COSEWIC
Assessment and Status Report

on the

Rayed Bean
Villosa fabalis

in Canada

ENDANGERED
2010

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

COSEWIC. 2010. COSEWIC assessment and status report on the Rayed Bean *Villosa fabalis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 40 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Previous report(s):

COSEWIC. 2000. In Press. COSEWIC assessment and status report on the Rayed Bean *Villosa fabalis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 29 pp.

West, E.L., J.L. Metcalfe-Smith and S.K. Staton. 2000. Update COSEWIC status report on the Rayed Bean *Villosa fabalis* in Canada *in* COSEWIC assessment and update status report on the Rayed Bean *Villosa fabalis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-29 pp.

West, E.L., J.L. Metcalfe-Smith and S.K. Staton. (unpublished). 1999. COSEWIC status report on the Rayed Bean *Villosa fabalis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-30 pp.

Production note:
COSEWIC acknowledges Daelyn A. Woolnough and Todd J. Morris for writing the provisional updated status report on the Rayed Bean, *Villosa fabalis*, prepared under contract with Environment Canada. Any modifications to the status report during the subsequent preparation of the 6-month interim and 2-month interim updated status reports were overseen by Dwayne Lepitzki, Molluscs Specialist Subcommittee Co-chair, with the continued assistance of the contractors.

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Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur la villeuse haricot (*Villosa fabalis*) au Canada.

Cover illustration/photo:
Rayed Bean — supplied by the authors.

Catalogue CW69-14/194-2010E-PDF
ISBN 978-1-100-16008-5

Recycled paper

COSEWIC
Assessment Summary

Assessment Summary – April 2010

Common name
Rayed Bean

Scientific name
Villosa fabalis

Status
Endangered

Reason for designation
This freshwater mussel is one of the smallest in Canada. It is found in two rivers in southern Ontario; more than 99% of the estimated total population is found in the Sydenham River. The original COSEWIC assessment (2000) concluded that it had been extirpated from most of its Canadian range and was confined to one river but a new, albeit small, population was discovered in 2004 in the North Thames River. Thirteen live individuals were found between 2004 and 2008 in this river. The main limiting factor is the availability of shallow, silt-free riffle habitat. Both riverine populations are in areas of intense agriculture and urban development, subject to siltation and pollution. Invasive Zebra Mussels have rendered much of the historic habitat unsuitable and pose a continuing threat to one of the last remaining populations.

Occurrence
Ontario

Status history
Designated Endangered in April 1999. Status re-examined and confirmed in May 2000 and April 2010.

COSEWIC
Executive Summary

Rayed Bean
Villosa fabalis

Wildlife species description and significance

The Rayed Bean is one of the smallest freshwater mussels in Canada (25-38 mm long). Its shell is elliptical in shape and has a light or dark green surface with crowded, wavy, darker green rays and unusually heavy hinge teeth for its size. The rays on the shell are clearly apparent except on old, blackened specimens. The outer shell surface has low concentric lines and wrinkles and dark growth rests. The inner shell surface is silvery white and iridescent. The shells of females are generally more inflated and more broadly rounded posteriorly than males.

Freshwater mussels are sensitive indicators of overall ecosystem health and play important roles in structuring aquatic communities. Mussels provide food and habitat for other animals ranging from microscopic bacteria and plankton to large aquatic and terrestrial vertebrates. The presence of mussel beds provides physical stability of substrates and their filtering capacity can have profound influences on water quality.

Distribution

The Rayed Bean is limited to central North America where it was once discontinuously distributed in Alabama, Illinois, Indiana, Kentucky, Michigan, New York, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia, and Ontario. It no longer occurs in Alabama, Illinois, Kentucky or Virginia and its range has been significantly reduced in all other areas. In Canada, it occurs only in Ontario where its range once included the Detroit, Sydenham and Thames rivers and western Lake Erie. The current distribution is restricted to the Sydenham River and a short reach of the North Thames River near Plover Mills and upstream of Fanshawe Lake. The Rayed Bean is either extirpated or occurs at few sites in all jurisdictions, including Ontario.

Habitat

This mussel occurs in the headwaters and smaller tributaries of river systems in sandy riffles and pools or gravel riffles and flats. It is occasionally reported from shallow water areas of lakes and large rivers. In the Sydenham River abundance is positively associated with areas dominated by gravel and sand substrate but the mussel is never reported in areas dominated by silt. They are most abundant in areas characterized by high flow (> 0.5 m/s) and shallow (wadable) water.

Biology

The Rayed Bean is a small, sexually dimorphic mussel. Females brood their young from the egg to the larval stage in their gills, using the posterior portions of their brood chambers (marsupia). It is a long-term brooder that holds its larvae (glochidia) over winter for spring release. They have been found gravid from late May until early August in the Sydenham River. Once expelled into the water the glochidia must attach to an appropriate host fish to complete development. The glochidia are rounded and are higher than they are long, which may indicate an adaptation to gill attachment. Glochidia from Rayed Bean in the Sydenham show no similarities to other species within the genus *Villosa*. The host fish, determined in the laboratory, are: Rainbow Darter, Greenside Darter, Mottled Sculpin, and Largemouth Bass. The Greenside Darter is the most likely host fish, given its abundance in the Sydenham River and results from the laboratory but this may differ elsewhere due to localized adaptive interactions. Although the mussel’s exact food preferences and optimum particle sizes are unknown, they are probably similar to those of other freshwater mussels (i.e., suspended organic particles such as detritus, bacteria and algae). Adult and juvenile Rayed Bean, especially those in the Sydenham River, use byssal threads (i.e., proteinaceous filament for anchoring), an adaptation that has not been documented in other adult freshwater mussels.

Population sizes and trends

Historically, the Rayed Bean has always been rare, but recent records and newer search methods (e.g., excavation surveys) indicate that densities are higher than previously thought. Of the 22 records in the Thames and Sydenham rivers, two are represented by single specimens at upstream limits of both rivers. Quantitative surveys in the Sydenham have shown high densities > 3 per m^2. At three sites surveyed in the Sydenham River it was the most abundant mussel and in the top five species in abundance at two additional sites. Overall, the population size in the Sydenham River appears to be much larger than historically thought. The North Thames River population is several orders of magnitude less dense than the Sydenham River population. The Rayed Bean has not been collected in either Lake Erie or the Detroit River for over 40 years and it is unclear if these few, scattered museum records represented viable populations.

Threats and limiting factors

The major factors determining the current distribution of this mussel in Canada are limited suitable riverine habitat (primarily restricted by the distribution of its presumed host fish) and the negative impacts of invasive Zebra and Quagga mussels (large portions of presumed historical habitat rendered unsuitable). Other invasive species such as the Round Goby threaten resource availability and habitat use of the Rayed Bean and its host fishes. Remaining populations are limited to relatively small river sections subject to declining water quality from agricultural and urban activities. These land use changes and poor land use practices are likely the largest threat to this species.

Protection, status, and ranks

The Rayed Bean is currently listed as Endangered on Schedule 1 of the *Species at Risk Act* (SARA) and as such it is currently illegal to kill, harm, harass, capture or take individuals. SARA also provides protection for the residence and critical habitat of listed species however, at this time, neither a residence nor critical habitat has been described or identified. The Rayed Bean is also listed as Endangered and protected under the Ontario *Endangered Species Act, 2007*. The federal *Fisheries Act* represents another piece of legislation currently protecting the Rayed Bean in Canada. As shellfish, freshwater mussels are considered 'fish' under the *Fisheries Act* and receive the same protection granted to finfish. In the U.S it is a candidate for federal listing under the U.S. *Endangered Species Act*. The species is considered globally imperiled (G2) and is ranked as nationally imperiled (N2) in the United States and critically imperiled (N1) in Canada with a General Status of "At Risk" (1).

TECHNICAL SUMMARY

Villosa fabalis
Rayed Bean — villeuse haricot
Range of occurrence in Canada: ON

Demographic Information

Generation time	Unknown but estimated 6-12 yrs
Is there an observed continuing decline in number of mature individuals?	No
Estimated percent of continuing decline in total number of mature individuals within 2 generations.	Unknown
Estimated percent increase in total number of mature individuals over the last 3 generations.	Unknown
Projected percent increase in total number of mature individuals over the next 3 generations.	Unknown
Suspected percent increase in total number of mature individuals over any 3 generations period, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible and understood and ceased? **Increase observed, although still threats that could cause declines in the future.**	No
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence **Area contained within a convex polygon drawn to include all confirmed occurrences. Past EO was only the Sydenham River. Thus, EO has increased.**	678.4 km²
Index of area of occupancy (IAO) **IAO calculated by applying a 2 km x 2 km grid around each occurrence record. Biological AO calculated by multiplying the length of the occupied reach in each river by the average river width for the reach and then summing across rivers.**	IAO = 180 km^2 AO = 2.1 km^2
Is the total population severely fragmented?	No
Number of "locations*" **Sydenham River and North Thames River**	2
Is there an inferred continuing decline in extent of occurrence?	No
Is there an inferred continuing decline in index of area of occupancy?	No
Is there an observed continuing decline in number of populations?	No
Is there an observed continuing decline in number of locations?	No
Is there an inferred continuing decline in quality of habitat? **Water quality trends are inferred to decline. Urbanization and agricultural land use continue and the threat of invasive species continues.**	Yes
Are there extreme fluctuations in number of populations?	No
Are there extreme fluctuations in number of locations*?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

* See definition of location.

Number of Mature Individuals (in each population)

Population (± 95% CI)	**N Mature Individuals**
Sydenham River:	est. 1,555,000 (± 658,800)
Thames River:	est. 4,300
All values presented above are for total individuals. Numbers of mature individuals are not known but it can be assumed (based on the size distributions presented in Figure 8) that virtually all individuals collected during the recent surveys were mature. Therefore these estimates likely closely approximate numbers of mature individuals.	1, 560,000

Quantitative Analysis

Probability of extinction in the wild	Not available

Threats (actual or imminent, to populations or habitats)

- Poor water quality resulting from rural, urban, and agricultural influences in the watersheds poses a threat as mussels in general are known to be sensitive to many aquatic pollutants.
- Dreissenid mussels have rendered much of the historical habitat in Lake Erie, the Detroit River unavailable and pose a continuing threat to remaining populations in the Thames River due to the proximity to Fanshawe Lake.
- Historic river fragmentation resulting from instream barriers and dams may restrict the upstream movement of the host fish species, thereby limiting the available habitat.

