COSEWIC
Assessment and Status Report

on the

Rainbow mussel
Villosa iris

in Canada

ENDANGERED
2006

COSEWIC
COMMITTEE ON THE STATUS OF
ENDANGERED WILDLIFE
IN CANADA

COSEPAC
COMITÉ SUR LA SITUATION
DES ESPÈCES EN PÉRIL
AU CANADA

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Please note that throughout the status report the Rainbow mussel is sometimes referred to as the "Rainbow".

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COSEWIC
Assessment Summary

Assessment Summary – April 2006

Common name
Rainbow mussel

Scientific name
Villosa iris

Status
Endangered

Reason for designation
This attractive yellowish green to brown mussel with green rays is widely distributed in southern Ontario but has been lost from Lake Erie and the Detroit and Niagara rivers and much of Lake St. Clair due to Zebra mussel infestations. It still occurs in small numbers in several watersheds but the area of occupancy and the quality and extent of habitat are declining, with concern that increasing industrial agricultural and intensive livestock activities will impact the largest population in the Maitland River.

Occurrence
Ontario

Status history
Designated Endangered in April 2006. Assessment based on a new status report.

COSEWIC
Executive Summary

Rainbow mussel
Villosa iris

Species information

The Rainbow mussel, *Villosa iris*, is a small freshwater mussel (average length in Canada about 55 mm) with a compressed, elongate-elliptical shape. The shell is yellowish, yellowish-green, or brown (in old specimens) with numerous narrow and/or wide broken dark green rays that cover the whole surface of the shell. Rays may be absent from the anterior portion of the shell. The nacre is silvery white and iridescent, which is the origin of the species' common name.

Distribution

The Rainbow was once widely distributed in North America from New York and Ontario west to Wisconsin and south to Oklahoma, Arkansas and Alabama. In Canada, there are records from the Ausable, Bayfield, Detroit, Grand, Maitland, Moira, Niagara, Salmon, Saugeen, Sydenham, Thames and Trent Rivers, as well as Lakes Huron, Ontario, Erie and St. Clair. The species appears to have been lost from the lower Great Lakes and connecting channels, except for the Lake St. Clair delta, but it is still extant in most rivers. It is also declining across the western part of its range in the U.S.

Habitat

The Rainbow is most abundant in small to medium-sized rivers, but can also be found in inland lakes. It once occurred throughout the shallow nearshore areas of the lower Great Lakes and connecting channels in firm sand or gravel substrates. In rivers, *Villosa iris* is usually found in or near riffles and along the edges of emergent vegetation in moderate to strong current. It occupies substrate mixtures of cobble, gravel, sand and occasionally mud or boulder. The Rainbow is most numerous in clean, well-oxygenated reaches at depths of less than 1 metre.

Biology

The Rainbow has separate sexes, but males and females differ only slightly in shell shape and are hard to tell apart. The glochidia (larvae) of *Villosa iris*, like those of most other freshwater mussels, are parasitic on fish. *Villosa iris* is a long-term brooder that spawns in the late summer, broods its glochidia over the winter and releases them in the early spring. Potential hosts for the Rainbow in Canada include striped shiner, smallmouth and largemouth bass, green sunfish, greenside darter, rainbow darter and yellow perch, but no testing has been done to identify the host(s) with certainty. Adult *V. iris* feed on bacteria, algae and other organic particles that they filter from the water column. Juvenile *V. iris* live completely buried in the substrate, where they feed on similar food items obtained directly from the substrate or interstitial water.

Population sizes and trends

The Rainbow has likely been extirpated from the Niagara and Detroit Rivers and most previously inhabited areas of Lake Erie and Lake St. Clair. A small population estimated at 7,200 individuals occupies the Canadian waters of the Lake St. Clair delta, but it is declining at an estimated rate of 7% per year based on data collected from 9 sites in 2001 and 2003. Populations in the Ausable, Grand, Saugeen and Sydenham Rivers are very small, with only 20 specimens collected from 148 sites in these rivers over the past 10 years. The population in the East Sydenham River consists of an estimated 18,900 individuals, but appears to be declining. The upper Thames River population is estimated at 40,000 mussels, but may also be declining. The Maitland River supports the largest and healthiest population of the Rainbow in Canada; Catch-Per-Unit-Effort for *V. iris* in this river is 10 to 100× higher than in any other waterbody.

Limiting factors and threats

The Rainbow has been lost from the lower Great Lakes and connecting channels due in large part to impacts of the Zebra mussel. If Zebra mussels become established in the reservoirs of impounded rivers, they could pose a threat to riverine populations of native mussels. Zebra mussels have already been found in 2 reservoirs in the Thames River. Heavy loadings of sediment, nutrients and toxic substances from urban and agricultural sources have degraded mussel habitat throughout southern Ontario. Studies have shown that the Rainbow is particularly sensitive to copper and ammonia.

Special significance of the species

There are 18 species in the genus *Villosa* in North America, but only *Villosa iris* and *Villosa fabalis* have ranges that extend into Canada. *Villosa fabalis* was designated as Endangered by COSEWIC in 1999 and is a candidate for listing in the United States. Only 2 species in the genus are listed as secure (G5) in North America, one of which is *V. iris*. Freshwater mussels are sensitive indicators of ecosystem health, including water and habitat quality and the fish community on which they depend. The Rainbow may be a particularly good indicator because of its sensitivity to toxic chemicals.

Existing protection

Freshwater mussels appear on the Species at Risk in Ontario (SARO) List, but are not regulated under the province's *Endangered Species Act* because aquatic species fall under federal jurisdiction. However, all species on the SARO List are afforded habitat protection under the Provincial Policy Statement of the *Planning Act* and the *Aggregate Resources Act*. Mussels are considered to be “fish” under the Ontario Fishery Regulations made under the federal *Fisheries Act*. Mussels cannot be collected in Ontario without a permit from the Ministry of Natural Resources. A portion of the Rainbow population in Lake St. Clair occurs in the territory of the Walpole Island First Nation. User permits are required to access WIFN territory, limiting human disturbance.

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 5th 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
(2006)

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 it 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

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SPECIES INFORMATION

Name and classification

Scientific name: *Villosa iris* (Lea, 1829)
English common name: Rainbow
French common name: Villeuse irisée

The recognized authority for the classification of aquatic molluscs in the United States and Canada is Turgeon *et al*. (1998). The current accepted classification of this species is as follows:

Phylum:	Mollusca
Class:	Bivalvia
Subclass:	Paleoheterodonta
Order:	Unionoida
Superfamily:	Unionoidea
Family:	Unionidae
Subfamily:	Lampsilinae
Genus:	*Villosa*
Species:	*Villosa iris*

Parmalee and Bogan (1998) provide a complete list of synonyms for this species. They note that *Villosa iris* is a species complex likely composed of several valid species that cannot be resolved by morphological characteristics alone. Dr. G. Thomas Watters (Curator, Division of Molluscs, Museum of Biological Diversity, Ohio State University) has used shell characteristics to separate *Villosa iris* into three subspecies across its range, namely, *V. iris iris*, *V. iris novieboraci* and *V. iris* "Missouri" (Ohio State University 2004). The *V. iris novieboraci* (Lea, 1838) form occurs in the Laurentian system as well as the Wabash and upper Mississippi river systems and is therefore the form found in Canada. The Ohio State University's Division of Molluscs has begun a comprehensive genetic study of the genus *Villosa* that will provide further insight into the taxonomy of this group.

Morphological description

The Rainbow is a small freshwater mussel that was first described by I. Lea in 1829 (Figure 1). The type locality is an unidentified waterbody in Ohio. The following description of the species was adapted from Clarke (1981), Strayer and Jirka (1997) and Parmalee and Bogan (1998). The shell is elongate-elliptical in shape, laterally compressed, and moderately thick anteriorly but becoming quite thin posteriorly. The posterior ridge is low and rounded. Male shells are bluntly pointed posteriorly whereas female shells are expanded and more broadly rounded, although the differences are subtle and visual separation of the sexes is difficult. The beaks are low and compressed; beak sculpture consists of 4-6 distinct bars – the first concentric and the rest becoming double-looped or irregular and nodulous. The hinge teeth are medium-sized, well developed and complete. Pseudocardinal teeth are elevated, a little compressed, conical and serrated. Lateral teeth are long, straight and thin. The surface of the shell is smooth with well-marked growth rests. The periostracum is yellowish, yellowish-green or brown (in old specimens) with numerous wide or both narrow and wide broken dark green rays that cover the whole surface of the shell or are absent anteriorly. Rays may become obscure in old specimens. The nacre is silvery white and iridescent, which is the origin of the common name for this species.

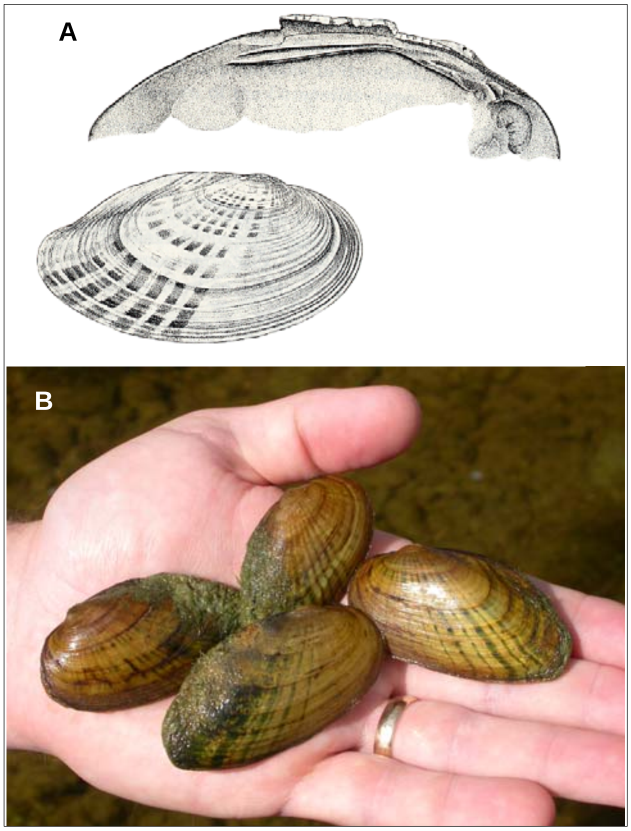

Figure 1. (A) Line drawing of the external features of the shell and internal structure of the left valve of *Villosa iris*. Reproduced with permission from Burch (1975). (B) Photograph of live specimens collected from the Maitland River near Wingham, Ontario in 2003. (Photo credit: D. McGoldrick, NWRI).

Villosa iris reaches a maximum length of about 85 mm in Canada. The average length of an adult shell is approximately 55 mm based on over 300 live specimens measured by the authors and their associates between 1997 and 2004. The Rainbow can be distinguished from all other species of freshwater mussel in Canada by its small size, narrow elliptical shape and interrupted green rays.

Genetic description

The authors are not aware of any published genetic description for *Villosa iris*. As noted previously, The Ohio State University recently initiated a genetic study of the Genus *Villosa*.

