species (24-hour LC50 = 38–80 µg/L). If *V. fabalis* is as sensitive to pollution as *V. iris*, then it is likely that toxic contaminants are at least partially responsible for reductions in the occurrence and abundance of *V. fabalis* throughout its range.

Siltation is probably the most immediate threat to *V. fabalis* in the Sydenham River, but eutrophication and pesticide inputs may also be significant factors. Cash crops, pasture and woodlot are the predominant types of agriculture in the basin (Muriel Andreae, St. Clair Region Conservation Authority, personal communication, March 1998), and there is an extensive tile drainage system (Mackie and Topping 1988). Twenty years ago, Clarke (1978) found the river to be largely unpolluted, and urged that it be made an ecological preserve so that its unique unionid community could be protected. By 1991, he observed that most of the riffles were covered in silt and many of the riffle-dwelling species were missing from his collections (Clarke 1992); thus, he attributed the loss of these species to the loss of clean riffle habitat. In a laboratory experiment, Aldridge et al. (1987) found that the intermittent exposure of several species of mussels to high levels of suspended solids (similar to what might occur after a rain event in an agricultural area) significantly altered their physiological energetics. Such metabolic changes could, in turn, affect survival rates. Metcalfe-Smith et al. (1998b, 1999) found that water clarity (measured as maximum depth at which the stream-bed was clearly visible) was poor in 1997–1998, averaging 23 cm for all sites and 19 cm for the sites where *V. fabalis* was found alive, indicating heavy suspended sediment loadings to the system.

Anthropogenic impacts on the Thames River appear to be more severe than those on the Sydenham River, and may have caused the extirpation of *V. fabalis* and several other mussel species from the system. Thirty percent of the species historically known from the Thames River were not found alive during the surveys of 1997–1998, but only 15% of species were missing from the Sydenham River (Metcalfe-Smith et al. 1998b, 1999). Furthermore, several of the remaining species in the Thames River were represented by remnant, non-reproducing populations. Livestock farming is the main form of agriculture in the upper portion of the Thames River, whereas cash crop farming predominates in the lower Thames. While over 80% of the basin was covered in forest prior to the 1880s, only 8% was still forested in 1989. The upper Thames supports a large urban population; in 1988, there were 22 sewage treatment plants and two industries discharging their wastes into this part of the system (WQB 1989). Tile drainage systems, wastewater drains, manure storage and spreading, and insufficient soil conservation practices all contribute to the impairment of water and habitat quality in the Thames River. Soil and streambank erosion is severe, causing high suspended sediment loads. There has been a steady increase in phosphorus and nitrogen inputs to the Thames River, and some of the highest livestock phosphorus loadings for the entire Great Lakes basin are attributable to the Upper Thames watershed (WQB 1989). Despite recent efforts to improve water quality throughout the basin, poor water quality still exists in some areas. For example, mean ammonia concentrations in all sub-basins exceed the Federal freshwater aquatic life guidelines, and mean concentrations of copper exceed the guideline in several sub-basins (WQB 1989). The physical destruction of mussel habitat by cattle having access to the river is undoubtedly a significant problem in the upper reaches of the Thames.

Although human impacts have been causing the reduction and extirpation of mussel populations for many years (Nalepa and Gauvin 1988), the introduction of the Zebra Mussel to the Great Lakes in the late 1980s (Hebert et al. 1989) has led to catastrophic declines of native mussels in Lake St. Clair (Nalepa et al. 1996), western Lake Erie (Schloesser and Nalepa 1994) and the upper St. Lawrence River (Ricciardi et al. 1996). Zebra mussels now infest a large portion of the former range of *V. fabalis* in Ontario, i.e., the Detroit River and western Lake Erie. As Zebra Mussels only attach to exposed surfaces, it is unlikely that they would threaten a burrowing unionid such as the Rayed Bean.