Rescue Effect (immigration from outside Canada)

Status of outside population(s)?

- USA: Nationally the Rayed Bean is N2 (Imperiled) and a candidate for federal listing as Endangered under the *Endangered Species Act*. It is presumed extirpated (SX) in four states, possibly extirpated (SH) in one state, and critically imperiled (S1) and listed as Endangered in six states.
- Globally: Imperiled (G2) - Last reviewed May 2007.

Is immigration known or possible?	Unlikely
Would immigrants be adapted to survive in Canada? Host fish switching would be required.	Unknown
Is there sufficient habitat for immigrants in Canada? Limited suitable riverine habitat available.	Unknown
Is rescue from outside populations likely?	No

Current Status

COSEWIC:
COSEWIC: Endangered (2010)
Canada SARA: Endangered (2003)
Ontario ESA: Endangered (2008)

Status and Reasons for Designation

Status: Endangered	**Alpha-numeric code:** B1ab(iii) + 2ab(iii)

Reasons for designation:
This freshwater mussel is one of the smallest in Canada. It is found in two rivers in southern Ontario; more than 99% of the estimated total population is found in the Sydenham River. The original COSEWIC assessment (2000) concluded that it had been extirpated from most of its Canadian range and was confined to one river but a new, albeit small, population was discovered in 2004 in the North Thames River. Thirteen live individuals were found between 2004 and 2008 in this river. The main limiting factor is the availability of shallow, silt-free riffle habitat. Both riverine populations are in areas of intense agriculture and urban development, subject to siltation and pollution. Invasive Zebra Mussels have rendered much of the historic habitat unsuitable and pose a continuing threat to one of the last remaining populations.

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable. The number of mature individuals appears to be stable.
Criterion B (Small Distribution Range and Decline or Fluctuation): Both B1 and B2 are applicable as EO (678.4 km^2) and IAO (180 km^2) are below the thresholds for Endangered (< 5,000 km^2 and < 500 km^2, respectively). As the species is found at only 2 locations, sub-criterion “a” (< or = 5 locations) is applicable. There is a continuing decline inferred in the quality of habitat so sub-criterion “b(iii)” also is applicable.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable. The total number of mature individuals is estimated to be 1.56 million, above the thresholds for this criterion (< 10,000 for threatened), although one of the two populations contains over 99% of the estimated total population.
Criterion D (Very Small or Restricted Total Population): Nearly meets the criteria for D2 Threatened as the species is found at fewer than 5 locations and while it is prone to the effects of human activities (e.g., degraded water quality, invasive species, and in-stream barriers) these activities are not occurring over a very short time frame in an uncertain future.
Criterion E (Quantitative Analysis): Probabilities for extinction in the wild have not been calculated.

PREFACE

Since the original 1999 COSEWIC status assessment of the Rayed Bean (*Villosa fabalis*) in Canada, a significant number of monitoring, research and management projects have occurred. The information gathered in the last 10 years has been incorporated to update the original COSEWIC report. Some highlights of the new information in the updated report are outlined below.

Additional qualitative surveys were conducted in the Thames River in 2004 and 2005 (Morris and Edwards 2007). These surveys failed to detect any Rayed Bean in the historic South Thames River habitat although a single weathered valve was collected from the North Thames River where no previous sign of Rayed Bean had ever been found. Morris (unpubl. data) used quantitative excavation surveys in this section of the North Thames River in 2004 and collected a single live animal. This led to Zanatta's (unpubl. data) and Woolnough and Morris' (unpubl. surveys for this updated report) additional targeted surveys in the North Thames River in 2008; they found an additional 11 live specimens and identified the second viable population in Canada.

Significant quantitative sampling (i.e., timed searches and excavation surveys) in the Sydenham River (Woolnough 2002; Metcalfe-Smith *et al*. 2007) has provided valuable information on the range, extent, and population demographics of this population. These surveys have provided a better understanding of proper search techniques for the Rayed Bean, one of the smallest freshwater mussels in Canada.

Vital information on host fish usage by the Rayed Bean in Canada has been studied at the University of Guelph (Woolnough 2002).

The Rayed Bean is part of a multi-species Recovery Strategy completed in 2006 under Canada's *Species at Risk Act* (Morris and Burridge 2006). The recovery strategy, as well as the watershed strategies for the Sydenham and Thames rivers, provide direction for much of the recent research.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2010)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune
Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and classification

Scientific name: *Villosa fabalis* (Lea 1831)
English common name: Rayed Bean
French common name: Villeuse haricot (Martel *et al.* 2007).

The currently accepted nomenclature (Turgeon *et al.* 1998) and classification (Graf and Cummings 2007) for this species is:

Kingdom Animalia
- Phylum Mollusca
  - Class Bivalvia
    - Subclass Paleoheterodonta
      - Order Unionoida
        - Superfamily Unionoidea
          - Family Unionidae
            - Subfamily Ambleminae
              - Tribe Lampsilini
                - Genus *Villosa*
                  - Species *Villosa fabalis*

Morphological description

The Rayed Bean can be distinguished from other Canadian freshwater mussels by its very small size, elliptical shape and crowded wavy green rays (Clarke 1981; Cummings and Mayer 1992). The shell is solid and elongate, elliptical in outline (Figure 1). Parmalee and Bogan (1998) state that maximum size is approximately 38 mm yet they have been found up to 45 mm in length in the Sydenham River (Woolnough 2002). Males are usually longer and less inflated than females, while females are more elliptical. However, there is a large overlap in dimensions between sexes and examination of gill structure may be required for sex determination (Figure 2; Woolnough 2002). Beaks are slightly elevated above the hinge line and have a double-looped structure. The left valve has two triangular pseudocardinal teeth, a short interdentum, and two short heavy lateral teeth. The right valve has a low triangular pseudocardinal tooth and a lateral tooth that is short and heavy (Parmalee and Bogan 1998). The teeth on the valves are unusually heavy for the size of the animal. The nacre (inner shell surface) is white or bluish and iridescent.

Figure 1. Live Rayed Bean (*Villosa fabalis*) from the North Thames River in 2008. All males. Photo courtesy of D. Woolnough.

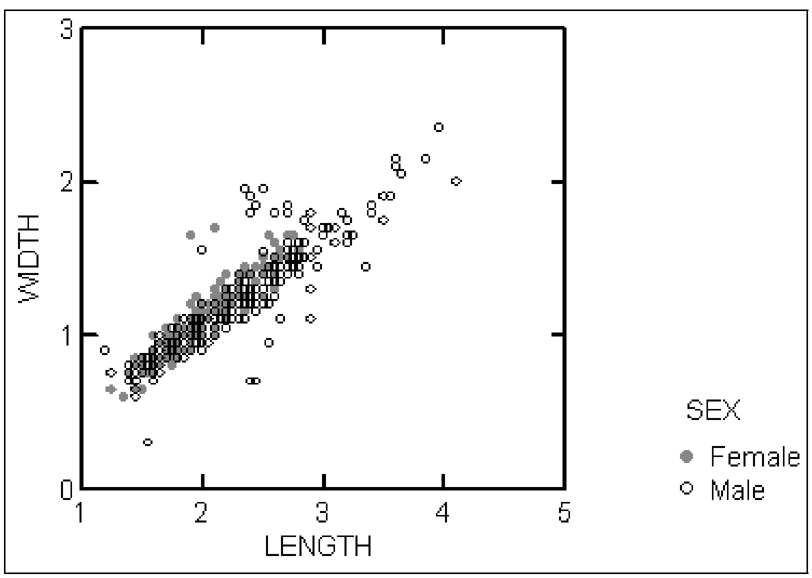

Figure 2. Male and female meristics of Rayed Bean (*Villosa fabalis*) from the Sydenham River 2000-2001 (n=563) (Woolnough 2002). Sizes in cm.

Viable glochidia (i.e., larvae found in gills of females) from the Sydenham River are the smallest of all known freshwater mussels (Hoggarth 1999). The average length of glochidia (n=10) was 230 ±11 μm and width was 185 ±15 μm (Woolnough 2002). The glochidia are rounded and higher than they are long, which may indicate an adaptation to gill attachment. Glochidia from Rayed Bean in the Sydenham show no similarities to other species within the genus *Villosa*.

Byssal threads (i.e., proteinaceous fibres that anchor an individual to the substrate) are produced by juvenile and adult stages and have been observed more often in the Sydenham River than in other places. The threads range in length from <1 cm to >10 cm (Woolnough 2002).

Population spatial structure and variability

The Rayed Bean is in the basal grade of lampsiline unionids, along with *Toxolasma*, *Obliquaria*, *Cyrtonaias*, and *Glebula* and may be closely related to some species currently placed in *Toxolasma* rather than *Villosa* (Zanatta and Murphy 2006; Campbell pers. comm. 2008). A comprehensive study of the genetics of the genus *Villosa* is underway at Ohio State University's Division of Molluscs, which will provide insight into the taxonomy of the group (Kuehnl pers. comm. 2008). Development of microsatellite markers for Rayed Bean (Boyer pers. comm. 2008) will help to understand population genetics. Preliminary results suggest that the genus *Villosa* is highly polymorphic and that the Rayed Bean is almost certainly not a member. It remains unclear to which genus (or genera) the Rayed Bean is most closely aligned. The extant Canadian populations (see **Canadian Range**) are isolated from one another and from populations in the U.S. by large distances (40–700 km). Zanatta and Murphy (2006) have shown that genetic isolation in Canadian populations of freshwater mussels is possible over these spatial scales. There are currently no genetic data on variation between and within Rayed Bean populations.

Designatable units

All Canadian populations are found within the Great Lakes-Upper St. Lawrence National Freshwater Biogeographic Zone. There are no known distinctions – genetic or taxonomic – among populations that warrant separate designatable units. However, without additional genetic evidence to the contrary, Canadian populations of Rayed Bean should not be mixed.