DISTRIBUTION

Global range

The Rainbow was once widely distributed in eastern North America from New York and Ontario west to Wisconsin and south to Oklahoma, Arkansas and Alabama. In the United States it has been recorded from Alabama, Arkansas, Illinois, Indiana, Kentucky, Michigan, Missouri, New York, Ohio, Oklahoma, Pennsylvania, Tennessee, Virginia, West Virginia and Wisconsin (Figure 2). The current distribution of the Rainbow is similar to its historical distribution, but the species has been declining across the western part of its range in the United States (Cummings and Mayer 1992).

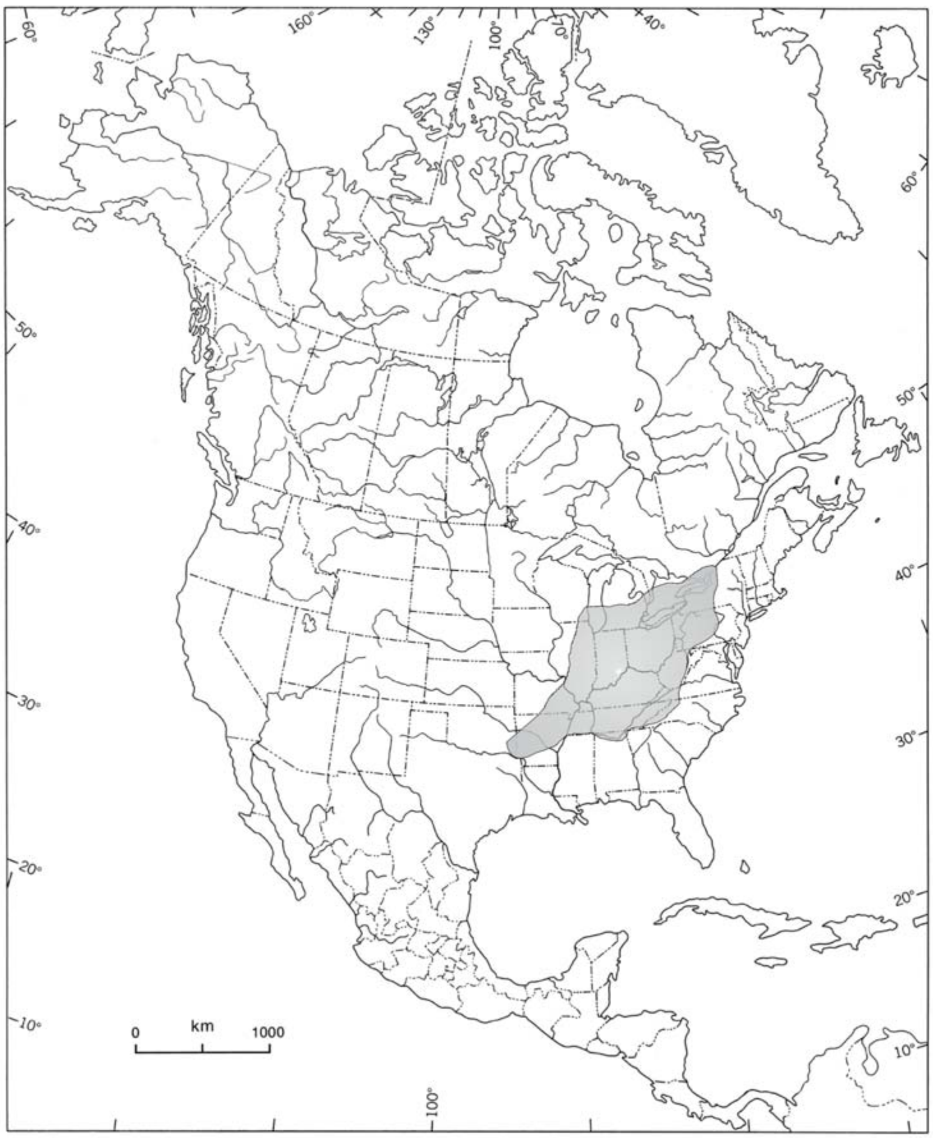

Figure 2. North American distribution of *Villosa iris* (based on information provided by jurisdictions).

Canadian range

In Canada, *Villosa iris* is known only from southern Ontario. It has been collected from the Ausable, Bayfield, Detroit, Grand, Maitland, Moira, Niagara, Salmon, Saugeen, Sydenham, Thames and Trent Rivers, as well as Lakes Huron, Ontario, Erie and St. Clair. The locations of these watersheds are shown in Figure 3. The earliest records of this species in Canada were collected in the 1890s by J. Macoun, who found specimens in the Detroit River near Windsor, the Grand River near Cayuga, and the Thames River near Chatham (specimens held by the Canadian Museum of Nature). Figure 4 shows the historical distribution of the Rainbow in Ontario based on 95 records (mostly from qualitative surveys) collected between 1890 and 1994. The current distribution of the species is shown in Figure 5 and is based on 133 records (live animals and shells many of which are from semi-quantitative and quantitative surveys) collected between 1995 and 2005. Live specimens were most recently collected from Fish Creek, a tributary of the Thames River, in October 2005.

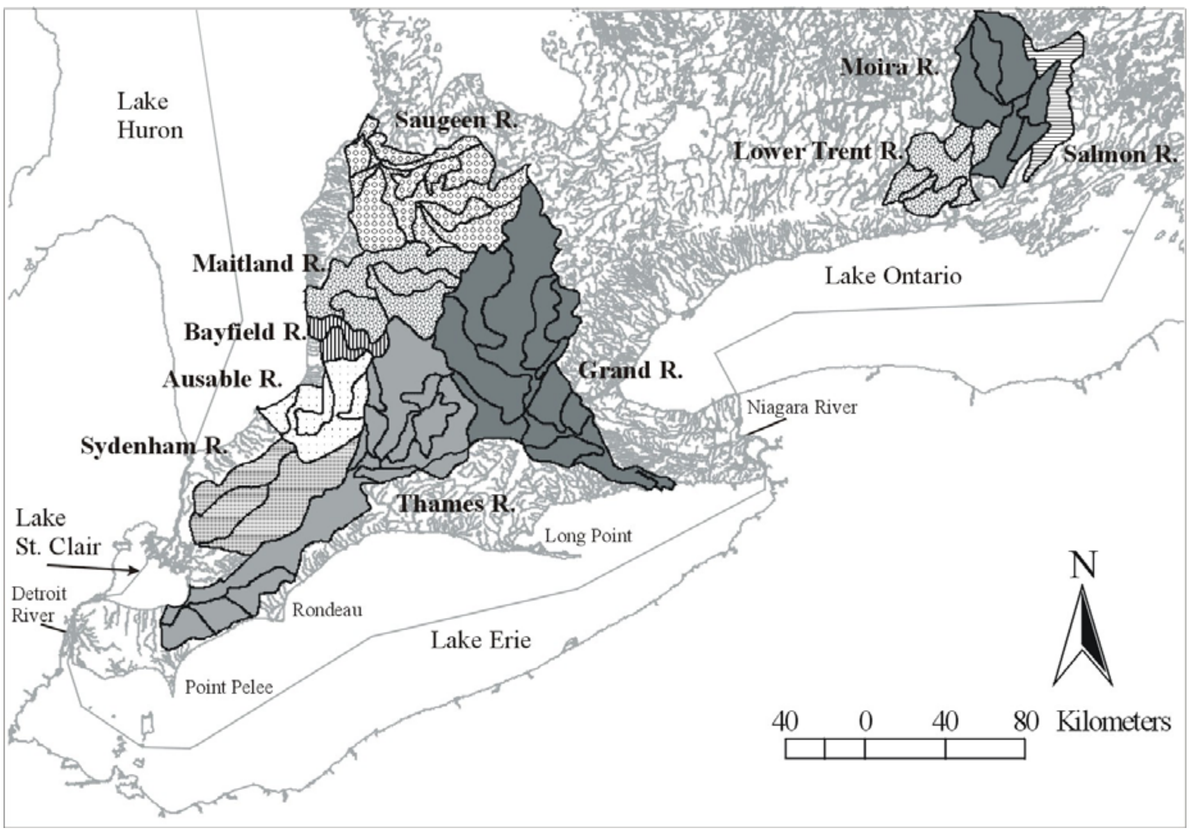

Figure 3. Location of watersheds where *Villosa iris* occurs or occurred historically in Ontario.

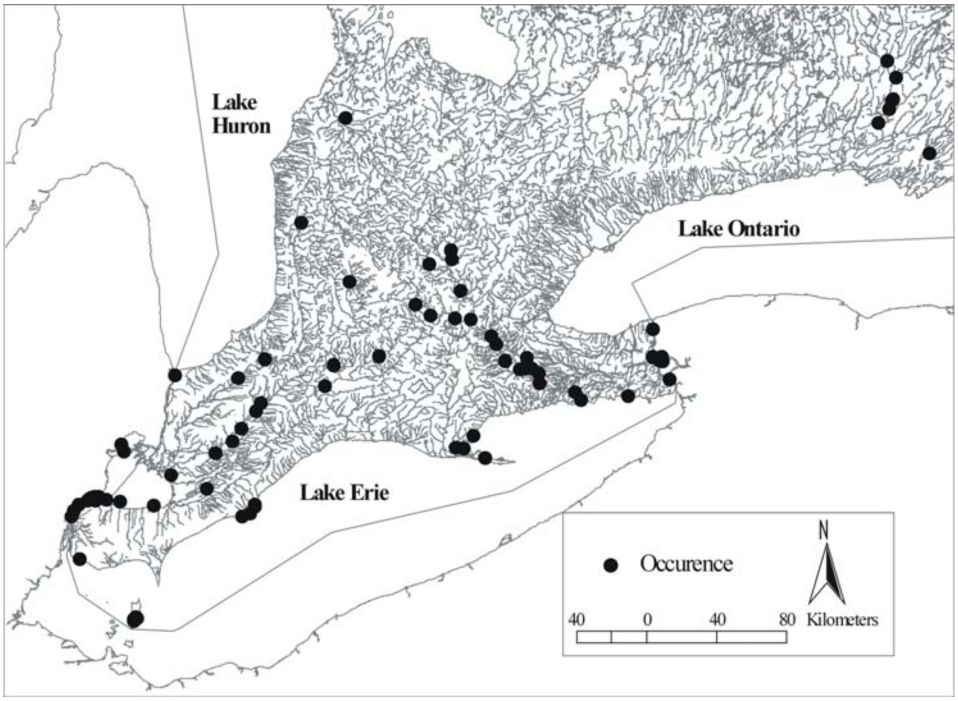

Figure 4. Historical distribution (1890-1994) of *Villosa iris* in Ontario (based on records from the Lower Great Lakes Unionid Database).