Predation by Muskrats (*Ondatra zibethicus*) is a potential limiting factor for some mussel species (e.g., Neves and Odom 1989; USFWS 1994). In the Sydenham River, anecdotal information suggests that Muskrat predation could be a contributing factor in the decline of the endangered Northern Riffleshell (Staton et al. 2000). However, this threat can probably be ruled out as a limiting factor for *V. fabalis*.

Convey et al. (1989) and Hanson et al. (1989) found that Muskrats do not feed on mussels smaller than 35–40 mm in shell length, which is close to the maximum size reported for *V. fabalis*.

Special Significance of the Species

Of the 18 species of North American mussels that belong to the genus *Villosa*, only two (*Villosa iris* and *Villosa fabalis*) occur in Canada. Merely one-third of these 18 species are presently considered to be stable in terms of their distribution and abundance (Williams et al. 1993). The current distribution of *V. fabalis* is discontinuous (TNC 1987*). In New York, for example, it is believed to be spatially restricted to small areas that still support reasonably healthy populations (D. L. Strayer, Institute of Ecosystem Studies, Millbrook, New York, personal communication, March 1998). Such populations are difficult to locate, mainly because of the small size of the animal and its unusual burrowing habits, and even harder to manage because of their spatial separation. Although there is a general consensus that the range of the species and size of its populations are decreasing, the persistence of healthy populations in some areas suggests that it has good potential for recovery. The Sydenham River in southwestern Ontario supports the only known reproducing population of *V. fabalis* in Canada.

Evaluation

Villosa fabalis was once widely, but discontinuously distributed throughout its original range in North America. It appears to have always been rare, with seldom more than a handful of live specimens found in a day's sampling at most sites. Although population trends are difficult to quantify due to the paucity of numerical data, there is a general consensus that the species has significantly declined in distribution and abundance in recent years. *Villosa fabalis* is more difficult to find in the field than most other species of unionids because of its very small size and burrowing habits; thus, its distribution and abundance may have been somewhat underestimated. *Villosa fabalis* was previously listed as a Category 2 Federal Candidate under the U.S. Endangered Species Act, but this category is no longer used. Its global rank was uplisted from G2 to G1G2 in February 1997, and its current sub-national ranks are SX in Illinois and Virginia, S1 in Indiana, Kentucky, Michigan, New York, Pennsylvania, Tennessee, West Virginia and Ontario, and S2 in Alabama and Ohio (TNC 1997*).

There are only a few recent references to the continued existence of "reasonably healthy" populations of *V. fabalis*, and these are for several sites in western New York, northwestern Ohio, and northeastern Pennsylvania. The Sydenham River in southwestern Ontario supports the only known reproducing population of *V. fabalis* in Canada. This population appears to be of low density and confined to a 45 km stretch of the middle section of the river, although there is evidence that recruitment is still occurring. The species appears to be extirpated from the Thames River, with little chance of being re-established because the headwaters where it once occurred are severely degraded.

Villosa fabalis's habitat requirements may not be as restrictive as those of other rare species with which it often co-occurs. For example, the Northern Riffleshell (*Epioblasma torulosa rangiana*) is confined to highly oxygenated riffle areas with rapid currents and coarse sand to fine gravel substrates, while *V. fabalis* prefers river margins and the edges of in-stream islands where it burrows among the roots of aquatic vegetation in shallow, slower-flowing zones. Such habitats are plentiful in most areas. The impact of Zebra Mussels on this species is not known, but may be insignificant. Agricultural chemicals and siltation are likely the most significant threats to the continued existence of the species throughout North America. There is some evidence that species of the genus *Villosa* may be very sensitive to environmental contaminants.

As the only remaining Canadian population of *V. fabalis* is found in the Sydenham River, where it is at continued risk of extirpation from intensifying agricultural activities in the region, it is recommended that the Rayed Bean be classified as Endangered in Ontario and Canada. This manuscript is based on the reports to COSEWIC and COSSARO, but has been updated to incorporate new data collected in 1998.

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