Special significance

Freshwater mussels in general play an integral role in the functioning of aquatic ecosystems. Vaughn and Hakenkamp (2001) summarized much of the literature relating to the role of unionids and identified numerous water column processes (e.g., size-selective filter-feeding; nutrient cycling) and sediment processes (e.g., biodeposition of feces and pseudofeces; epizoic invertebrates and epiphytic algae colonize shells; benthic invertebrate densities positively correlated with mussel density) mediated by the presence of mussels. Welker and Walz (1998) demonstrated that freshwater mussels are capable of limiting plankton in European rivers, while Neves and Odum (1989) reported that mussels also play a role in the transfer of energy to the terrestrial environment through predation by Muskrats (*Ondatra zibethicus*) and Raccoons (*Procyon lotor*). However, given the small size of the Rayed Bean, it appears that its relative contribution to these processes is likely minor.

No Aboriginal Traditional Knowledge was available at the time this report was prepared.

DISTRIBUTION

Global range

The Rayed Bean is limited to central North America where it was widely distributed, occurring in 11 U.S. states (Alabama, Illinois, Indiana, Kentucky, Michigan, New York, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia; Figure 3) and one Canadian province (Ontario). It was historically known from 106 streams, lakes and some man-made canals (NatureServe 2009). It occurred in the Great Lakes system, and throughout most of the Ohio and Tennessee river systems including in the Wabash, Monongahela, Elk, Allegheny, Green, Rouge, Clinch, Powell, North Fork Holston, and Duck Rivers in the U.S. (NatureServe 2009). It also occurred in western Lake Erie and its tributaries, including the Maumee River, and in tributaries to Lake St. Clair (Strayer 1980) and the St. Clair River (Hoeh and Trdan 1985). Its occurrence in the “St. Lawrence River system” (TNC 1987) refers to it having been found in Lake Erie and its tributaries, which drain into the St. Lawrence River, but not in the river itself. The easternmost records for this species are from western New York (see Strayer and Fetterman 1999). The overall global short-term trend (typically over a period spanning the past 10 years or 3 generations, whichever is longer, up to a maximum of 100 years) is that the Rayed Bean is “very rapidly declining” (i.e., decline of 50-70%) as this species has been eliminated from 78% of the total number of streams and other waterbodies and from half the U.S. states it occupied historically (NatureServe 2009). Global long-term trends (approximately the last 200 years) show a substantial decline (i.e., 50-75%) (NatureServe 2009).

Figure 3. North American distribution of the Rayed Bean (*Villosa fabalis*).

Canadian range

In Canada, the Rayed Bean is historically known only from the Great Lakes drainage in southern Ontario including the Lake Erie and the Lake St. Clair drainage basins (Figure 4). There are no records from any other Canadian province or territory. Its range in Ontario once included the Detroit River (museum records only; no indication of live animals or dead, empty shells on labels), the Sydenham and Thames rivers in the Lake St. Clair drainage, and western Lake Erie (La Rocque 1953; Clarke 1981; museum records). It is now restricted to the Sydenham and Thames rivers.

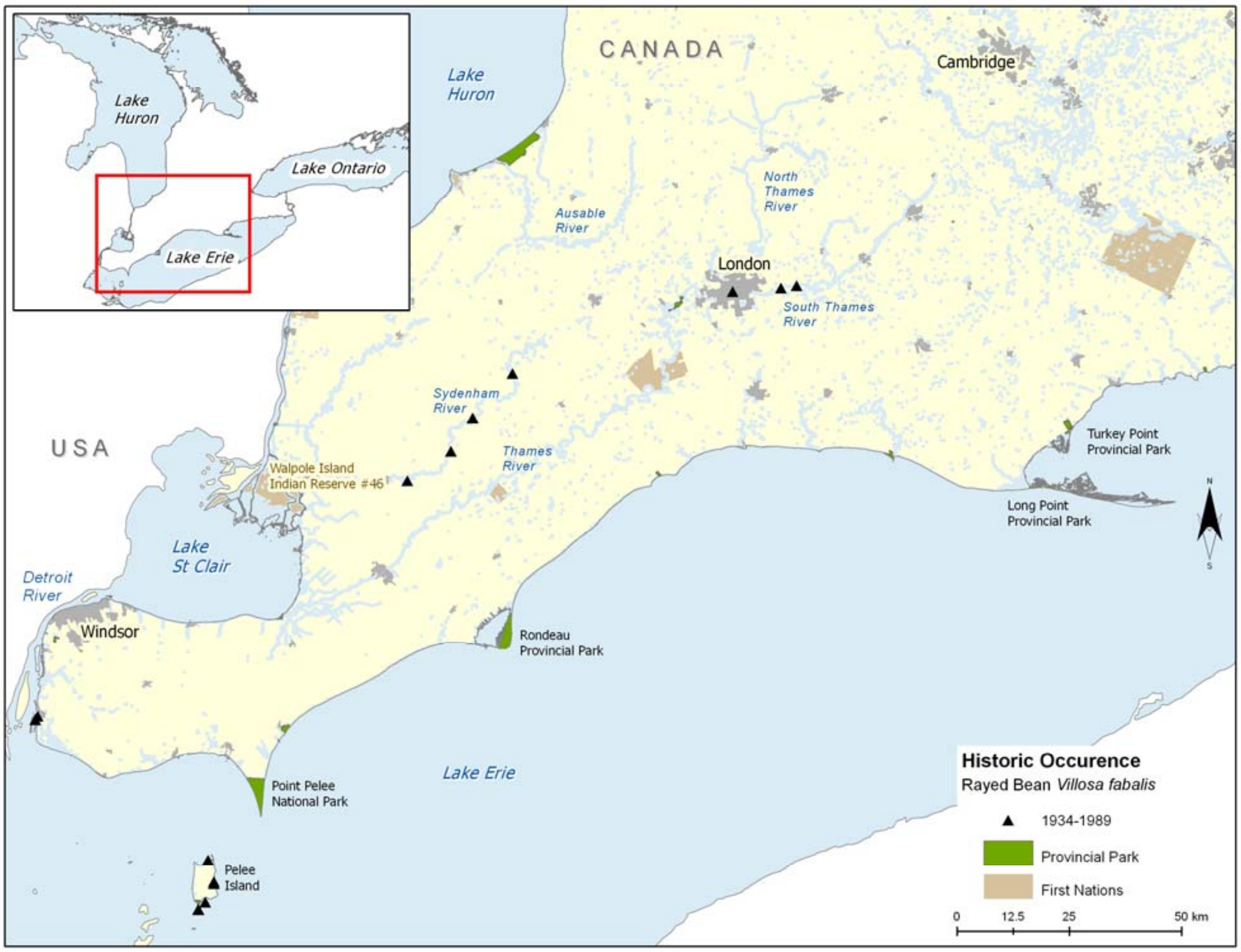

Figure 4. Historic occurrence (1930-1989) of the Rayed Bean (*Villosa fabalis*) in Canada. Records from the Lower Great Lakes Unionid Database.

Search effort

The Lower Great lakes Unionid Database (see **COLLECTIONS EXAMINED**) only contains 15 Canadian records of Rayed Bean from surveys between the 1930s and 1989; four are museum specimens for which there is no information available on search effort at sites where the Rayed Bean was collected nor from sites where the Rayed Bean was not detected. In the 15 records prior to 1990, there are only four confirmed live individuals, all from the Sydenham River (West *et al.* 2000). Information on sampling effort is available for all historic locations: Detroit River, Lake Erie, Sydenham and Thames rivers (Table 1).

Table 1. Summary of historic (1930-1989) mussel sampling effort within the range of the Rayed Bean.

Water body	# of sites	Year	Effort	Notes	Source
Detroit River	13	1982-83	SCUBA searches over 500 m^2 area over 60 minute period. Additional 15 – 30 min if live unionids detected.		Schloesser *et al*. (1998)
		1930			Wright (1955)
		1951-52			Wood (1963)
Lake Erie		1973-74			Wood and Fink (1984)
	17	1961, 1972, 1982	3 – 5 benthic grabs per site with either a Ponar or Peterson sampler.		Nalepa *et al*. (1991)
Sydenham River	12	1971	0.7 - >4 person-hours		Clarke (1973)
	22	1985	minimum of 1 person-hour	includes 12 sites of Clarke 1973	Mackie and Topping (1988)
Thames River	1	1983	240 0.5 m^2 quadrats		Salmon and Green (1983)

All recent (1990-2008) records for Rayed Bean in the Lower Great Lakes Unionid Database are from surveys designed to assess mussel assemblage composition, abundance and/or density (Table 2). Prior to 1990 directed search effort for Rayed Bean never exceeded 4 person-hours (p-h) per site. From the late 1990s to the present, biologists have used extensive searches including greater than 4.5 p-h as suggested by Metcalfe-Smith *et al.* (2000) for sampling rare species. Also, excavation surveys were employed to find this smaller unionid. All of these records have information on survey methodology and effort. Generally these methods involve either semi-quantitative timed-searches or more detailed quantitative methods involving substrate excavations (see **Sampling Effort and Methods** for details on methodology).

Table 2. Summary of current (1990-2008) mussel sampling effort within the range of the Rayed Bean.