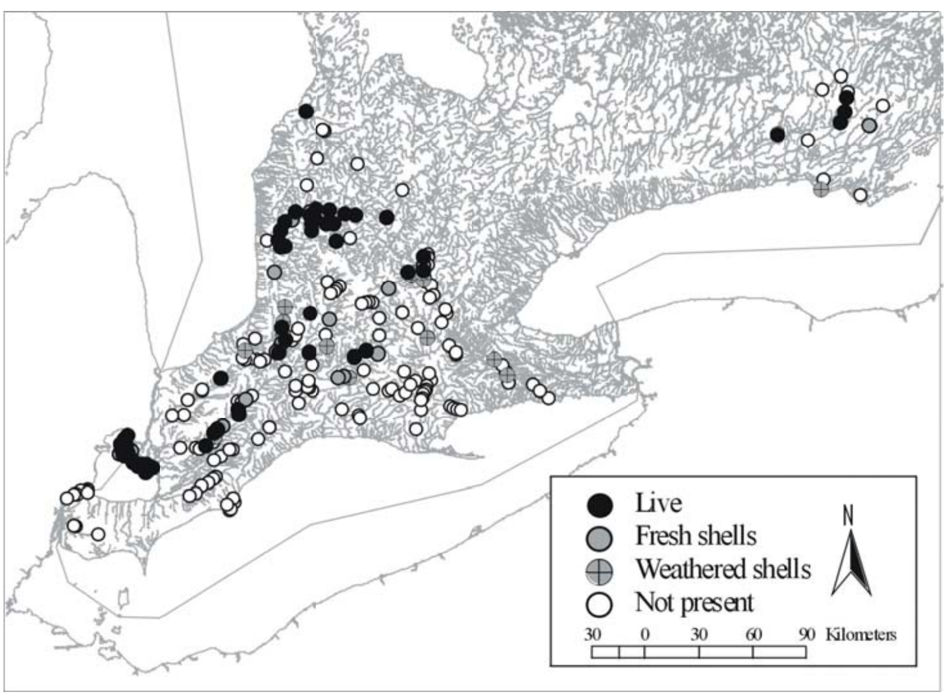

Figure 5. Current distribution (1995-2005) of *Villosa iris* in Ontario (based on records from the Lower Great Lakes Unionid Database).

Populations of freshwater mussels in the Canadian and U.S. waters of the lower Great Lakes and connecting channels have been virtually lost due to the impacts of dreissenid mussels (*Dreissena polymorpha* and *D. bugensis*). Small isolated populations can still be found in some nearshore areas where densities of dreissenids have remained low (e.g., Nichols and Wilcox 1997). Zanatta *et al*. (2002) surveyed 95 sites in nearshore areas around Lake St. Clair between 1999 and 2001 and found live mussels at 33 sites, most of which were in the Canadian waters of the St. Clair delta. The Rainbow was found at 39% of these sites. Metcalfe-Smith *et al*. (2004) surveyed 28 sites in the delta in 2003 and found the species to be much more common in U.S. than Canadian waters (70% vs. 30% of sites sampled, respectively). *Villosa iris* was not recorded from the offshore waters of Lake St. Clair either before or after the Zebra mussel invasion (Nalepa *et al*. 1996). *V. iris* was found alive at 5 of 6 sites surveyed in the upper Detroit River between 1987 and 1992, but no specimens were found during follow-up surveys in 1997-98 (Schloesser *et al*. in press). *V. iris* was collected from Long Point Bay, Rondeau Bay and Pelee Island in Lake Erie in the 1930s, 1960s and 1970s. Zanatta and Woolnough surveyed 6 sites in Rondeau Bay in 2001 while working for J.L. Metcalfe-Smith. They found one live mussel (*Amblema plicata*) and weathered shells of 15 other species, but none were *V. iris*. Long Point and Pelee Island have not been surveyed recently, but 33 sites in U.S. waters of the western basin and around the Bass Islands were surveyed in 1998 and no live unionids were found (Ecological Specialists 1999). Weathered shells of 17 species were recorded, including *V. iris* at one site. *V. iris* was also collected alive from the Niagara River as recently as 1983. When 13 sites were surveyed for the New York Power Authority in 2001, old weathered shells of 16 species and a few live animals of 3 unidentified species were all that was found (Schneider pers. comm. 2002).

The Rainbow was once widely distributed throughout the main stem and tributaries of the lower Grand River system, but has not been found alive in these areas since 1971 (Kidd 1973; Mackie 1996; Metcalfe-Smith *et al*. 2000b). The Rainbow has also declined in the Sydenham River, especially the east branch where it was found at 33% of 15 sites surveyed between 1929 and 1991 vs. 17% of 12 sites surveyed in the same reaches in 1997-1999 (Metcalfe-Smith *et al*. 2003). Only a few specimens were found alive at 2 of 10 sites sampled quantitatively in 1999-2002 (Metcalfe-Smith *et al*. 2003). Small populations persist in the Ausable and Saugeen Rivers, but it is not known if the distributions have changed because no data are available prior to 1993 for either watershed. The distribution of *Villosa iris* in the Moira River appears to be stable, although current and past sampling effort has been limited. Eighty-three sites in the Thames River and its tributaries were surveyed over the past 10 years (Morris 1996; Metcalfe-Smith *et al*. 1998b, 1999; Morris pers. comm. 2005). The Rainbow is currently restricted to several tributaries of the North Thames River and a small reach of the Middle Thames River, but nearly all historical records are also from this area. There is only one historical record for the Rainbow in the Maitland River; it was collected in the lower main stem near Auburn in 1935. The authors surveyed 21 sites throughout the Maitland watershed between 1998 and 2004 and found Rainbows at 80% of the sites, often in large numbers (J.L. Metcalfe-Smith, unpublished data). The Maitland River appears to support the largest remaining population of the Rainbow in Canada.

The Rainbow was collected from the lower Trent River in 1996 (2 live specimens) and the Salmon River in 1998 (1 weathered shell). Schueler (pers. comm. 2005) collected 7 weathered shells and valves from a site on the Salmon River in October 2005 as well as 109 weathered shells and valves (a few were fresh) from a muskrat midden located 0.2 km upstream of the site. A fresh shell was also found in the Bayfield River in 2005 (Veliz pers. comm. 2005). As there are no previous records of the species in these watersheds and formal surveys have not been conducted, we cannot determine distribution trends for the Rainbow in these systems.

Overall, *Villosa iris* has been lost from approximately 30% of its former range, in terms of extent of occurrence, in Canada (Figures 4 and 5). The current extent of occurrence (EO) is approximately 53,700 km^2 as compared with 76,500 km^2 historically. The current area of occupancy (AO) is approximately 11 km^2 (Table 1).

Table 1. Current Area of Occupancy (AO) for all known populations of *Villosa iris* in Ontario and Canada.

Waterbody	Length of occupied reach (km)	Mean width of reach (m)	Area of Occupancy (km^2)
Saugeen River	0.5	20	0.01
Maitland River	135	28	3.78
Ausable River	10	7.5	0.08
Sydenham River	30	21	0.63
Thames River	40.5	20	0.81
Grand River	15	43	0.65
Trent River	0.5	20	0.01
Moira River	20	20	0.40
Lake St. Clair	N/A	N/A	4.5
TOTAL AO			10.87

HABITAT

Habitat requirements

The Rainbow is most abundant in small to medium-sized rivers (van der Schalie 1938; Strayer 1983; Parmalee and Bogan 1998), but can also be found in inland lakes and once occurred throughout the shallow nearshore areas of the lower Great Lakes and connecting channels in firm sand or gravel substrates (Clarke 1981; Strayer and Jirka 1997; Zanatta *et al*. 2002). In rivers, *Villosa iris* is usually found in or near riffles and along the edges of emergent vegetation in moderate to strong current. The species occupies substrate mixtures of cobble, gravel, sand and occasionally mud or boulder. The Rainbow is most numerous in clean, well-oxygenated reaches at depths of less than 1 m (van der Shalie 1938; Gordon and Layzer 1989; Parmalee and Bogan 1998).

Habitat trends

The invasion of the Great Lakes by the Zebra mussel began in 1986 (Hebert e*t al*. 1989) and resulted in the near extirpation of native mussels from Lake Erie, Lake St. Clair and the Detroit and Niagara Rivers by the mid-1990s (Schloesser *et al*. 1998; Scloesser *et al*. in press; Schneider pers. comm. 2002). Only isolated communities with reduced species richness and low abundance still survive in several bays and marshes along the U.S. shore of Lake Erie and in the delta area of Lake St. Clair where Zebra mussel densities are low. As 50% of historical records for the Rainbow are from areas now infested with Zebra mussels, the loss of habitat is significant for this species.

Mussel communities in the Grand River declined dramatically from a historical total of 31 species to only 17 by the early 1970s. Kidd (1973) blamed this decline on pollution, siltation and the presence of dams. He found few mussels living below dams or in reservoirs and noted that none of the dams had fishways. He also found that dissolved oxygen concentrations were low and turbidity was high in the lower reaches of the river, most likely due to agricultural runoff. Sewage pollution was probably the major cause of the decline of mussels in this river (Metcalfe-Smith *et al*. 2000b). At the time of Kidd's surveys, only 7 of the river's 22 sewage treatment plants (STPs) had had secondary treatment in place for the past 10 years, 7 others had upgraded from no treatment to secondary treatment during that time and the remaining 8 were in the process of installing treatment facilities for the first time. Twenty-five years later, Metcalfe-Smith *et al*. (2000b) found that the mussel communities of the river had rebounded – most likely in response to significant improvements in water quality and a corresponding increase in the number of warmwater fishes from 16 to 26 species (Coleman 1991). Unfortunately, this trend is unlikely to continue. The human population of the watershed doubled from 375,000 to 787,000 between 1971 and 1996 and is expected to grow by another 300,000 over the next 25 years (GRCA 1997). The percentage of the minimum daily flow consisting of treated effluent from STPs ranged from 1% to 22% in 1993 and the capacity of the river to receive additional wastewater at reasonable cost is in question. The proportion of the Grand River basin in agricultural use increased from 68% in 1976 to 75% by 1998 (GRCA 1998). Row crop farming has increased, and along with it the potential for greater soil erosion and runoff of pesticides and fertilizers. Livestock production has changed, becoming more concentrated and specialized, and focusing on pigs and sheep rather than cattle. There has also been a change in manure handling from solid to liquid, and inadequate management of these liquid wastes has become a problem in some areas (GRCA 1998).

Habitat trends for the Sydenham River watershed are summarized from Staton *et al*. (2003). Prior to European settlement, the Sydenham River watershed was 70% forest and 30% swamp. By 1983, 81% of the land area was in intensive agriculture (mainly corn and soybean crops), with only 12% forest and <1% swamp remaining. Sixty percent of the watershed is tile drained. Total phosphorus (TP) levels have consistently exceeded the provincial water quality objective (PWQO) over the past 30 years. Concentrations of TP and total Kjeldahl nitrogen continue to increase in the East branch and most of the phosphorus is associated with particulate material that probably originates from agricultural runoff. Chloride levels have been relatively low but are slowly increasing – a widespread pattern that has been attributed to the increased use of road salt. Sediment loadings from overland runoff and tile drains are high and the north branch of the river is particularly turbid. Wooded riparian zones, which are important for bank stabilization and interception of nutrients and sediments from overland runoff, are very limited. The human population of the Sydenham River watershed is small (74,000), with 50% rural and 50% living in towns and villages. Despite a modest rate of population growth, all municipalities have upgraded their sewage treatment facilities over the past 30 years. Leakage of nutrients and contaminants from rural septic systems is a significant and ongoing problem, especially in the north branch.

Habitat trends for the Thames River watershed are summarized from Taylor *et al*. (2004). Agriculture is the dominant form of land use in the Thames River watershed, with 78% of the land area in the upper Thames and 88% in the lower Thames in agricultural use. Forested areas have been reduced to 12% of the land area in the upper Thames and 5% in the lower Thames. Eight percent of the watershed is classified as urban, with concentrations in the cities of London (population 350,000), Stratford and Woodstock in the upper watershed and Chatham in the lower watershed. As the land was cleared, flooding became a serious problem. Three large dams and reservoirs were constructed in the upper watershed between 1952 and 1965. Numerous private dams and weirs have been installed since the 1980s and there are now 173 structures in the upper watershed and 65 in the lower watershed. Zebra mussels were discovered in Fanshawe and Springbank reservoirs in 2003 and have since spread downstream where they were found attached to native mussels in 2004 (Morris pers. comm. 2004). Fortunately, these two reservoirs are located downstream of the existing populations of the Rainbow. The extent of tile drainage in the watershed is not known. Water quality data collected since the 1960s show that concentrations of phosphorus and heavy metals are declining while nitrate and chloride levels are on the rise. The upper Thames River where the Rainbow mainly occurs is moderately turbid, while the lower Thames is highly turbid. Soil conservation remains a serious issue in the watershed.

Habitat trends for the Ausable River watershed are summarized from Nelson *et al*. 2003. Mussel habitat in the Ausable River has been dramatically altered over time. Prior to European settlement, 80% of the basin was covered in forest, 19% was in lowland vegetation and 1% was marsh. By 1983, 85% of the land area was in agriculture (70% in row crops), and only 13% remained in small unconnected woodlots. Over 70% of the basin is now in tile drainage. The natural course of the lower portion of the river was destroyed in the late 1800s, when it was diverted in two places to alleviate flooding. The Ausable River has been described as “event responsive”, which means that there are large increases in flow during runoff events following storms. The nearby Sydenham, Thames and Maitland Rivers are more stable in this regard (Richards 1990). There are 21 dams in the watershed that cause sediment retention upstream and scouring downstream. Water quality data collected since 1965 show that TP levels are consistently above the PWQO and have decreased only marginally over the past 35 years. Nitrate levels currently exceed federal guidelines for the prevention of eutrophication and the protection of aquatic life and are slowly rising. Mean total suspended solid concentrations in the lower Ausable River exceed levels required for good fisheries.

There have been significant land use changes in the Maitland River watershed over the past 30 years (Malhiot pers. comm. 2004). Although there have been some minor impacts from urban and industrial expansion, these are greatly overshadowed by technological changes in the agricultural industry. Typical farming in the 1960s and 1970s focused on pasture and hay crops. Small grains were rotated through the grass fields and corn was cropped on the better lands. An extensive tile drainage system was installed during the 1970s. Better outlets were required to accommodate the improved drainage, which necessitated the installation or improvement of open drains, especially in wetlands. There was also a move towards larger farm implements in the 1970s and this required the expansion of field size through the clearing of fencelines/hedgerows and the straightening of field edges. It is now possible to grow corn and beans on lands that had only been suitable for grazing and hay in the past. The amount of row cropping greatly expanded through the 1980s as improved seed varieties were developed. The overall impact of these technological changes would have resulted in more nutrients, pesticides and sediment entering watercourses. As land prices increased due to improved crop values, there was also a move towards cattle feedlots. Factory farming for hogs expanded significantly in the 1990s. These two changes resulted in fewer livestock having access to watercourses, but there were now new impacts in the form of liquid manure applications on tiled crop lands. Environmental programs introduced to keep pace with these changes have had some success through efforts in conservation tillage, watercourse rehabilitation (fencing livestock and reforestation) and most recently with nutrient management.

Land use changes have also occurred in the Saugeen River basin (Nichol pers. comm. 2005). Parts of the watershed (Huron-Kinloss, Kincardine) are undergoing a change to more intensive agricultural operations. More systematic tile drainage is being installed in the western portions of the basin and there is continuing development around existing urban areas and along the Lake Huron shoreline. Many landowners are implementing Best Management Practices that would improve water quality, but only when incentives are available. Water quality monitoring by the Ministry of Environment began in the 1960s, was discontinued in the 1990s, and started up again in 2001. The data show that phosphorus concentrations are below the PWQO except during storm events or spring run-off, and may be generally declining. Nitrate concentrations are showing an upward trend but generally remain below the PWQO. There are high levels of *E. coli* in many areas of the watershed, particularly during the spring and summer and usually associated with elevated flows.

Only 15 species of mussels have been reported from the Moira River and community composition has changed little over time (Metcalfe-Smith *et al*. 1998b). *Villosa iris* was the 5th most commonly encountered species between 1960 and 1968 and 7th in 1996, based on surveys of 8 sites. Two-thirds of the Moira River watershed is on the Canadian Shield and agricultural activity is limited (Sprague pers. comm. 1997). Contamination of the river with metals due to a long history of mining and smelting activities is likely the main source of stress to the aquatic community.

Habitat protection/ownership

Land ownership along the reaches of the Sydenham, Thames, Ausable, Maitland, Grand and Saugeen Rivers currently occupied by *Villosa iris* is mainly private and in agricultural use. Only two small properties in the Sydenham River watershed, the 7 ha Shetland Conservation Area and the 20 ha Mosa Township forest, are publicly owned and somewhat protected (Andreae pers. comm. 1998). There are 21 natural areas totalling 6,200 ha in the Thames River watershed and most of these are in the upper reaches where the Rainbow occurs (Thames River Background Study Research Team 1998). Four Indian Reserves occupy over 6,700 ha of land along ~ 45 km of the river downstream of the City of London, but *V. iris* has never been found in this area. The Ausable Bayfield Conservation Authority owns a number of properties totalling 1,830 ha throughout the basin (Snell and Cecile Environmental Research 1995). The Maitland Valley Conservation Authority owns 28 conservation areas covering 1,750 ha, but these areas represent only about 0.5% of the land in the Maitland River watershed (Kenny pers. comm. 2005). Less than 3% of the land in the Grand River watershed is publicly owned (GRCA 1998). There are 11 conservation areas, one of which (Elora Gorge) is about 10 km upstream of the reach occupied by *V. iris*. Saugeen Conservation owns over 8,498 ha of Conservation Areas and Lands comprised of wetland complexes, managed forests and recreation parks (Nicol pers. comm. 2005). It should be noted that recovery strategies and action plans are being developed or implemented for the Sydenham, Thames and Ausable River aquatic ecosystems to protect and recover aquatic and semi-aquatic Species at Risk including fishes, mussels, turtles and snakes. Many landowners are participating in riparian rehabilitation projects and improved land use practices that will ultimately benefit all aquatic species.

The Trent River is part of the Trent-Severn Waterway, one of seven national historic canals that are managed and protected by Parks Canada. Parks Canada is developing policies for in-water and shoreline works and related activities that will “ensure that the (natural and cultural) heritage and recreational values of the waterways will continue to be sustained…” (Parks Canada 2005). Information was not available for the Moira and Salmon Rivers.

Occupied habitats in Canadian waters of the Lake St. Clair delta fall within the territory of the Walpole Island First Nation. These areas are primarily used for hunting and fishing and are protected from urban development as well as certain recreational uses (e.g., jet skis are prohibited). Walpole Island contains over 12,000 ha of World Class Wetlands – one of the largest wetland complexes in the Great Lakes Basin (Bowles 2004) – and freshwater mussels occupy the transition zone between these wetlands and the open waters of Lake St. Clair. The Rainbow is currently more abundant in U.S. waters where habitat protection is minimal because the shoreline is almost completely urbanized and the waters are heavily utilized for recreational purposes. It is not known why the Rainbow is more abundant in U.S. waters than in Canadian waters, as substrate type and Zebra mussel infestation rates are similar in both areas of the delta.

BIOLOGY

Villosa iris, like all freshwater mussels, is a sedentary animal that buries itself partially or completely in the substrates of rivers, streams or lakes. Adult freshwater mussels are filter-feeders that obtain nourishment by siphoning particles of organic detritus, algae and bacteria from the water column and, as recently shown, the sediment (Nichols *et al*. 2005). Juvenile *V. iris* live completely buried in the substrate, where they feed on similar food items obtained directly from the substrate or from interstitial water (Yeager *et al*. 1994; Gatenby *et al*. 1997). Aspects of the life history of *V. iris* summarized in the following sections were derived from a review of the available literature as well as the authors' knowledge of the species.

Life cycle and reproduction

The life cycle of the Rainbow is similar to that of all freshwater mussels and is described as follows (adapted from Kat 1984, Watters 1999, and Nedeau *et al*. 2000): during spawning, males release sperm into the water and females living downstream filter the sperm out of the water with their gills. Ova are fertilized in specialized regions of the female gills, called marsupia, where they are held until they reach a larval stage called the glochidium (plural = glochidia). The female mussel then releases the glochidia, which must attach to an appropriate host – usually a fish. The glochidia become encysted on the host and are nourished by its body fluids until they metamorphose into juveniles. The juveniles then release themselves from the host and fall to the substrate to begin life as free-living mussels. The proportion of glochidia that survive to the juvenile stage is estimated to be as low as 0.000001%. Mussels overcome the extremely high mortality associated with this life cycle by producing large numbers of glochidia – often more than a million. Juvenile mussels are difficult to find because of their small size and because they quickly burrow into the sediment upon release. Juvenile mussels remain buried until they are nearly sexually mature, at which time they move to the surface for the dispersal/intake of gametes (Watters *et al*. 2001).

Villosa iris is believed to be dioecious, but is occasionally reported as being hermaphroditic. There are subtle differences in the external shell features of males and females (see **Morphological description**). Rainbows are bradytictic (long-term brooders); that is, they spawn in late summer, brood their glochidia over the winter, and release them in the early spring (Parmalee and Bogan 1998). Glochidia are semi-elliptical, large, with a short hinge line and measure approximately 230 µm in length and 290 µm in height (Clarke 1981). Based on studies conducted in the United States, fish hosts for the Rainbow are the striped shiner (*Luxilus chrysocephalus*), streamline chub (*Erimystax dissimilis*), smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), green sunfish (*Lepomis cyanellus*), bluebreast darter (*Etheostoma camurum*), greenside darter (*Etheostoma blennioides*), rainbow darter (*Etheostoma caeruleum*) and yellow perch (*Perca flavescens*) (Watters and O'Dee 1997). All species except for the streamline chub and bluebreast darter occur in Ontario throughout the range of *V. iris* and therefore have the potential to serve as glochidial hosts in Canadian waters. Specific hosts for Canadian populations have not yet been identified. Female *V. iris* have modified mantle flaps that mimic a crawling crayfish in both shape and movement (Figure 6). When the glochidia are ready for release, the female mussel displays this crayfish-like “lure” in order to attract the host fish. The glochidia are discharged when the fish approaches close enough to touch the lure. There is no information on age to maturity, maximum life span, nor generation length.