Water body	# of sites	Year	Effort	Notes	Source
Detroit River	17	1992	SCUBA searches over 500 m^2 area over 60 minute period. Additional 15 – 30 min if live unionids detected.		Schloesser *et al*. (1998)
	9	1994	SCUBA searches over 500 m^2 area over 60 minute period. Additional 15 – 30 min if live unionids detected.		Schloesser *et al*. (1998)
	1	1997	4 x 120 m^2 line transects		Schloesser *et al*. (2006)
	4	1998	500 m^2 area searched for 60 minutes using SCUBA, second 500 m^2 area searched for 25 minutes	sites where live unionids were observed in 1992 and 1994	Schloesser *et al*. (2006)
	1	1998	10 x 1 m^2 quadrats within a 10 m x 10 m grid		Schloesser *et al*. (2006)
Lake Erie	17	1991	3 0.05 m^2 ponar grabs and 5 min tow with epibenthic sled (0.46 x 0.26 m)		Schloesser and Nalepa (1994)
	2	1997	4.5 person-hours		Metcalfe-Smith *et al*. (2000)
	6	2001	approximately 2 person-hours snorkelling		D. Zanatta and D. Woolnough (unpubl. data)
	12	2005	1.5 person-hours snorkelling		D. McGoldrick (unpubl. data)
	5	2005	beach search		D. McGoldrick (unpubli. data)
Sydenham River	16	1991	0.4 – 8.0 person-hours	most productive sites of Clarke 1973	Clarke (1992)
	17	1997-98	4.5 person-hours		Metcalfe-Smith *et al*. (2003)
	15	1999-03	60 – 80 x 1 m^2 quadrats	includes 12 sites surveyed in 1997-98	Metcalfe-Smith *et al*. (2007)
	15	2000-2001	10-60 person-hours per site	Includes historic sites	Woolnough (2002)
Thames River	?	1993	1 person-hour		Bowles (1992)
	16	1994	1 person-hour		Morris and DiMaio (1998-1999)
	16	1996	1 person-hour	Includes sites of Salmon and Green (1983) and overlap with Bowles 1994	Morris (1996)
	48	1997-98, 2004	4.5 person hours in 2004		Metcalfe-Smith (unpubl. data) and Morris and Edwards (2007)
	5	2004-2005	60-80 x 1 m^2 quadrats	Sites included in Morris and Edwards 2007	Morris (unpubl. data)
	2	2008	16 person-hours		Zanatta (unpubl. data)
	5	2008	4.5 person-hours (1 site 5 person hours)		Woolnough and Morris (unpubl. data)

The following descriptions of the distribution of the Rayed Bean for each waterbody are based on historic surveys and the occurrence of live animals in surveys by the report writers and colleagues since 1990. The area of occupancy of each waterbody was determined as that area in which live Rayed Bean were found. The lengths of the occupied area for each watershed were determined using ArcGIS v.9.2.

Of the 15 historic distribution (1930–1989) records (Figure 4), seven are of shells around Pelee Island in Lake Erie. The Rayed Bean appears to have been extirpated from Lake Erie, as it was not found during a survey of 17 sites in this area in 1991 (Schloesser and Nalepa 1994) or 2005 (McGoldrick unpubl. data), or from the Detroit River (Scholesser *et al.* 2006).

The first record of the Rayed Bean in the Sydenham River was by Athearn in 1963 (Mackie and Topping 1988). It was subsequently found alive in 1965 and 1967 by Stein, who sampled only one site in each year. Athearn also reported it from a site in 1967, but did not indicate whether it was alive. Stein surveyed two sites in 1973, including her 1965 site, and found only one fresh shell at each site (museum samples). The first extensive survey of the Sydenham River was in 1971 by Clarke (1973). He visited 11 sites and used a sampling effort of 1 hour per site, but did not find Rayed Bean. Mackie and Topping (1988) surveyed 20 sites on the Sydenham River and its major tributary, Bear Creek, in 1985 and found no trace of this species. A further survey of 16 sites in 1991 by Clarke (1992) produced one live specimen at one site (and no shells at any site) despite an intensive sampling effort averaging 2.3 p-h/site. A few shells also were found in 1991 and 1992 by Oldham (personal records) near the site where Clarke (1992) found the live specimen in 1991. Metcalfe-Smith *et al.* (1998) also visited nine sites on the Sydenham River in 1997, including three sites that had been sampled approximately 30 years earlier but only nine live individuals were found at four sites. Woolnough (2002) undertook extensive timed surveys in 2000-2001 producing the most extensive record of the species in the Sydenham River.

The first Canadian record for the Rayed Bean was from the Thames River in London when Medcof collected one fresh shell in 1934 (Royal Ontario Museum accession number ROM218). The species was not reported again from the Thames River until Metcalfe-Smith (unpub. data) collected 41 valves from four sites on the South Thames River above London in 1997-98. Morris and Edwards (2007) surveyed this area in 2004 and Morris (unpubl. data) quantitatively sampled one of the sites in 2004-2005 reported by Metcalfe-Smith (unpubl. data) and found no sign of the species. Since 1999 the South Thames River population of Rayed Bean has been searched for by mussel experts using methods known to detect the species at other sites. It appears that the historically occurring South Thames population has been extirpated.

Morris and Edwards (2007) found one fresh shell from a site on the North Thames where no previous records existed. Quantitative sampling in 2004 (Morris unpubl. data) produced a single live animal from a site near Plover Mills. In 2008, this area of the North Thames River was sampled again and six live Rayed Bean were found at two sites (16 p-h); all were gravid (Zanatta pers. comm. 2008). Timed surveys in September 2008 at five sites in the North Thames found live individuals at two additional sites (six live individuals) including males and females.

In summary, the Rayed Bean appears to have been extirpated from western Lake Erie and from the Detroit and South Thames rivers. It still lives in the Sydenham River and was recently found in a new waterbody – the North Thames River. There are two populations (see **Dispersal and Migration,** and **Rescue Effect**) and each population is a separate location as the mussels in the two rivers cannot be eliminated by any single threatening event (IUCN 2001). The number of years since the species disappeared from the Detroit River and Lake Erie can not be determined because it is uncertain if any live individuals were ever collected from these two waterbodies. Extensive quantitative excavation surveys along with timed surveys since 1990 have found this mussel only throughout a 61 km reach of the Sydenham River and a 7.2 km reach of the Thames River (Figure 5). The population appears to be continuous along the Sydenham River whereas the very small population in the North Thames appears discontinuous and patchy. The 61 km stretch of the Sydenham River occupied between Alvinston and Dawn Mills yields an area of occupancy (AO) (length of occupied reach multiplied by the average width of the reach) of 1.83 km^2 and an index of area of occupancy (IAO) (calculated using a 2 km x 2 km grid or 1 km x 1 km grid around each occurrence) of 160 km^2 or 85 km^2 (1 km x 1 km grid) (Table 3). The four sites spanning a 7.2 km reach of the North Thames River in the area of Plover Mills yields a current AO of 0.27 km^2 (Table 3) and an IAO of 20 km^2 (2 km x 2 km grid) or 10 km^2 (1 km x 1 km grid).

The extent of occurrence (EO), calculated in ArcGIS 9.2 using the maximum convex polygon around the current distribution (Figure 5) is 678 km^2.

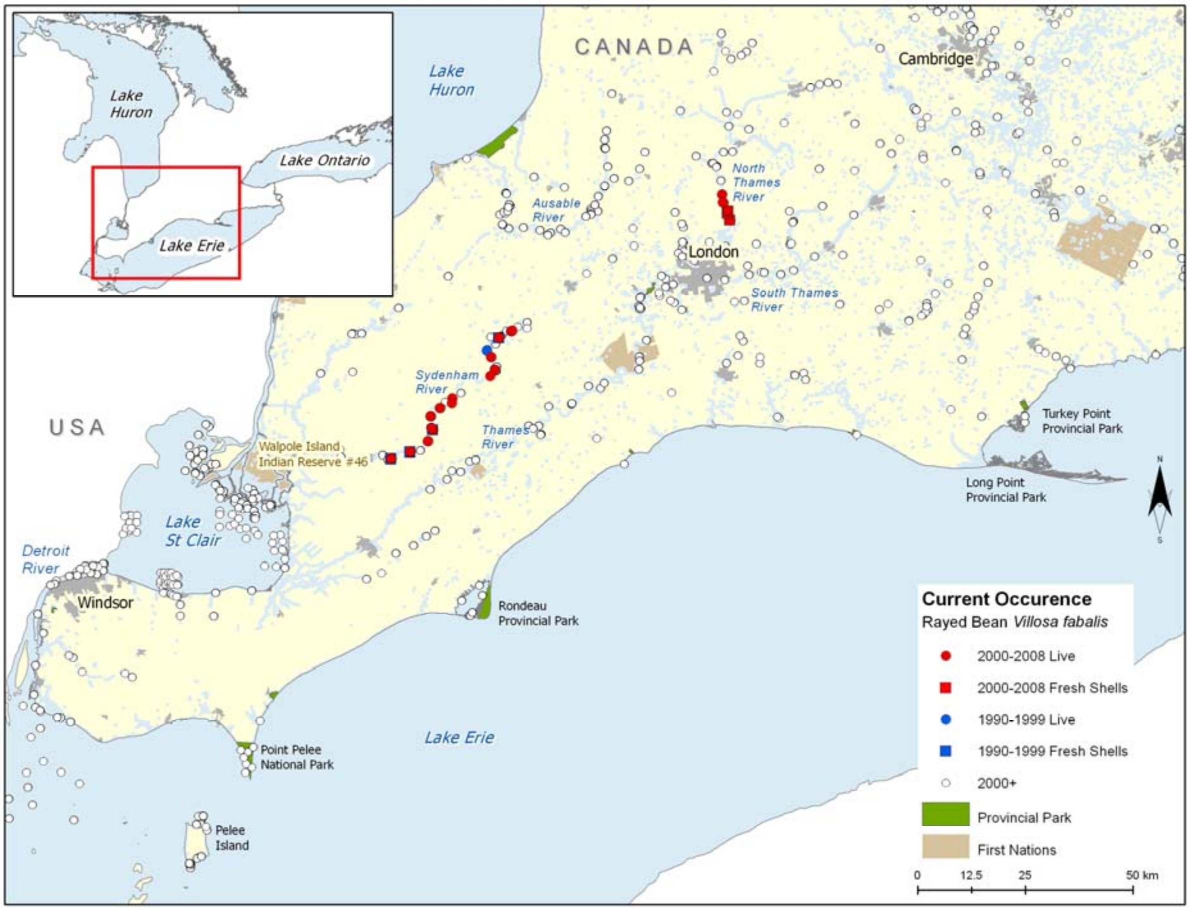

Figure 5. Search effort and current occurrence (1990-2008) of the Rayed Bean (*Villosa fabalis*) in Canada, based on records from the Lower Great Lakes Unionid Database. Open circles represent areas searched but the species was not detected.

Table 3. Estimated population size (total individuals) for the Rayed Bean in the Sydenham and North Thames rivers.

Location	Density[1] (#/m^2) (SE)	Length of occupied area (m)	Average width of occupied area (m)	Area of Occupancy (km^2)	Index of Area of Occupancy (km^2)		Abundance (± 95% CI)
					(2 km x 2 km grid)	(1 km x 1 km grid)	
Sydenham River	0.85 (0.36)	61000	30	1.83	160	85	1,555,000 (±658,800)
North Thames River	0.016	7200	38	0.27	20	10	4300

[1]Density estimates were derived from quadrat samples. Quadrat sampling (see **Sampling Effort and Methods**) is effective at detecting both adult and juvenile mussels. However, given the size distributions presented in Figure 8 and the small size of the Rayed Bean it is likely that the samples and the density estimates derived from them represent mature individuals. Therefore the reported abundance estimates are representative of numbers of mature individuals.