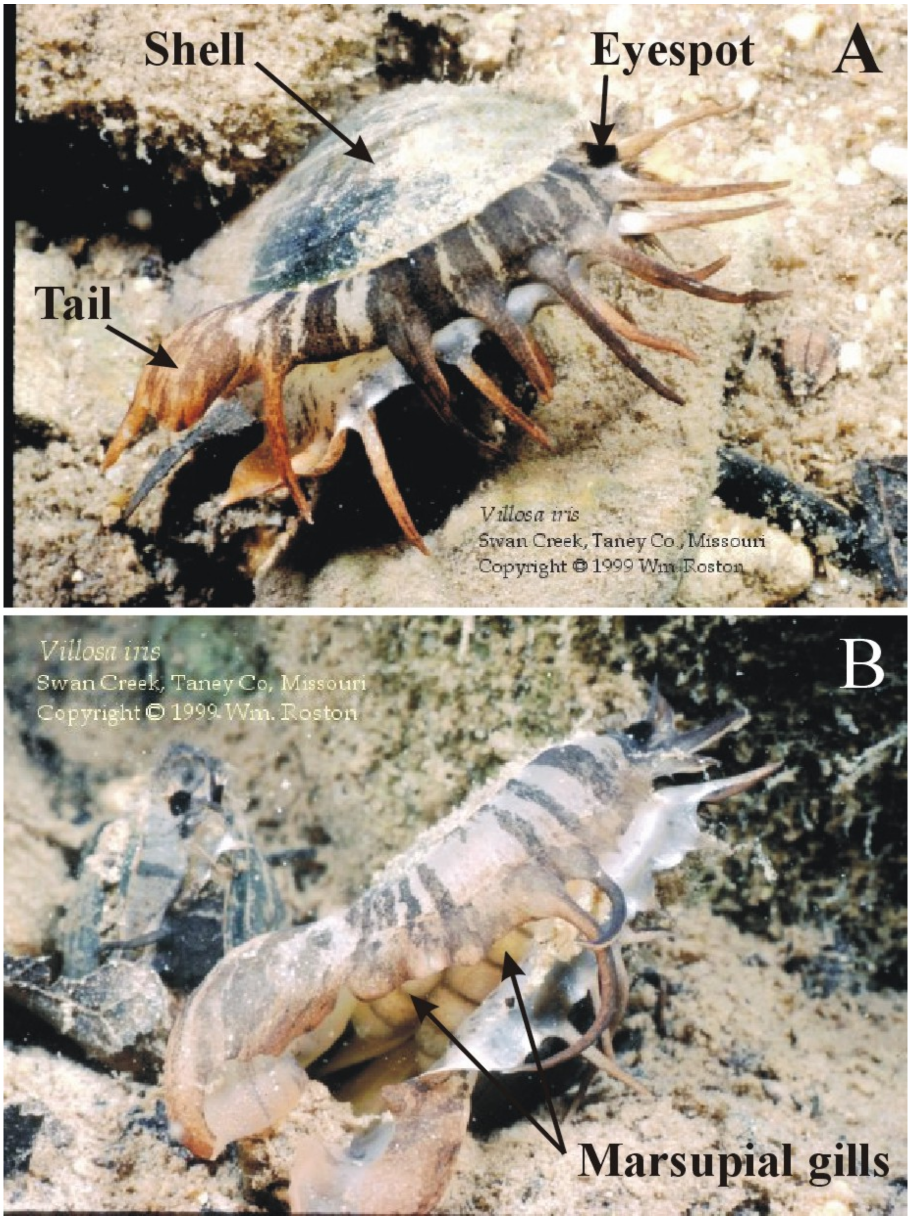

Figure 6. Photographs of a gravid female *Villosa iris*: (A) displaying a crayfish-like lure to attract its host and (B) showing the marsupial gills filled with glochidia. Reproduced with permission from M.C. Barnhart, Southwest Missouri State University, Springfield, MO

Predation

River otter (*Lutra canadensis*), mink (*Mustela vison*) and muskrat (*Ondatra zibethicus*) have been identified as feeding “more or less heavily” on freshwater mussels, and raccoons (*Procyon lotor*) are said to be occasional mussel predators (Fuller 1974). The impacts of these predators on mussels in Ontario waters have not been investigated and the extent to which they limit the distribution of *Villosa iris* in Canada is not known (see LIMITING FACTORS AND THREATS).

Physiology

Freshwater mussels are sensitive indicators of environmental conditions in rivers and lakes because many species require optimal water and habitat quality for survival (see LIMITING FACTORS AND THREATS). The specific environmental requirements (e.g. water temperature, water velocity, pH, etc.) of *Villosa iris* are unknown.

Dispersal/migration

Freshwater mussels are basically sessile as adults, with movement limited to a few metres of the lake or river bottom. If local habitat becomes unsuitable (due, for example, to a drop in water level), some species are capable of moving up to several metres a day. The only time that significant dispersal can take place is during the parasitic phase. Infected host fishes can transport larval unionids hundreds of metres or kilometres into new habitats and replenish depleted populations with new individuals. Dispersal is particularly important for genetic exchange between populations (Nedeau *et al*. 2000).

Interspecific interactions

The larvae of *Villosa iris* are obligate parasites on fish. Specific fish hosts for Canadian populations of this species have not yet been identified (see Life cycle and reproduction).

Adaptability

Freshwater mussels are particularly sensitive to environmental perturbations because of their complicated life cycle. They are threatened not only by disturbances that impact them directly, but also by those that affect their host fish populations. Recent successes in the captive-rearing of several species of freshwater mussels have been reported (e.g., Hanlon and Neves 2000); however, the authors are not aware of any programs involving the Rainbow. The release of artificially reared juvenile mussels has taken place on a trial basis in the United States, but the long-term outcome of such releases is still being evaluated.

POPULATION SIZES AND TRENDS

Search effort

Historical surveys

Approximately 70% of the historical records for *Villosa iris* in Canada are based on either museum specimens or occurrence data. For most of these records, there is little if any information on sampling method, search effort, numbers of sites visited where the species did *not* occur, or even whether the animals were dead or alive when collected. Abundance data from this period are extremely limited. Estimates of relative abundance (Catch-Per-Unit-Effort or CPUE) are available from timed-search surveys of several sites on the Sydenham River in the 1960s (Stein pers. comm. 1996) and 1991 (Clarke 1992). These sites were revisited in 1997-98 (Metcalfe-Smith *et al*. 1998b, 1999) and the results can be compared. Kidd (1973) surveyed 68 sites on the Grand River in 1970-72 and 14 of these sites were re-surveyed 25 years later using a similar sampling effort (Metcalfe-Smith *et al*. 2000b). One site on the Thames River was sampled quantitatively in 1977 and a nearby site was sampled using the same method in 2004.

Recent surveys

Surveys conducted between 1995 and 2005 within the range of the Rainbow in Ontario have been either semi-quantitative (timed-searches) or quantitative (quadrat surveys). The same sampling methods were used throughout and are described below.

Timed-searches surveys:

In rivers, surveys were conducted using an intensive timed-search technique developed by Janice Metcalfe-Smith and her team for detecting rare species of mussels. The technique is described in detail in Metcalfe-Smith *et al*. (2000a). Briefly, the riverbed is visually searched by a team of 3 or more persons using waders, polarized sunglasses, and underwater viewers for a total of 4.5 person-hours (p-h) of sampling effort. Where visibility is poor, searching is done by feel. The length of reach searched varies depending on river width, but is generally 100 to 300-m. Live mussels are held in the water in mesh diver’s bags until the end of the search period when they are identified to species, counted, measured (shell length), sexed (if sexually dimorphic) and returned to the riverbed. Over the past 10 years, such surveys have been conducted in the Grand, Thames, Sydenham, Ausable, Maitland, Saugeen and Moira Rivers and several smaller tributaries to Lake Ontario and Lake Erie by several different researchers. Sampling efforts of researchers other than Janice Metcalfe-Smith and her team were 1.0, 1.5 or 4.5 p-h per site.

In Lake St. Clair, searches at water depths greater than 2 m were conducted by two SCUBA divers for a total effort of 0.5 p-h whereas searches at depths less than 2 m were conducted by three people using mask and snorkel for a total of 0.75 p-h (Zanatta *et al*. 2002). At sites where live mussels were found (all were shallow), snorkel searches were extended to a total of 1.5 p-h.

Quantitative surveys:

Surveys in rivers employed an intensive quantitative sampling technique that would allow the generation of precise estimates of demographic variables such as density, size class frequencies and recruitment levels. The monitoring protocol was developed in consultation with Dr. David R. Smith, a biostatistician with the U.S. Geological Survey who advises the U.S. Army Corps of Engineers on methods for assessing the impacts of development projects on federally endangered mussels in the United States. Dr. Smith and Dr. David L. Strayer, another American mussel expert, were recently commissioned by the Guidelines and Techniques Committee of the Freshwater Mollusk Conservation Society to prepare a guide to sampling freshwater mussel populations. This guide (Strayer and Smith 2003) includes a description of the protocol, which is summarized below:

Sampling employed a 2-person search team and a data recorder and required approximately 2 days of work per site. At each site, roughly 400 m^2 of the most productive portion of the reach (usually a riffle) was selected for sampling. Quantitative sampling was conducted using 1-m^2 quadrats and a systematic sampling design with three random starts. The area to be sampled was divided into blocks of equal size (5 m long × 3 m wide) and each block was further divided into 15 - 1-m^2 quadrats. The same three randomly chosen quadrats were sampled in each block; thus, 20% of the 400 m^2 area was sampled at each site. Each quadrat was searched by two people until all live mussels had been recovered (~ 8 person-minutes). All embedded stones (except large boulders) were removed and the substrate was excavated to a depth of 10-15 cm in order to obtain juveniles. Young mussels are known to burrow deeply in the substrate for the first three years of life. All live mussels found in each quadrat were identified, counted, measured, sexed where possible and returned to the riverbed. Several habitat variables (e.g., depth, current velocity, substrate composition) were also measured and recorded. Quantitative surveys have been conducted on only two rivers to date, the Sydenham and the Thames.

Quantitative surveys were also conducted in the delta area of Lake St. Clair. At each site, sampling was performed by several (usually three) 2-person teams, with each team consisting of a snorkeler and a helper to carry the gear and mussels. Each snorkeler swam until a mussel was seen, then surveyed a 65-m^2 circular area around the mussel and collected any other live mussels found. Each team surveyed 10 such circle plots. All live mussels were identified, counted, measured, sexed and returned to the lake bottom. Methods are described in detail in Metcalfe-Smith *et al*. (2004). Such surveys were conducted in 2001 and 2003 and to a limited extent in 2004.