HABITAT

The Rayed Bean is usually found deeply buried in the gravel and sand substrates in rivers that are fast flowing. There are too few sites where Rayed Bean occurs to permit quantification of habitat. However, what follows is a summary of habitat where Rayed Bean is currently found.

Habitat requirements

The Rayed Bean occurs in the headwaters and smaller tributaries of river systems, where it is found in or near riffle areas (NatureServe 2009). Cummings and Mayer (1992) describe its habitat as “lakes and small to large streams in sand or gravel”. It is occasionally found in shallow water areas of lakes and large rivers. For example, historic records show that it has been found along the edges of islands in Lake Erie and the Detroit River. Strayer (1983) found it in streams that are characterized by low gradients, clear water, steady flows, and substrates of sand and gravel. In the Sydenham River abundance is positively associated with areas dominated by gravel and sand substrate, and the mussel is never found in areas dominated by silt (Staton *et al.* 2003). They are most abundant in areas characterized by higher flow (> 0.5 m/s) and shallow (wadable) water (Woolnough 2002). The higher flow habitat preferred by Rayed Bean provides a refuge from the lentic (non-flowing) habitat where Zebra Mussels (*Dreissena polymorpha*) are found. Thus far, Zebra Mussels have not been found in areas recently occupied by Rayed Bean and the invasive is only found in lower reaches in the Sydenham. The Rayed Bean is usually found deeply buried in the substrate (approximately 5-15 cm), among the roots of aquatic vegetation. As a result, this species may not be as sensitive to flow rate fluctuations in its habitat as are some other mussels (TNC 1987). In 1998 live specimens were found in the Sydenham River buried in stable substrates of sand or fine gravel, generally in areas along river margins or the edges of small islands (Metcalfe-Smith *et al.* 2007). In the Sydenham River they may rely on the presence of gravel substrate for stability in flowing rivers where adults use byssal threads for anchoring, likely an adaptation to their small size relative to other freshwater mussels (Figure 6).

Figure 6. Byssal threads of three adult Rayed Bean attached to stones from the Sydenham River (2001) (Woolnough 2002).

Habitat trends

Habitat trends for riverine populations are difficult to assess as there are few historic records.

The Plover Mills region in the North Thames River watershed where the Rayed Bean occurs is subjected to intense agricultural pressure. Seventy-four percent of the land in the lower watershed is agricultural and less than 12% of the historic forest cover remains (Upper Thames Conservation Authority 2007). In 2006, the region had a human population of 6,428, an increase from 6,112 in 1996. The City of London, downstream of this region, is the largest urban centre in the watershed and has a population of approximately 330,000. The City of London has undergone a 10-fold population increase in the last century. The impacts of such a large urban centre (e.g., wastewater treatment outflows) and its expansion are likely to be observed in the areas where the species occurs. The surface water quality of the Plover Mills region is poor (i.e., 2001-2005 mean total phosphorus is 0.077 mg/L, 99 *E. coli* per 100 ml) but the best in the North Thames River watershed. Surrounding regions exhibit poorer water quality (i.e, 2001-2005 mean total phosphorus 0.110 mg/L, 317 *E. coli* per 100 ml) than the Plover Mills region (Upper Thames Conservation Authority 2007). Similar to many watersheds, nitrate levels have been increasing in the Plover Mills region since the 1970s. There are water quality problems specifically within Fanshawe Lake, downstream of sites occupied by Rayed Bean, caused by years of nutrient (total phosphorus, nitrate) and sediment deposition on the lake bottom (Upper Thames Conservation Authority 2007).

The Sydenham River flows through an area of prime agricultural land in southwestern Ontario. Over 85% of the land in the watershed is agricultural, with 60% of land in tile drainage (Dextrase *et al.* 2003). Large areas of the river have little to no riparian vegetation as only 12% of the original forest cover remains. Strayer and Fetterman (1999) identified high sediment and nutrient loads and toxic chemicals from non-point sources, especially agricultural activities, as the primary threat to riverine mussels. Agricultural lands, particularly those with little riparian vegetation and large amounts of tile drain, allow large inputs of sediments into the watercourse. In tile drained land, the sediment is often very fine grained that can clog the gill structures of mussels and result in decreased feeding and respiration rates and reductions in growth efficiency (Strayer and Fetterman 1999). The Sydenham River has had high nutrient levels with total phosphorus levels consistently exceeding provincial water quality levels over the last 30 years while chloride levels have increased due to an increased use of road salt (Dextrase *et al.* 2003). Human population pressure within the watershed is low as the total population is less than 90,000 with roughly half occurring in urban settings. The lower portion of the river is subject to commercial shipping activities, with the potential for contamination from an accidental spill or the release of contaminated ship bilge. Commercial shipping tends to fluctuate in response to economic conditions.

It is possible that habitat change for the Rayed Bean in the Detroit River and Lake Erie is associated with the invasion of the dreissenid mussels (Zebra Mussel, *Dreissena polymorpha* and Quagga Mussel, *D. rostiformis*) in the mid-1980s. Dreissenid mussels compete with native unionids for space and food; by attaching directly to native mussel shells, they impair the ability of the native mussels to feed, respire and move normally (see **THREATS AND LIMITING FACTORS**) (Mackie 1991). Within a decade of the first invasion, native unionids had been almost completely eradicated from Lake St. Clair, Lake Erie and the Detroit and Niagara rivers (Schloesser and Nalepa 1994; Nalepa *et al*. 1996; Schloesser *et al.* 2006). The historic Rayed Bean records in Lake Erie and the Detroit River (see **Search Effort**) were from areas that have been taken over by dreissenid mussels, areas where unionids are now considered extirpated. Despite these catastrophic effects, there are still sites where dreissenid mussels occur in sufficiently low densities to allow coexistence with unionids, such as the Lake St. Clair delta (Zanatta *et al.* 2002). Strayer and Malcom (2007) suggested the potential for continued coexistence in areas where the impacts of dreissenids are more related to competition for food (e.g., the Hudson River in New York) than biofouling.

BIOLOGY

The following is based on a review of the literature and personal observations of the report writers.

Life cycle and reproduction

The Rayed Bean likely has the same general reproductive biology as most mussels. During spawning, males release sperm into the water and females living downstream filter it out of the water with their gills. Female mussels brood their young from the egg to the larval stage in specialized regions of their gills known as marsupia (Parmalee and Bogan 1998). Larvae, known as glochidia, develop in the gill marsupia and are released by the female into the water column to undergo a period of parasitism on a suitable host fish species (Parmalee and Bogan 1998). Further development to the juvenile stage cannot continue without a period of encystment on a vertebrate host. During encystment, the immature juvenile will feed on body fluids of the host and undergo significant differentiation, although virtually no growth occurs during this time. Natural glochidial mortality is difficult to estimate but is assumed to be extremely high (Wächtler *et al.* 2000). The duration of encystment for the Rayed Bean is 7-14 days, depending on water temperature and host fish (Woolnough 2002). After excysting from the host, the juveniles settle to the river bottom and begin life as free-living mussels. Juveniles remain burrowed in the sediment, completely below the substrate surface, for 3 to 5 years (Balfour and Smock 1995; Schwalb and Pusch 2007) until sexually mature, when they migrate to the substrate surface and begin the cycle again (Watters *et al.* 2001). Adults are found at the substrate surface during the summer months, but burrow below the surface during the winter, likely in response to dropping water temperatures or changing flow regimes (Schwalb and Pusch 2007). Juveniles likely feed on a combination of detritus, algae and bacteria obtained from the interstitial pore water or through pedal feeding (Wächtler *et al.* 2000) (pedal feeding occurs when juveniles drop off the host fish and scoop food particles into their mouth using the foot before the filters are fully developed). Adults feed by siphoning algae from the water column but may also engage in some pedal feeding (Nichols *et al.* 2005).

Age at maturity is unknown for the Rayed Bean, but the average age of maturity for unionids is 6-12 years (McMahon 1991) which is the estimated generation time for this species. Heller (1991) reports lifespans for the lampsiline mussels of approximately 20 years. It is possible the Rayed Bean matures younger as 20 mm individuals can be gravid (Woolnough pers. obs.).

The Rayed Bean is dioecious (has separate sexes) and males and females are dimorphic in shell shape (see **Morphological Description**). The spawning season is not well known but Parmalee and Bogan (1998) reported that this species is probably bradytictic (glochidia overwinter in the female). Females in the Sydenham River are gravid from late May until early August (Woolnough 2002).

The Tippecanoe Darter (*Etheostoma tippecanoe*) is thought to be a host in the U.S. (Neves and Weaver 1985), but it does not occur in Canada. Four fish species were found to be host fish for the Rayed Bean from the Sydenham River in laboratory trials: Rainbow Darter (*Etheostoma caeruleum*), Greenside Darter (*Etheostoma blennioides*), Mottled Sculpin (*Cottus bairdii*), and Largemouth Bass (*Micropterus salmoides*) (Figure 7) (Woolnough 2002). The Mottled Sculpin is predominately found in areas of different substrate in the Sydenham River than the Rayed Bean; however, the Mottled Sculpin is a good “surrogate host” species for many mussels in the laboratory, even if it is not found directly near the mussels’ habitat in the wild (Yeager and Saylor 1995; Gatenby *et al.* 1997). Recent sampling shows that all three other host fishes are also found in the Sydenham River in reaches occupied by the Rayed Bean. Most abundant is the Greenside Darter, which can comprise >50% of the fish community (Woolnough unpubl. data).

Figure 7. Host fish of the Rayed Bean as determined from laboratory testing at the University of Guelph 2000-2001 (Woolnough 2002). Total glochidia (grey bars) indicates the total number of glochidia used in the experiment. Not all glochidia transformed into juveniles and fish determined to be hosts transformed glochidia to juveniles (white bars) with varying success.

The host fish for the Rayed Bean in the Thames River is unknown because laboratory tests have not been performed. However, the Greenside Darter is a probable host as it is abundant throughout the Thames watershed, including areas occupied by the mussel, and its range has increased in recent years (COSEWIC 2006a). Rainbow Darters occur somewhat sporadically through the watershed and their numbers and range seem to have declined from historic levels. There are no records of Rainbow Darters in the Plover Mills area (Schwindt pers. comm. 2009).