Abundance

To the best of our knowledge, the only location in the Canadian waters of the lower Great Lakes and connecting channels where *Villosa iris* still survives is the delta area of Lake St. Clair. The species also occurs in the Moira River (Lake Ontario drainage), Grand River (Lake Erie drainage), Thames and Sydenham Rivers (Lake St. Clair drainage) and Ausable, Maitland and Saugeen Rivers (lower Lake Huron drainage) of southern Ontario. Timed-search surveys were conducted at a total of 274 sites between 1994 and 2004 using sampling efforts ranging from 1.0 to 4.5 p-h/site. Results of such semi-quantitative surveys can be used to compare the relative strengths of *V. iris* populations among waterbodies (Table 2). The Rainbow is a very small component of the mussel community in the Saugeen, Sydenham, Ausable and Grand Rivers, with CPUE ranging from 0.02 to 0.11 specimens/p-h search effort. The species occurs infrequently in the Thames River but is occasionally abundant, which accounts for the higher overall CPUE in this system. The Rainbow has been found more frequently in the Moira River and Lake St. Clair (50% and 39% of sites, respectively) with a CPUE of about 1 animal/p-h in both cases. *Villosa iris* is a large component of the mussel fauna in the Maitland River where it occurred at over 80% of sites and accounted for about 20% of all mussels collected. A total of 458 live Rainbows were found resulting in a CPUE of nearly 5 specimens/p-h.

Table 2. Comparisons of population strength for *Villosa iris* in various waterbodies, based on semi-quantitative (timed-search) surveys.

Waterbody	Number of sites surveyed	Number of live mussels collected (all species)	Frequency of occurrence of *V. iris* (% of sites)	Relative abundance of *V. iris* (% of community)	Catch-Per-Unit-Effort for *V. iris* (number/ person-hour)	Year(s) of surveys
Ausable River	25	5013	12%	0.1%	0.05/p-h	1998[3], 2002[3], 2004[4]
Grand River	99	2382	4%	0.2%	0.02/p-h	1995[1], 1997-98 [2,3], 2004[4]
Lake St. Clair	28	1819	39%	1.9%	0.83/p-h	1999[8]
Maitland River	21	2413	81%	19.0%	4.80/p-h	1998[3], 2003-04[4]
Moira River	6	1260	50%	2.4%	1.11/p-h	1996[4]
Sydenham River	18	2357	16%	0.1%	0.04/p-h	1997-98[2,3], 2002[4]
Saugeen River	6	247	17%	0.4%	0.11/p-h	1993-94[7]
Thames River	83	9671	11%	1.2%	0.37/p-h	1995[5], 1997-98 [2,3], 2004-05[6]

[1]Mackie (1996); [2]Metcalfe-Smith *et al*. (1998b); [3]Metcalfe-Smith *et al*. (1999); [4]Metcalfe-Smith *et al*. (unpublished data); [5]Morris (1996); [6]Morris (unpublished data); [7]Morris and Di Maio (1998); [8]Zanatta *et al*. (2002). Note that the 2002 surveys in the Sydenham River were targeted searches for the Wavyrayed Lampmussel, *Lampsilis fasciola*; records for *V. iris* were incidental.

Catch-Per-Unit-Effort data obtained from timed-search surveys provide information on relative population density. True density estimates are only available at present for the Sydenham River, Thames River and Lake St. Clair (Table 3). Twelve sites on the East Sydenham River and 3 sites on the north branch of the river (known as Bear Creek) were quantitatively sampled between 1999 and 2003. The Rainbow was found at 2 sites on the East Sydenham at an average density of 0.03 individuals/m^2. As the species was found at all three sites surveyed by timed-searches or quadrat sampling within the occupied reach, it is reasonable to assume that the population is continuous. Based on an average density of 0.03 individuals/m^2 and an AO of 0.63 km^2, population size is estimated at 18,900 animals. The Rainbow was also found at 2 of 5 sites sampled on the Thames River at an average density of 0.05 individuals/m^2. Assuming again that the population is continuous throughout the occupied reach, the population size is estimated to be 40,000 animals (0.05 individuals/m^2 × 0.80 km^2). Eighteen sites were surveyed in the delta area of Lake St. Clair in 2003 – nine sites in Canadian waters and nine in U.S. waters (Metcalfe-Smith *et al*. 2004). *Villosa iris* was found at 3 of the 9 sites in Canadian waters at an average density of 0.0016 individuals/m^2. The area of mussel habitat in Canadian waters is about 12 km^2; however, 12 km^2 is not an appropriate AO for *V. iris* because it was only found at a few sites. The AO was therefore calculated as follows: the total area of lake bottom searched at the 9 sites was 14,560 m^2. The Rainbow was found at 3 sites where the total area searched was 5,590 m^2, or about 38% of the total area searched. Assuming that these sampling sites are representative of the entire area of habitat, this suggests that *V. iris* occupies 38% of the area or 4.5 km^2 and the estimated size of the population would be 7,200 animals. Data for the 9 sites surveyed in U.S. waters are included in Table 3 for comparison. The Rainbow was found at all sites surveyed at a density of about 3× that in Canadian waters. Assuming that the species is found throughout the AO of 35 km^2, the population estimate for U.S. waters is 185,500 animals.

Table 3. Comparisons of population strength for *Villosa iris* in the Sydenham and Thames Rivers and Lake St. Clair, based on quantitative (quadrat) surveys.

Waterbody	Number of sites surveyed	Number of live mussels collected (all species)	Frequency of occurrence of *V. iris* (% of sites)	Relative Abundance of *V. iris* (% of community)	Density of *V. iris* (number of individuals/m^2)	Area of Occupancy (km^2) for *V. iris*	Estimated population size for *V. iris*	Year(s) of surveys
Sydenham River	15	5450	13%	0.09%	0.03	0.63	18,900	1999-2003[2]
Thames River	5	517	40%	2.9%	0.05	0.80	40,000	2004[3]
Lake St. Clair (Canada)	9	814	33%	1.11%	0.0016	4.5	7,200	2003[1]
Lake St. Clair (U.S.)	9	693	100%	10.82%	0.0053	35.0	185,500	2003[1]

[1]Metcalfe-Smith *et al*. (2004); [2]Metcalfe-Smith *et al*. (unpublished data); [3]Morris (unpublished data).

Shell length of the live mussels collected during most of the above-described surveys was recorded. Lengths of the small numbers of live *Villosa iris* collected from the Grand, Ausable and Sydenham Rivers ranged from 59-74 mm (n = 3), 42-73 mm (n = 6) and 31-85 mm (n = 9), respectively, indicating the presence of several year classes in each river. Size frequency distributions for live *V. iris* collected in Lake

St. Clair (data for Canadian and U.S. waters combined) and the Maitland and Thames Rivers are presented in Figure 7. Specimens captured in the Maitland River measured 36 to 80 mm in shell length with good representation in many different size classes. Such a distribution is indicative of a healthy, reproducing population. Lengths of specimens in the Thames River ranged from 46-89 mm and were also normally distributed, suggesting that the Rainbow may have a faster growth rate in this river. Specimens in Lake St. Clair were considerably smaller, with the largest specimen measuring 67 mm. The Great Lakes form of many species is smaller than the river form. All three of these populations appear to be recruiting.

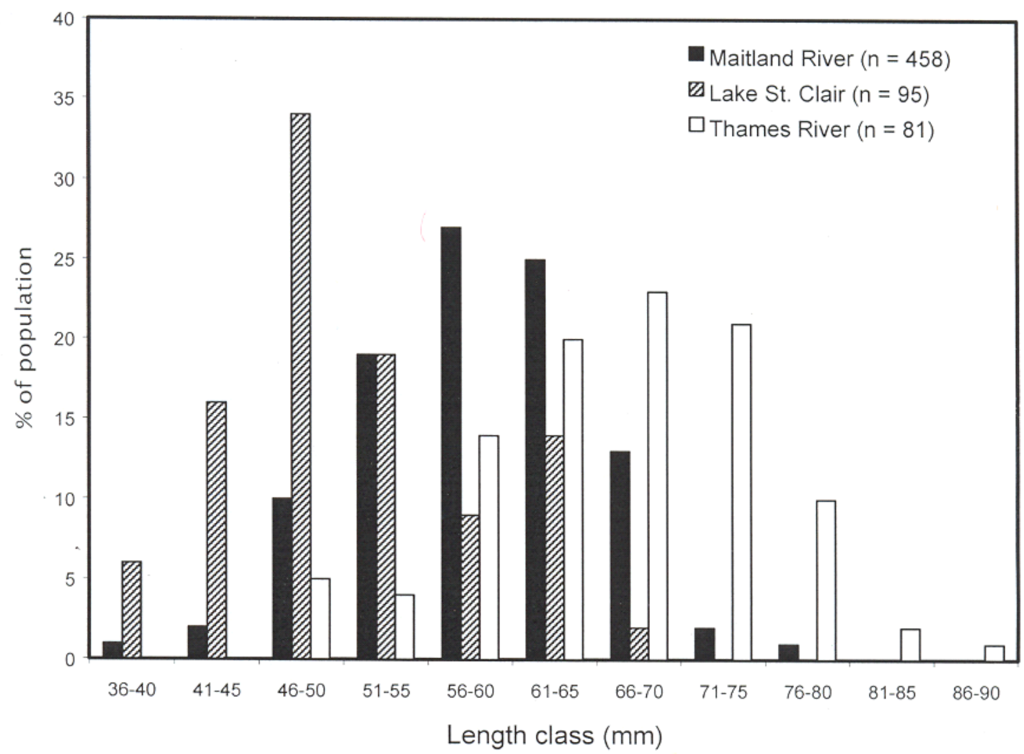

Figure 7. Size frequency distributions for live *Villosa iris* collected from the Maitland and Thames Rivers and Lake St. Clair between 1997 and 2004.

Villosa iris exhibits subtle sexual dimorphism, with the female shell being slightly more inflated and rounded than the male shell. Live specimens collected from the Maitland River in 2004 were visually sexed using these shell features and the ratio of females to males was found to be 25%F:75%M (n = 241) (Metcalfe-Smith *et al*. unpublished data). This may be a normal sex ratio for a healthy mussel population as it is very similar to ratios for two other common species in the same river, namely, the Fatmucket (*Lampsilis siliquoidea*) at 22%F:78%M (n = 313) and the Plain Pocketbook (*Lampsilis cardium*) at 25%F:75%M (n = 431) (Metcalfe-Smith *et al*. unpublished data).

As mentioned under “DISTRIBUTION”, the Rainbow was recently collected from the lower Trent River (2 live specimens in 1996) and the Salmon River (116 mainly weathered shells in 2005) (Schueler pers. comm. 2005) and the Bayfield River (1 fresh shell in 2005; Veliz pers. comm. 2005). Abundance estimates are not available for the Rainbow in these rivers because formal surveys have not been conducted.