Many species of freshwater mussels have evolved complex host attraction strategies to increase the probability of encountering a suitable host (Zanatta and Murphy 2006). These strategies range from the formation and release of conglutinates (bundles of glochidia bound in mucus) and the development of complex lures, to extreme cases of host capture in the genus *Epioblasma*. Little is known of the reproductive behaviours of the Rayed Bean; however, Woolnough (2002) reported a potential string-like lure in the laboratory and Zanatta and Murphy (2006) indicate that there is a simple, but active mantle-flap which has been recorded on video (Zanatta 2009). When gravid, the female mussel gapes and exposes the bright white swollen marsupia containing the glochidia.

Predation

Predation by Muskrats and Raccoons can be an important limiting factor for some populations of freshwater mussels (Neves and Odum 1989). Muskrats are both size and species-specific predators and although they will consume the Rayed Bean, Tyrrell and Hornbach (1998) report that predators did not select smaller mussels in the St. Croix River (New Brunswick), likely because of their small size and deep burrowing behaviour – characteristics of Rayed Bean. Metcalfe-Smith and McGoldrick (2003) reported Raccoon predation on mussels in Ontario waters. Many shells of Rayed Bean have been found on the shoreline of the Sydenham River during surveys (2000-2001) with evidence of predation by mammals, although the exact predator was not determined (Woolnough 2002). Human-related activities, such as conservation tillage practices, have resulted in surges in predator populations (e.g., Raccoon in the Sydenham River watershed), which may increase the importance of predation-related threats in the future (Metcalfe-Smith and McGoldrick 2003). This anecdotal observation needs verification.

Physiology and adaptability

No specific studies on the physiology of the Rayed Bean have occurred. In general, freshwater mussels of the family Unionidae are good indicators of overall ecosystem health and are particularly sensitive to heavy metals (Keller and Zam 1990), ammonia (Goudreau *et al.* 1993; Mummert *et al.* 2003), acidity (Huebner and Pynnonen 1992), and salinity (Liquori and Insler 1985, as cited in USFWS 1994). Sediment, pore water, and diet are the predominant exposure routes for contaminants during the first 4 years of life whereas contaminated surface water run-off is also a concern during later life stages (Cope *et al.* 2008).

The Rayed Bean is reported to have fairly broad habitat tolerances (see **Habitat Requirements**) both in terms of flow and substrate preferences suggesting they may be able to tolerate some environmental changes. However, the sedentary nature of adult mussels, general sensitivity to water quality (see **THREATS AND LIMITING FACTORS**), and host dependency may offset these broader habitat tolerances. The Rayed Bean can be considered a host specialist as only a limited number of hosts are known (n=4) although numerous other fish species have been tested (Woolnough 2002; McNichols pers. comm. 2008). This limits the ability of host switching to a less preferred fish.

Dispersal and migration

There are no specific studies on movement of the Rayed Bean. In general, adult mussels have limited dispersal abilities. Major movement (i.e., >100 m) of freshwater mussels typically occurs in one of three early life stages: passive movement of glochidial larvae, transport of the parasitic larval stage on host fish, and juvenile movement. During the first stage of life, glochidia (larvae) are released from the female into the water column and can live up to several weeks (Ingersoll *et al.* 2007); however, they likely sink to the substrate within days and are then unlikely to encounter a host fish. Once released, glochidia must encounter a host fish within several hours to a few days in the water column or they die in the substrate (Wächtler *et al.* 2000). After developing on the host fish, they detach and begin their free-living juvenile phase in sediments (Ingersoll *et al*. 2007). Juveniles can be transported by water movement from a few metres to several kilometres (Morales *et al.* 2006). Adult movement (tens of metres) can be upstream or downstream but there is an overall net downstream movement (Balfour and Smock 1995; Villella *et al.* 2004). Small-scale movements of Unionidae (e.g., centimetres/week) have been reported (Amyot and Downing 1998). Adults only disperse short distances so long-range or upstream movement is accomplished largely through transport by host fish during the glochidial stage (Fuller 1974). Three host fish for the Rayed Bean in Canada (Rainbow Darter, Greenside Darter, and Mottled Sculpin) generally disperse about 500 m and up to 1 km, but typically most darter species have low dispersal abilities and small home ranges (Hill and Grossman 1987; Warren and Pardew 1998). However, Largemouth Bass – the fourth known host fish – exhibit home ranges that are larger than the other known Canadian hosts. Largemouth Bass home ranges vary from 0.1 to 50 ha in lake systems but are not well known in riverine systems (Sammons and Maceina 2005). As such, the chances of Rayed Bean migrating from one of the occupied watersheds to the other on a host fish are nearly zero and the two populations are completely isolated. Furthermore, dams on the Thames River prevent Largemouth Bass from reaching the North Thames location.

Interspecific interactions

Larval Rayed Bean are obligate parasites on vertebrate hosts. Based on laboratory trials, the hosts for the Sydenham River population are Rainbow Darter, Greenside Darter, Mottled Sculpin, and Largemouth Bass; host fish for the Thames River population are currently unknown (see **Life Cycle and Reproduction**). Freshwater mussels of the Great Lakes region have been severely impacted by negative interactions with introduced dreissenid mussels. Host fishes have the potential to be negatively impacted by other invasive species such as the Round Goby (*Neogobius melanostomus*) (see **Fluctuations and Trends** and **THREATS AND LIMITING FACTORS**). Metcalfe-Smith *et al.* (2007) showed Elktoe (*Alasmidonta marginata*), Purple Wartyback (*Cyclonaias tuberculata*), Mucket (*Actinonaias ligamentina*), and Flutedshell (*Lasmigona costata*) are the freshwater mussels that most closely associate with the Rayed Bean in the Sydenham River.

POPULATION SIZES AND TRENDS

Sampling effort and methods

Timed-Searches

Timed-searches collect data on species presence/absence and provide relative measures of abundance (Woolnough 2002). Metcalfe-Smith *et al.* (2000) describe the methods in detail but they are summarized as follows. The riverbed is searched by a team (usually three to five individuals) for a period equal to 4.5 person-hours (p-h). Searches may be by the naked eye when conditions are favourable or through polarized sunglasses, view boxes or even manually by searching the substrate when turbidity is high. Individual mussels are collected, held in mesh diver's bags until the end of the sampling period, and then identified to species, sexed if possible, counted, measured, and finally returned to their collection spot alive. Since 1990 these methods have been employed at 17 sites in the Sydenham River and seven sites in the Thames River (Table 2).

Quadrat Excavations

Additional surveys have been conducted in rivers of southern Ontario using a quadrat excavation method developed by Metcalfe-Smith *et al.* (2007) in an effort to establish long-term unionid monitoring stations. With this method, an area of approximately 400 m^2 encompassing the most productive portion of the reach, as defined by previous sampling, is selected. Sampling is conducted using a systematic sampling design with three random starts whereby the area is divided into 3 m x 5 m blocks and sampled using a 1 m^2 quadrat. Each quadrat is excavated to a depth of approximately 10 cm and all mussels are removed. Similar to the timed-searches, individuals are identified, sexed if possible, counted and measured before being returned to the quadrat alive. This excavation approach allows for the determination of assemblage composition, total and species-specific density estimates, sex ratios, size frequencies, and estimates of recruitment. To date, the quadrat approach of Metcalfe-Smith *et al.* (2007) has been employed at 15 riverine sites within the Canadian range of the Rayed Bean (Table 2).

Abundance

The Rayed Bean was found at 15 sites sampled by extensive timed searching in the Sydenham River between 2000 and 2001 (Woolnough 2002). Sampling efforts were expanded from the traditional 4.5 p-h to 10 to 60 p-h/site to find gravid females for laboratory host fish testing. In total 563 live individuals were found at these 15 sites with numbers of individuals ranging from 1 to 117. While density cannot be estimated from timed searches, sex ratios, sizes, and presence of byssal thread were recorded. Overall the female:male ratio was 1:1.5 and females ranged in length from 12 to 36 mm and males 12 to 45 mm (Figure 8; only 522 were used as some were juveniles and could not be reliably sexed). Byssal threads were found on 49% of the males and 45% of the females. Females produced byssal threads when they were smaller in length and larger in width while males do not seem to produce byssal threads in any predictable trend (Woolnough 2002).

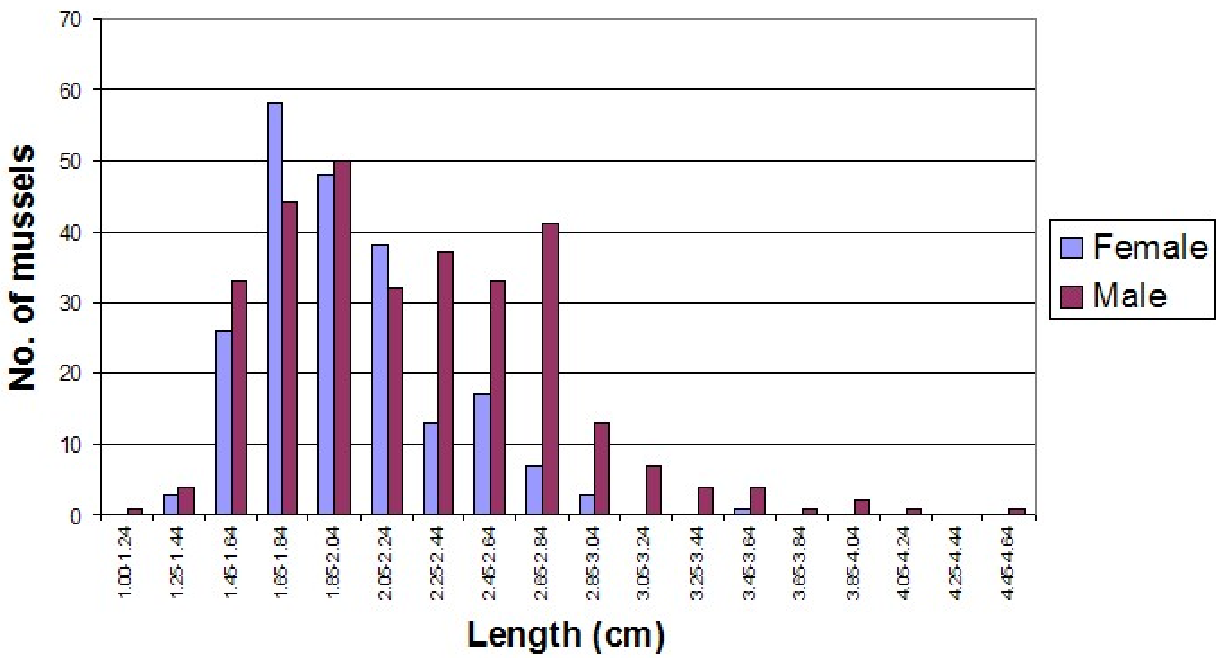

Figure 8. Size distribution of the Rayed Bean from the Sydenham River using timed-search methods 2000-2001 (n=15 sites) (Woolnough 2002).

Between 1999 and 2003, the Rayed Bean was found at 10 of 22 sites by quantitative quadrat excavation sampling in the Sydenham River (Metcalfe-Smith *et al.* 2007). In total 646 individuals were found at these 10 sites with the number of individuals ranging from one to 263 per site. Overall density of the Rayed Bean ranged from 0.01 to 3.35 per m^2 per site. Assuming the distribution is continuous within the area bounded by the next upstream and downstream sites where it was not found, as it appears to be, the occupied reach is calculated as 61 km. The average width of the river in this stretch is approximately 30 m yielding a potential of 1,830,000 m^2 of habitat and a population estimate of 1,555,000 (± 658,800) (95% CI) individuals (Table 3). The normally distributed size frequency indicates recruitment (Metcalfe-Smith *et al*. 2007).

Live Rayed Bean were found at a total of 18 sites in the Sydenham River between 1999 and 2008 using both methods (Woolnough 2002; Metcalfe-Smith *et al.* 2007). Only one live individual was found at the furthest upstream site. At three sites surveyed in the Sydenham River it was the most abundant mussel and in the top five species in abundance at two additional sites.

A total of 13 live Rayed Bean were collected from four of 48 sites in the North Thames River between 1990 and 2008 (Table 2). All four sites were located over a 7.2 km stretch of the North Thames River between Plover Mills to just below Thorndale and upstream of Fanshawe Lake. Only a single animal, the 2004 specimen, was found during quadrat excavations yielding a density estimate of 0.016/m^2. Assuming a continuous and even distribution throughout the 7.2 km occupied reach yields a population estimate of 4300 individuals (Table 3).

Individuals found between 2004 and 2008 in the North Thames River were older, indicated by the number of growth lines, and their size was larger relative to those in the Sydenham River (Figure 1). Males (n=3) were 30 to 35 mm and females (n=10) 24 to 34 mm with one smaller female 17 mm (Zanatta unpubl. data; Woolnough and Morris unpubl. data). Even though only a small number of individuals were found in 2008 (n=13) there was evidence of fertilization and all females were gravid. However, there was no evidence of multiple size classes (e.g., younger individuals) in the North Thames River.

All population estimates are for total individuals. Numbers of mature individuals are not known but it can be assumed that virtually all individuals collected during the recent surveys were mature as even the small females were often found gravid (Woolnough 2002). Therefore these estimates closely approximate numbers of mature individuals.

Fluctuations and trends

It is difficult to evaluate fluctuations or trends in Rayed Bean populations over time as there are few historic records.

The Rayed Bean appears to be extirpated from Lake St. Clair, Lake Erie and the Detroit River as a result of the invasion of dreissenid mussels. Even prior to the invasion, the Rayed Bean was never a large part of the native mussel fauna in these areas as only shells were found (West *et al.* 2000).

It is not possible to assess fluctuations or trends in the Sydenham River as it was not until the most recent surveys that extensive search effort and excavation techniques were used. However, there appears to be a much larger population in the Sydenham River than documented prior to 2000; the numbers found recently could not have been overlooked in historic studies.

It is not possible to assess fluctuations or trends in the North Thames River as there are so few records. However, it should be noted that prior to 2004 the Rayed Bean was only known from the South Thames River upstream of the City of London. These historic sites are separated from the current occupied reach by tens of kilometres and several man-made barriers including the City of London and Fanshawe Lake. Although a new occurrence has been found in the North Thames River (see **Search Effort**) it appears the historic South Thames population has been extirpated, likely due to expanding urban development and land use practices.

Rescue effect

All Canadian populations are isolated from one another and from U.S. populations by large areas of unsuitable habitat. The probability of recolonization of extirpated populations through natural immigration is highly unlikely. Three of the four known hosts in Canada – Rainbow Darter, Greenside Darter, and Mottled Sculpin - are not capable of moving the large-scale distances required to connect populations. However, the Largemouth Bass, the fourth known host, is capable of the large-scale movements. Movements of this magnitude are typically associated with fish spawning (Mesing and Wicker 1986). In Ontario, Largemouth Bass spawn in late spring/early-mid summer and could possibly overlap with the period when female Rayed Bean are gravid. The known host for U.S. populations – the Tippecanoe Darter – is not found in Canadian reaches occupied by Rayed Bean, so host switching would have to occur if mussels are transferred from U.S. to Canadian populations. Furthermore, the source populations in adjacent U.S. states are not considered stable but are critically imperiled (S1), possibly extirpated, or presumed extirpated (Table 4).

Table 4. Subnational conservation rankings for the Rayed Bean in the U.S. Tied rankings have been assigned the higher conservation rank. All information is from NatureServe (2009).

Conservation rank	Description	Jurisdiction
SX	Presumed extirpated	Alabama, Illinois, Kentucky, Virginia
SH	Possibly extirpated	West Virginia
S1	Critically imperiled	Indiana, Michigan, New York, Ohio, Pennsylvania, Tennessee

THREATS AND LIMITING FACTORS

All threats to the Rayed Bean are present and ongoing with the exception of invasive species, which are either imminent or directly affecting Rayed Bean.

The main factor limiting the occurrence of Rayed Bean is the availability of shallow, silt-free, riffle habitat. Siltation, urbanization and flood plain development have led to the deterioration of water and habitat quality for mussels in general (Biggins *et al.* 1995). Agriculture and forestry practices which cause excessive siltation are detrimental to mussels as heavy silt loads can bury mussels and interfere with respiration and feeding. Siltation also has an indirect effect on mussels, by transporting pollutants (USFWS 1994). Susceptibility to siltation varies among species. The only remaining populations of Rayed Bean in Canada are in the Sydenham and Thames rivers, which are both in areas of intensive agriculture. Thus, in addition to siltation, the distribution and abundance of this mussel may be limited by agricultural chemicals, including fertilizers and pesticides. Given the general sensitivity of freshwater mussels, particularly glochidia and juveniles (Cope *et al.* 2008) to aquatic pollutants, the levels of pollution observed in these watersheds may be negatively impacting the remaining riverine populations of the Rayed Bean.

A report on the geology, land use and water quality of the Thames River (WQB 1989) describes the major impacts on water quality in this system as run-off from agricultural land and rural septic systems. In 1988, 22 sewage treatment plants and two industries discharged their wastes into the upper portion of the watershed. Problems from agricultural and rural septic system failures are ongoing. Water quality in the Thames River basin has historically suffered greatly from agricultural activities. 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 basin (Taylor *et al.* 2004). Mean ammonia concentrations in all sub-basins of the Thames River exceed the federal freshwater aquatic life guidelines (Taylor *et al.* 2004). Soil and streambank erosion in the Thames River basin are severe, causing high loads of suspended sediments. There has been a steady increase in phosphorus and nitrogen inputs to the Thames River, and the Upper Thames basin has some of the highest livestock phosphorus loadings for the entire Great Lakes basin (WQB 1989). Despite recent efforts to improve water quality throughout the basin, poor water quality still exists in some areas and overall water quality is declining (see **Habitat Trends**).

High inputs of silt from agricultural lands may adversely affect mussels by clogging gill structures and negatively impacting feeding, respiration and reproduction (Strayer and Fetterman 1999). The primary land use in the Sydenham River basin is agriculture. Dextrase *et al.* (2003) report suspended solids levels as high as 900 mg/L leading to the conclusion that siltation and turbidity are the predominant threat to species at risk in this watershed.

The sensitivity of Rayed Bean to specific environmental pollutants is unknown because this species has never been subjected to toxicity tests. However, glochidia of unionids have been tested for response to several common river pollutants. Glochidia of *Villosa iris* (Rainbow Mussel) 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 (Goudreau *et al.* 1993). Jacobson *et al.* (1997) determined the toxicity of aqueous copper to the released glochidia of *V. iris* was the second most sensitive compared to the other mussels tested (24-hour LC50 = 38-80 μg/L). If Rayed Bean is as sensitive to pollution as *V. iris*, toxic contaminants are likely at least partially responsible for any decreases in the population densities downstream of Fanshawe Lake and could be considered potential future threats for the Sydenham and Thames river Rayed Bean populations. Freshwater mussels are also sensitive to PCBs, DDT, Malathion and Rotenone, all of which can inhibit respiration and accumulate in mussel tissue (USFWS 1994) (see **Physiology and Adaptibility**). Juvenile freshwater mussels are among the most sensitive aquatic organisms to un-ionized ammonia toxicity, typically showing adverse responses at levels well below those used as guidelines for aquatic safety in U.S. waterways (Newton 2003; Newton *et al.* 2003).

Invasive species are considered a threat to the survival of freshwater mussels. For the Rayed Bean, it is the introduction in the late 1980s and subsequent spread of dreissenid mussels (*D. rostiformis* and *D. polymorpha*). The attachment of dreissenid mussels to the shells of native mussels can interfere with normal metabolic functions, impede feeding, respiration, reproduction and locomotion regardless of the size of the unionid (Mackie 1991; Haag *et al.* 1993; Baker and Hornbach 1997). Lake Erie and Detroit River populations are likely extirpated due to the dreissenid mussels. Most of the area in these two waterbodies is now completely devoid of unionids (Western Lake Erie – Schloesser and Nalepa 1994; Detroit River - Schloesser *et al.* 2006). Dreissenid mussels were detected in Fanshawe Lake in the North Thames River in 2003 and are now found at virtually every site examined between the reservoir and the river mouth (Morris and Edwards 2007). Although this distribution is currently downstream of the occupied reach, it is less than 1 km from where the live Rayed Bean population was found in 2008. Should dreissenid mussels spread upstream or become established in Wildwood Reservoir, upstream of the occupied reach, they may represent a significant threat. The dam at the Town of St. Marys, upstream of the occupied reach, is also a potential area for dreissenid establishment.