Fluctuations and trends

The Rainbow appears to be extirpated from the Detroit and Niagara Rivers as well as the nearshore waters of Lake Erie and much of Lake St. Clair (Schloesser and Nalepa 1994). The species has never been reported from the deeper waters of Lake St. Clair or the western basin of Lake Erie (Nalepa *et al*. 1996). Quantitative surveys were conducted at 9 sites in the delta area of Lake St. Clair in both 2001 and 2003. The same method was used in both years, except that the area searched was 3 × greater in 2003 (~ 15,500 m^2) than in 2001. Based on the results of these surveys, the density of *Villosa iris* in the St. Clair delta declined by 14% between 2001 and 2003 (Metcalfe-Smith *et al*. 2004). This rate of decline should be interpreted with caution because: (a) it is based on data from only one time interval and (b) density estimates for a species as rare as the Rainbow will be imprecise. The Formula for Calculating Decline provided on the COSEWIC web site was used to project the decline in this population over the next 10 years (COSEWIC 2004). The population in Canadian waters is currently estimated to be ~ 7,200 individuals (Table 3). If the rate of decline is 7% per year, the population would be expected to decline by about 52% to 3,500 individuals over the next decade.

Catch-per-unit-effort for the Rainbow in the Sydenham River was 0.04 individuals/p-h over 18 sites surveyed in 1997-98 using 4.5 p-h sampling effort/site (Metcalfe-Smith *et al*. 1998b, 1999). No live specimens were collected at any of 32 sites surveyed in 1985 (Mackie and Topping 1988) or at any of 16 sites surveyed in 1991 (Clarke 1992), but less sampling effort was used than in 1997-98. Athearn (pers. comm. 1997) searched a site near Sheltand in 1963 using 4.0 p-h of effort and found one live *V. iris*; none were found during 4.5 p-h of effort at the same site in 1997. Stein and Stillwell (Stein pers. comm. 1996) surveyed a site near Florence in 1965 using 6.0 p-h of effort and found 2 live Rainbows; again, none were found using 4.5 p-h of effort in 1997. Stein and Heffelfinger (Stein pers. comm. 1996) also searched a site near Alvinston in 1967 and found 7 live animals in 6.0 p-h effort for a CPUE of 1.17/p-h. In 1997, the CPUE for this species was 0.22/p-h. These comparisons suggest that the Rainbow has declined in abundance as well as distribution in the Sydenham River.

Only 4 live *Villosa iris* were found at 99 sites surveyed on the Grand River in 1995 and 1997-98 (Metcalfe-Smith *et al*. 2000b); total search effort was 235.5 p-h and CPUE was 0.02 individuals/p-h. Kidd (1973) surveyed 68 sites on the river in 1970-72 and found 15 live Rainbows for a CPUE of approximately 0.05/p-h. Although Kidd did not specify his sampling effort, the description of his method suggests it was comparable to the 1997-98 surveys. Ten of the 15 specimens were found at a single site on Boston Creek and if this site is removed from the dataset, CPUE for the 1970-72 and 1995-98 surveys is comparable. Many species of mussels in the Grand River have rebounded since the time of Kidd’s surveys due to significant improvements in wastewater treatment. Unfortunately, the Rainbow has not recovered and continues to occupy only a fraction of its historical range in the system.

Salmon and Green (1983) sampled a site on the Middle Thames River above Thamesford in 1977 and Morris (pers. comm. 2004) sampled a nearby site in 2004. Quadrat sampling was used for both surveys. The density of *V. iris* was an order of magnitude lower in 2004 than in 1977 ($0.09/m^2$ vs. $0.9/m^2$), suggesting that the species may be declining in this system.

There are no data available for determining trends over time in the abundance of *V. iris* in the Ausable, Maitland, Moira or Saugeen Rivers.

Rescue effect

The Rainbow occurs in four Great Lakes states (Michigan, New York, Ohio and Pennsylvania) that are connected to Ontario waterways via Lakes Ontario, Erie, St. Clair and Huron. If riverine populations of the Rainbow became extirpated from Canada, natural immigration of animals from the United States would be highly unlikely because the vast area of Zebra mussel-infested habitat separating the two populations would act as a barrier to dispersal by all but the most wide-ranging fishes. There is a large population of *Villosa iris* in the U.S. waters of the St. Clair delta which is in close proximity to a smaller population in Canadian waters. If the Canadian population were to disappear, it is possible that the species could return naturally to the Canadian waters of the delta through the movement of infected fish hosts, provided the U.S. population remains healthy.

LIMITING FACTORS AND THREATS

The introduction and spread of the non-native Zebra mussel throughout the Great Lakes has led to dramatic declines of native freshwater mussels in colonized areas (Schoesser *et al*. 1996). Nearly 50% of sites where *Villosa iris* was known to occur historically are now infested with Zebra mussels. These biofouling organisms continue to threaten the population in the delta area of Lake St. Clair. Metcalfe-Smith *et al*. 2004 reported that densities of *V. iris* declined between 2001 and 2003. The Rainbow was the most heavily infested of 10 species of unionids collected from Bass Bay in the Canadian waters of the Delta in 2004 (Metcalfe-Smith *et al*. unpublished data). Zebra mussels are a potential threat in rivers that have significant impoundments along their course. Reservoirs with retention times greater than 20-30 days allow veligers to develop and settle, after which the impounded populations will seed downstream reaches on an annual basis (Metcalfe-Smith *et al*. 2000b). Zebra mussels have already become established in the Fanshawe and Springbank reservoirs in the middle reaches of the Thames River. Should Zebra mussels be introduced into the Wildwood or Pittock reservoirs in the upper reaches of the watershed, they would pose a major threat to the Rainbow population in the river. The lower Trent River is subject to a constant infusion of Zebra mussel veligers from Percy’s Reach and Rice Lake upstream. Zebra mussels are unlikely to endanger the most significant population of *V. iris* in Ontario, i.e., the population in the Maitland River, because the river is not navigable by boats and has few impoundments that could support a permanent colony.

Anthropogenic stressors such as high loadings of sediment, nutrients and toxic compounds originating from urban and agricultural sources are potential problems in southern Ontario where *Villosa iris* occurs. Siltation resulting from intensive agriculture has fouled many of the sand and gravel riffles in rivers inhabited by this species. Tile drains, cattle access to streams, and the reduction or elimination of riparian buffer strips have all contributed to this problem. Nutrient loadings through the application of fertilizers and the discharge of municipal sewage can have detrimental effects on rare fauna. Pesticides from farms and chlorides from winter road salting can also impact the benthic fauna (Jacques Whitford Environment Limited 2001). Freshwater mussels are among the most sensitive aquatic organisms to environmental contaminants and there is growing evidence that *V. iris* may be particularly sensitive. For example, Goudreau *et al*. (1993) reported 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. Similarly, Mummert *et al*. (2003) found that juvenile Rainbows and Wavyrayed Lampmussels (*Lampsilis fasciola*) were among the most sensitive aquatic organisms to un-ionized ammonia, with *V. iris* being more sensitive than *L. fasciola* (96-hour LC50s = 0.11 and 0.26 mg/L NH_3-N, respectively). Based on reported levels of un-ionized ammonia in the aquatic environment, this contaminant may limit the distribution of *V. iris* and other freshwater mussels in some systems (Mummert *et al*. 2003). Juvenile freshwater mussels remain buried in the sediment for the first few years of life where they feed exclusively on particles in the interstitial water. Such behaviour may increase their exposure to sediment-bound contaminants (Yeager *et al*. 1994) and this could have implications for the survival of species that are especially sensitive to toxic chemicals.

The most significant natural controls on the size and distribution of mussel populations are the distribution and abundance of their host fishes, and predation. Unionids can not complete their life cycle without access to the appropriate glochidial host. If host fish populations disappear or decline in abundance to levels below that which can sustain a mussel population, recruitment will no longer occur and the mussel species may become functionally extinct (Bogan 1993). As noted earlier (**Life cycle and reproduction**), several fishes known to be glochidial hosts for the Rainbow in the United States also occur and are common throughout the mussel's range in Canada. Laboratory testing and field confirmation is required to identify the functional host(s) in Ontario waters with certainty. Follow-up studies on the health of host fish populations in areas supporting populations of *Villosa iris* would then be needed to determine if access to hosts is a limiting factor for this mussel in Ontario.

Freshwater mussels are known to be food sources for a variety of mammals and fishes (Fuller 1974). Predation by muskrats (*Ondatra zibethicus*), in particular, may be a limiting factor for some mussel species. Hanson *et al*. (1989) and Tyrrell and Hornbach (1998) have shown that muskrats are both size- and species-selective in their foraging, and can therefore significantly affect both the size structure and species composition of mussel communities. There have been several studies of muskrat predation on freshwater mussels (Neves and Odum 1989; Watters 1993-1994; Tyrrell and Hornbach 1998). None of these studies reported the presence of *Villosa iris* shells in muskrat middens, suggesting that this mussel is not a preferred prey species. The raccoon (*Procyon lotor*) is another potential predator. Although we are not aware of any studies on raccoon predation, we have observed raccoons feeding on mussels in the field and there is a need to study the impacts of raccoon predation on freshwater mussels in Ontario.

SPECIAL SIGNIFICANCE OF THE SPECIES

There are 18 species in the genus *Villosa* (recognized by Turgeon *et al*. 1998), but only *Villosa iris* and *V. fabalis* (the Rayed Bean) have ranges that extend into Canada. *V. fabalis* was designated as Endangered by COSEWIC in 1999 and was elevated to candidate status for possible addition to the Federal List of Endangered and Threatened Wildlife and Plants under the U.S. *Endangered Species Act* in December 2002 (U.S. Fish and Wildlife Service 2004). Two other species, *V. trabalis* (the Cumberland Bean) and *V. perpurpurea* (the Purple Bean) have been designated as federally endangered in the U.S. Only two species in the Genus *Villosa* are listed as secure (G5) in North America, one of which is *V. iris* (NatureServe 2004). Freshwater mussels are sensitive indicators of the health of freshwater ecosystems, including water and habitat quality and especially the fish community on which they depend for successful reproduction. The Rainbow may be a particularly good indicator of ecosystem health because it is more sensitive to environmental contaminants than most other mussel species tested to date (see **LIMITING FACTORS**).

EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

Villosa iris is listed as secure (G5) in North America; its national status is N5 in the United States and N3 in Canada (NatureServe 2004). It is not currently listed or proposed for listing under the U.S. *Endangered Species Act* and it does not appear on the IUCN Red List of Threatened Species. The national general status of freshwater mussels in Canada was completed in 2004 (Metcalfe-Smith and Cudmore-Vokey 2004) and the Rainbow was ranked as 2 (May be at Risk) nationally and in Ontario. The species is ranked as S2S3 (between very rare and rare to uncommon) by Ontario's Natural Heritage Information Centre (Sutherland pers. comm. 2004). According to NatureServe (2004), current state ranks for *V. iris* are: Alabama (S3), Arkansas (S2S3), Illinois (S1), Indiana (S3), Kentucky (S4S5), Michigan (S2S3), Missouri (SNR), New York (S2S3), North Carolina (S1), Ohio (SNR), Oklahoma (S1), Pennsylvania (S1), Tennessee (S5), Virginia (S4), West Virginia (S2) and Wisconsin (S1). All state and provincial ranks are shown in Figure 8. The Rainbow is listed as endangered in Illinois and Wisconsin (Cummings and Mayer 1992), special concern in Michigan (Badra and Goforth 2003) and North Carolina (Bogan 2002) and proposed for endangered status in Pennsylvania (Crabtree pers. comm. 2004) and is therefore afforded some protection in these states.

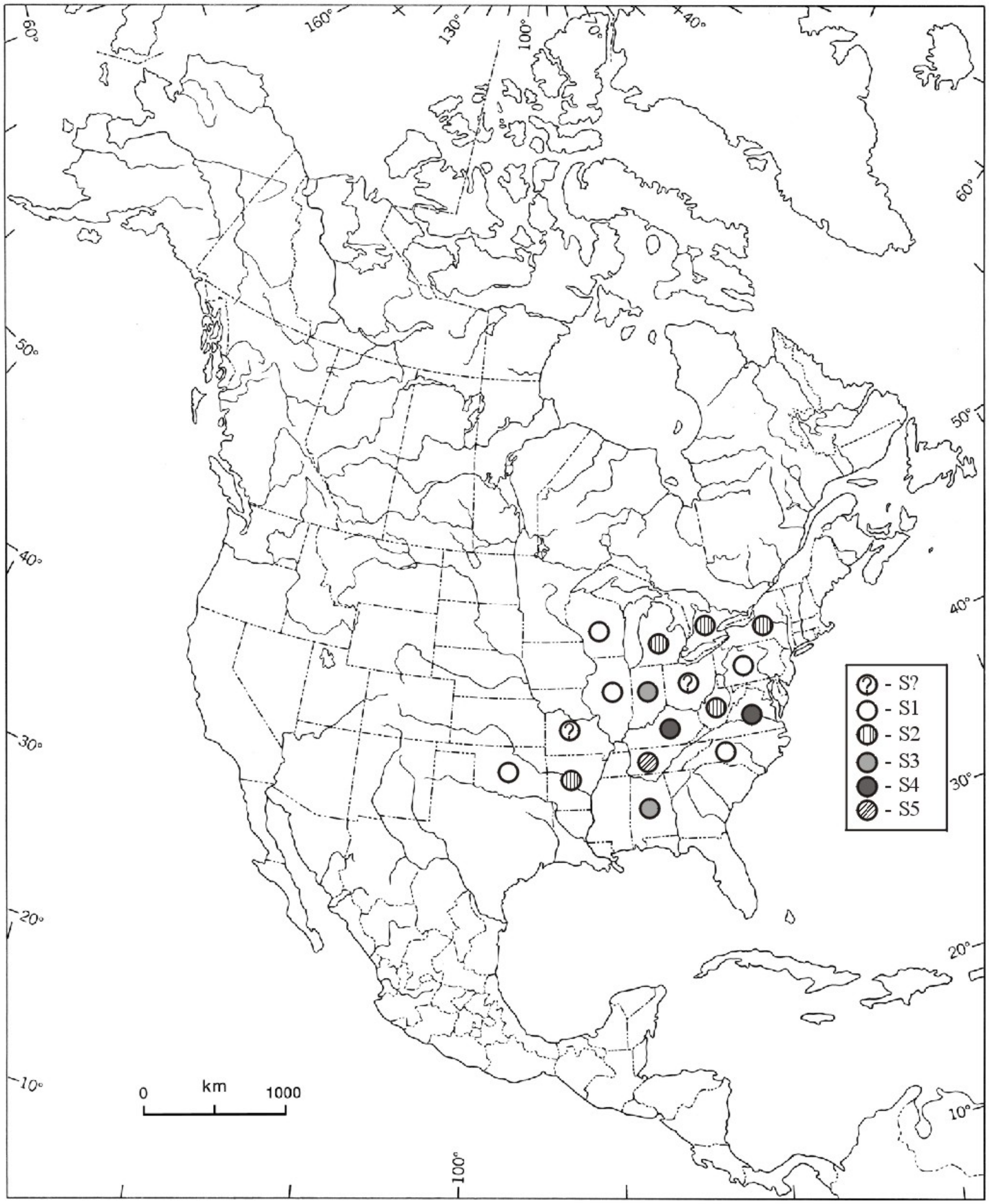

Figure 8. State and provincial conservation priority ranks (S-ranks) for *Villosa iris* (adapted from information provided on www.natureserve.org; S?=not ranked/under review; S1=critically imperiled; S2=imperiled; S3=vulnerable; S4=apparently secure; S5=secure). Where S-ranks were hybridized (i.e. S2S3) the rank of greater priority is displayed.

Species listed as Endangered in Ontario, and their habitats, are protected from willful destruction under the province's *Endangered Species Act*. There are seven species of freshwater mussels on the Species at Risk in Ontario (SARO) List, but they are not regulated under the provincial Act because aquatic species fall under federal jurisdiction. However, all species on the SARO List, whether regulated or not, are afforded habitat protection under the Provincial Policy Statement of the *Planning Act* and the *Aggregate Resources Act*. The Ontario *Lakes and Rivers Improvement Act* (prohibiting the impoundment or diversion of watercourses that would lead to siltation) and the voluntary Land Stewardship II program of OMAFRA (designed to reduce the erosion of agricultural lands) also protect mussel habitat. Stream-side development in Ontario is managed through flood plain regulations enforced by local Conservation Authorities. The federal *Fisheries Act* may represent the most important legislation protecting mussel habitat in Canada. Freshwater mussels are considered to be shellfish and, as such, are included in the definition of "fish" under the Act. Collection of live mussels is considered "fishing" and falls under the Ontario Fishery Regulations made under the federal *Fisheries Act*, which means that mussels cannot be collected in Ontario without a permit from the Ontario Ministry of Natural Resources.

A portion of the Rainbow population in Lake St. Clair occurs within the territory of the Walpole Island First Nation (WIFN). Special user permits are required to access First Nation territory and waters, thus limiting human disturbance in the area. The WIFN recently drafted the Walpole Island Recovery Strategy which has the following goal: "To conserve and recover the ecosystems of the Walpole Island Territory in a way that is compliant with the Walpole Island First Nation Environmental Policy Statement and provides opportunities for cultural and economic development and protection for Species at Risk" (Bowles 2004).

TECHNICAL SUMMARY

***Villosa iris* (I. Lea, 1829)**
Rainbow mussel — Villeuse irisée
Range of Occurrence in Canada: Southern Ontario

Extent and Area Information	
• *Extent of occurrence (EO)(km²)* **[Area contained within the polygon drawn to contain all current extant occurrences of *Villosa iris* as indicated in the 20 February 2004 version of the instructions to authors. Historical = 1890-1994; Current = 1995 - 2004]**	Historical: ~76,500 km^2 Current: ~53,700 km^2
• *Specify trend in EO*	Decline (~30%)
• *Are there extreme fluctuations in EO?*	No
• *Area of occupancy (AO) (km²)* **[Lake St Clair: approximate area of occupied nearshore habitat within the extent of occurrence of *V. iris*; Rivers: Length of the occupied reach in each river multiplied by an average width of the occupied reach]**	Lake St Clair: 4.5 km^2 Ausable R.: 0.08 km^2 Grand R.: 0.65 km^2 Maitland R.: 3.78 km^2 Moira R.: 0.4 km^2 Saugeen R.: 0.01 km^2 Sydenham R.:0.63 km^2 Thames R.: 0.81 km^2 Trent R.: 0.01 km^2 **Total: 10.87 km^2**
• *Specify trend in AO*	Decline
• *Are there extreme fluctuations in AO?*	No
• *Number of known or inferred current locations*	9
• *Specify trend in #*	Decline
• *Are there extreme fluctuations in number of locations?*	No
• *Specify trend in area, extent or quality of habitat*	Decline
Population Information	
• *Generation time (average age of parents in the population)*	Unknown
• *Number of mature individuals*	Unknown
• *Total population trend:*	Declining
• *% decline over the last/next 10 years or 3 generations.*	Unknown
• *Are there extreme fluctuations in number of mature individuals?*	No
• *Is the total population severely fragmented?*	Yes; there is no mixing among populations in different watersheds
• *Specify trend in number of populations*	Decline
• *Are there extreme fluctuations in number of populations?*	No

• List populations with number of mature individuals in each: Total number of individuals (# mature not known): - Lake St. Clair: ~ 7,200 - Ausable River*: 0.05/person-hour - Grand River*: 0.02/person-hour - Maitland River*: 4.8/person-hour - Moira River*: 1.8/person-hour - Saugeen River*: 0.17/person-hour - Sydenham River: ~18,900 - Thames River: ~ 40,000 - Trent River: unknown *Quantitative data are not available for these watersheds; thus, we have substituted Catch-Per-Unit-Effort data (# individuals collected/person-hour of searching)	
Threats (actual or imminent threats to populations or habitats)	
Lake St. Clair: Dreissenid mussels (invasive species) Rivers: Habitat loss and degradation due to the combined impacts of agriculture and urbanization (siltation, nutrient loading, altered flow regimes, deleterious substances, municipal and industrial effluents)	
Rescue Effect (immigration from an outside source)	
• *Status of outside population(s)?* **USA: Endangered – IL, WI** **Endangered (proposed) – PA** **Special Concern – MI, NC**	
• *Is immigration known or possible?*	Highly unlikely
• *Would immigrants be adapted to survive in Canada?*	Likely (genetic testing required)
• *Is there sufficient habitat for immigrants in Canada?*	No
• *Is rescue from outside populations likely?*	Rivers: Not without human assistance (reintroduction) Lake St. Clair: Possible
Quantitative Analysis	PVA analysis models have not yet been developed for freshwater mussels
Current Status COSEWIC: Endangered (2006)	

Status and Reasons for Designation

Villosa iris, Rainbow mussel

Status: Endangered	**Alpha-numeric code**: B2ab (i,ii,iii,iv)
Reasons for Designation: This attractive yellowish green to brown mussel with green rays is widely distributed in southern Ontario but has been lost from Lake Erie and the Detroit and Niagara rivers and much of Lake St. Clair due to Zebra mussel infestations. It still occurs in small numbers in several watersheds but the area of occupancy and the quality and extent of habitat are declining, with concern that increasing industrial agricultural and intensive livestock activities will impact the largest population in the Maitland River.	
Applicability of Criteria **Criterion A**: (Declining Total Population): Not applicable **Criterion B**: (Small Distribution, and Decline or Fluctuation): Qualifies for Endangered, B2ab(i,ii,iii,iv) **Criterion C**: (Small Total Population Size and Decline): Not applicable **Criterion D**: (Very Small Population or Restricted Distribution): Qualifies for threatened, D2, population has a very restricted area of occupancy < 20 km² **Criterion E**: (Quantitative Analysis): Not applicable	

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COLLECTIONS EXAMINED

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 the National Water Research Institute in Burlington, Ontario. 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 data acquired. One of us (J.L. 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 and now contains approximately 8,200 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.