Round Goby is an invasive fish that has recently invaded reaches of the Sydenham River occupied by Rayed Bean (Poos *et al.* 2009). Although gobies belong to a family of fish with a worldwide distribution in both salt and fresh water, they were not in the Great Lakes prior to 1990. Round Gobies are bottom-dwelling fish that perch on rocks and other substrates. They are aggressive and voracious feeders. They vigorously defend spawning sites in rocky or gravel habitats, thereby restricting access of other less aggressive fish to prime spawning areas (Charlebois *et al.* 1996). The threat to Rayed Bean is competition with Round Goby for host fish habitat. In addition, while there has been no evidence that Round Goby eat Rayed Bean, the Round Goby could be a predator in the future (Simonovic *et al.* 2001).

Damming of rivers has been shown to detrimentally affect mussels in many ways. Reservoirs alter downstream flow patterns, completely disrupting the natural hydrograph, and have been shown to change the natural thermal profiles of the watercourse (Vaughn and Taylor 1999). Impoundments also act as physical barriers to host movement making large areas of potential habitat completely unavailable to some mussels. Watters (1996) observed that the distributions of two mussel species (*Leptodea fragilis* – Fragile Papershell and *Potamilus alatus* – Pink Heelsplitter) in Indiana, Ohio and West Virginia were limited by the presence of small dams that acted to restrict movement of their host, the Freshwater Drum (*Aplodinotus grunniens*).

There are no historic data for southern Ontario that could be used to directly evaluate the impact of dam construction on fish and mussel populations. The Thames River is a unique river in southern Ontario as it is unregulated for nearly 200 km from the mouth to the first dam at Springbank Park, in the city of London. However, the occupied reach of the Rayed Bean (historic and current) is located above the first dam in this system. The historic distribution in the South Thames River was located between Springbank and Pittock reservoirs and their associated dams. The current distribution is now isolated to the North Thames River above Fanshawe Dam and Lake, the largest in the system. This barrier represents a complete barrier to fish passage. The Fanshawe Dam also separates the historic distribution in the South Thames River from the current distribution in the North Thames. It is unlikely that there has been any connectivity between these two areas since the dam was built. The first major barrier on the Sydenham River is located well above the current distribution of the Rayed Bean.

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 for the Rayed Bean. Natural levels of predation by other species outlined earlier (see **Predation**) are not likely to adversely impact healthy populations of the Rayed Bean due to its small size and the availability of larger mussels; however, if the range of the mussel continues to shrink then these influences may become larger.

In summary, the major factors limiting the current distribution of the Rayed Bean in Canada are the availability of required habitat, an inferred continuing decline in water quality affecting early life stages and adults, establishment of invasive species such as dreissenid mussels and Round Goby, and impoundments limiting host fish movements.

PROTECTION, STATUS, AND RANKS

Legal protection and status

The Rayed Bean is currently listed as Endangered on Schedule 1 of the *Species at Risk Act* (SARA) and as such it is currently illegal to kill, harm, harass, capture or take individuals. SARA also provides protection for the residence and critical habitat of listed species; however, at this time, neither a residence nor critical habitat have been described or identified (Morris 2006).

The Rayed Bean was listed as Endangered and protected under the *Ontario Endangered Species Act, 2007*, effective June 2008. While habitat is not currently protected under this *Act*, habitat protection will come into place in June 2013 unless a specific habitat regulation is made at an earlier date. However, the *Ontario Lakes and Rivers Improvement Act* prohibits the impoundment or diversion of a watercourse if siltation will result and also has jurisdiction over alterations to existing dams/barriers which could affect mussels.

The federal *Fisheries Act* represents another piece of legislation currently protecting the Rayed Bean in Canada. As shellfish, freshwater mussels are considered "fish" under the *Fisheries Act* and receive the same protection granted to finfish. The collection of freshwater mussels requires a collection permit issued under authority of the *Fisheries Act*. In Ontario, this permit is issued by the Ontario Ministry of Natural Resources.

The Rayed Bean is a candidate for federal listing as Endangered under the *U.S. Endangered Species Act* (Ohio River Valley Ecosystem Team 2002; Butler pers. comm. 2008). It is presumed extirpated in four U.S. jurisdictions, possibly extirpated in one U.S. jurisdiction, and considered critically imperiled in the remaining six jurisdictions (Table 4). This species is state-listed as endangered in Michigan, New York and Illinois; a species of special concern in Indiana; critically imperiled in Pennsylvania and a Tier I Fauna listing in Tennessee (Ohio River Valley Ecosystem Team 2002). The level of protection it receives from state-listing varies among states.

Non-legal status and ranks

The General Status of Species in Canada ranks the Rayed Bean as "At Risk" (1) which is the automatic ranking of COSEWIC Endangered or Threatened species. The Rayed Bean is considered globally imperiled (G2) and is ranked as nationally imperiled (N2) in the U.S. (NatureServe 2009). It is critically imperiled (N1) in Canada (NatureServe 2009) but is not on the IUCN's Red List.

Habitat protection and ownership

Stream-side development in Ontario is managed through floodplain regulations enforced by local conservation authorities. A majority of the land adjacent to the rivers where the Rayed Bean is found is privately owned; however, the river bottom is generally owned by the Crown.

The St. Clair Region Conservation Authority and the Upper Thames Conservation Authority located in southwestern Ontario are accountable for the conservation of local renewable natural resources in the Sydenham and Thames river watersheds, respectively. The portion of the North Thames River where the Rayed Bean is found is in the Plover Mills watershed, where the Fanshawe Conservation Area, owned by the Upper Thames Conservation Authority, is located.

ACKNOWLEDGEMENTS AND AUTHORITIES CONTACTED

The report writers would like to thank Carolyn Bakelaar (GIS Analyst, DFO) for the production of distribution maps, the authors of past Status Reports of the Rayed Bean (E.J. West, J.L. Metcalfe-Smith, and S.K. Staton), and multiple anonymous reviewers for insightful comments.

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BIOGRAPHICAL SUMMARY OF REPORT WRITERS

Dr. Daelyn A. Woolnough is an Assistant Professor at Central Michigan University in the Department of Biology. She has a B.Sc. (Env) with a major in Environmental Protection from the University of Guelph (1999), an Advanced Diploma in Marine Geomatics from the College of Geographic Sciences (2000), an M.Sc. in Zoology from the University of Guelph (2002) and a Ph.D. in Ecology and Evolutionary Biology from Iowa State University (2006). Dr. Woolnough's research focuses on spatial ecology and statistics and focuses on limnology, invertebrates and fish. She has conducted research and published on the early life history of freshwater mussels, reviewed and contributed to many of the status reports on freshwater molluscs and fish for COSEWIC, is on the Sydenham River Recovery Team and the Ontario Freshwater Mussel Recovery Team as well as the Ontario Freshwater Fish Recovery Team. Along with Dr. Gerald Mackie (University of Guelph) she was the first in Canada to help develop the host-testing facility for freshwater mussels. During her M.Sc. Dr. Woolnough collected quantitative data on *V. fabalis* morphometrics (adult and early life stages), distributions, life history traits and confirmed hosts for this species in Canada.

Dr. Todd J. Morris is a Species at Risk Research Biologist with the Great Lakes Laboratory for Fisheries and Aquatic Sciences with Fisheries and Oceans Canada in Burlington, Ontario, Canada. He has a B.Sc. (Hons.) in Zoology from the University of Western Ontario (1993), a Diploma in Honours Standing in Ecology and Evolution from the University of Western Ontario (1994), an M.Sc. in Aquatic Ecology from the University of Windsor (1996) and a Ph.D. in Zoology from the University of Toronto (2002). Dr. Morris's research interests focus on the biotic and abiotic factors structuring aquatic ecosystems, and he has worked with a wide variety of aquatic taxa ranging from zooplankton to predatory fishes. He has been studying Ontario's freshwater mussel fauna since 1993, has authored three recovery strategies addressing eight COSEWIC-listed freshwater mussel species, chairs the Ontario Freshwater Mussel Recovery Team and is a member of the Molluscs Specialist Subcommittee of COSEWIC.

COLLECTIONS EXAMINED

The following description of the creation of the Lower Great Lakes Unionid Database was modified from COSEWIC (2006b).

In 1996, all available historical and recent data on the occurrences of freshwater mussel species throughout the lower Great Lakes drainage basin were compiled into a computerized, GIS-linked database referred to as the Lower Great Lakes Unionid Database. The database is housed at Fisheries and Oceans Canada's Great Lakes Laboratory for Fisheries and Aquatic Sciences in Burlington, Ontario. Original data sources included the primary literature, natural history museums, federal, provincial, and municipal government agencies (and some American agencies), conservation authorities, Remedial Action Plans for the Great Lakes Areas of Concern, university theses and environmental consulting firms. Mussel collections held by six natural history museums in the Great Lakes region (Canadian Museum of Nature, Ohio State University Museum of Zoology, Royal Ontario Museum, University of Michigan Museum of Zoology, Rochester Museum and Science Center, and Buffalo Museum of Science) were the primary sources of information, accounting for over two-thirds of the initial data acquired. Janice Metcalfe-Smith personally examined the collections held by the Royal Ontario Museum, University of Michigan Museum of Zoology and Buffalo Museum of Science, as well as smaller collections held by the Ontario Ministry of Natural Resources. The database continues to be updated with new field data and now contains approximately 8200 records of unionids from Lake Ontario, Lake Erie, Lake St. Clair and their drainage basins as well as several of the major tributaries to lower Lake Huron. The majority of records in the database are now from recent (post 1996) field collections made by Fisheries and Oceans Canada, Environment Canada, provincial agencies, universities and conservation authorities. This database is the source for all information on Canadian populations of the Rayed Bean discussed in this report.

D. A. Woolnough (Central Michigan University) and T. J. Morris (DFO) have personally verified live specimens (Sydenham River, North Thames River), shell vouchers or digital vouchers from all populations described in this report.