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Research Document 2010/120 / **Document de recherche 2010/120**

Information in support of a Recovery Potential Assessment of Eastern Pondmussel (*Ligumia nasuta*), Fawnsfoot (*Truncilla donaciformis*), Mapleleaf (*Quadrula quadrula*), and Rainbow (*Villosa iris*) in Canada

Information à l'appui de l'évaluation du potentiel de rétablissement de la ligumie pointue (*Ligumia nasuta*), de la troncille pied-de-faon (*Truncilla donaciformis*), de la mulette feuille-d'érable (*Quadrula quadrula*) et de la villeuse irisée (*Villosa iris*) au Canada

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ABSTRACT

Fisheries and Oceans Canada (DFO) Science has been asked to undertake a Recovery Potential Assessment (RPA) of Eastern Pondmussel (*Ligumia nasuta*), Fawnsfoot (*Truncilla donaciformis*), Mapleleaf (*Quadrula quadrula*), and Rainbow (*Villosa iris*). A RPA process has been developed by DFO to provide information and scientific advice needed to fulfill requirements under the *Species at Risk Act* (SARA). These requirements include listing decisions, authorizations to carry out activities that would otherwise violate the SARA and development of recovery strategies (DFO 2007). The advice in the RPA may be used to inform both scientific and socio-economic elements of the listing decision, as well as development of a recovery strategy and action plan, and to support decision-making with regards to the issuance of permits, agreements and related conditions of the SARA. This document describes the biology, life history, habitat preferences, current status, and threats related to the Canadian populations of Eastern Pondmussel, Fawnsfoot, Mapleleaf and Rainbow. Mitigation measures and alternative activities related to the identified threats, that can be used to protect the species, are also presented.

RÉSUMÉ

Le secteur des Sciences de Pêches et Océans Canada (MPO) a été demandé d'effectuer une évaluation du potentiel de rétablissement (EPR) de la ligumie pointue (*Ligumia nasuta*), de la troncille pied-de-faon (*Truncilla donaciformis*), de la mulette feuille-d'érable (*Quadrula quadrula*) et de la villeuse irisée (*Villosa iris*). MPO a élaboré un processus pour l'EPR afin de fournir l'information et l'avis scientifique nécessaires afin de répondre aux diverses exigences de la *Loi sur les espèces en péril* (LEP). Ces exigences comprennent les décisions relatives à l'inscription à la liste, l'autorisation d'effectuer des activités qui iraient autrement à l'encontre de la LEP et l'élaboration de programmes de rétablissement (MPO 2007). L'avis donné dans l'EPR peut être utiliser à informer les aspects scientifiques et socioéconomiques de la décision relative à l'inscription à la liste, de même qu'à élaborer un programme de rétablissement et un plan d'action, ainsi que pour appuyer la prise de décisions en ce qui concerne la délivrance de permis, les accords et les conditions connexes de la LEP. Ce document décrit la biologie, le cycle vital, les préférences en matière d'habitat, l'état actuel et les menaces pour les populations canadiennes de ligumie pointue, de troncille pied-de-faon, de mulette feuille-d'érable et de villeuse irisée. On y présente aussi les mesures d'atténuation et les activités de remplacement en lien avec les menaces identifiées qui peuvent servir à protéger les espèces.

SPECIES INFORMATION AND CURRENT STATUS

Information contained within this report was drawn from data contained within the Lower Great Lakes Unionid Database as well as additional sources including COSEWIC reports (COSEWIC 2006a, 2006b, 2007, 2008), unpublished reports and information from the Bishops Mills Natural History Centre. For a detailed description of the Lower Great Lakes Unionid database and its historical data sources, see Metcalfe-Smith *et al*. (1998). Ontario records generally resulted from formal studies directed at sampling unionids using both qualitative and quantitative methods. These records included 200 Eastern Pondmussel records, 52 Fawnsfoot records, 164 Mapleleaf records and 231 Rainbow records. There were a total of 46 records of Mapleleaf from Manitoba and records stemmed from formal studies, personal observations and incomplete records. Sampling locations of all known sampling sites in both Ontario (Figure 1) and Manitoba (Figure 2) are shown to provide context of mussel sampling effort.

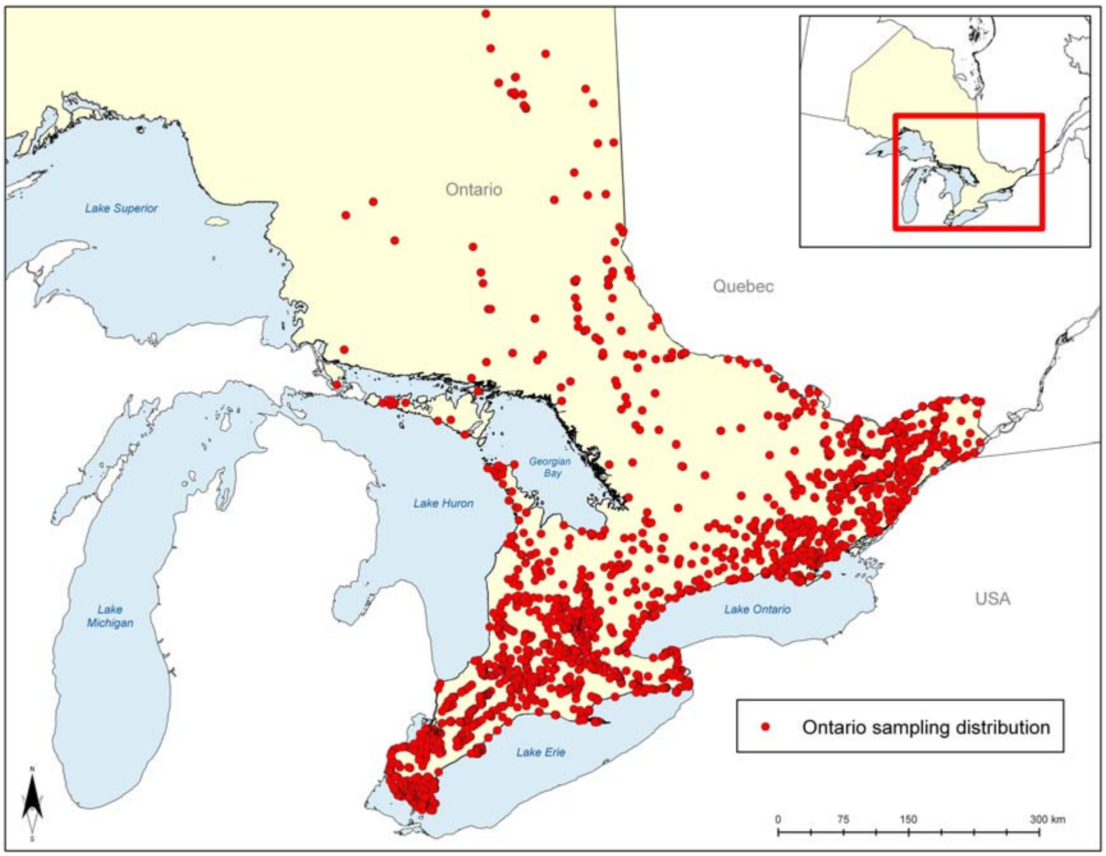

Figure 1. Distribution of all known historic and current freshwater mussel sampling effort in Ontario.

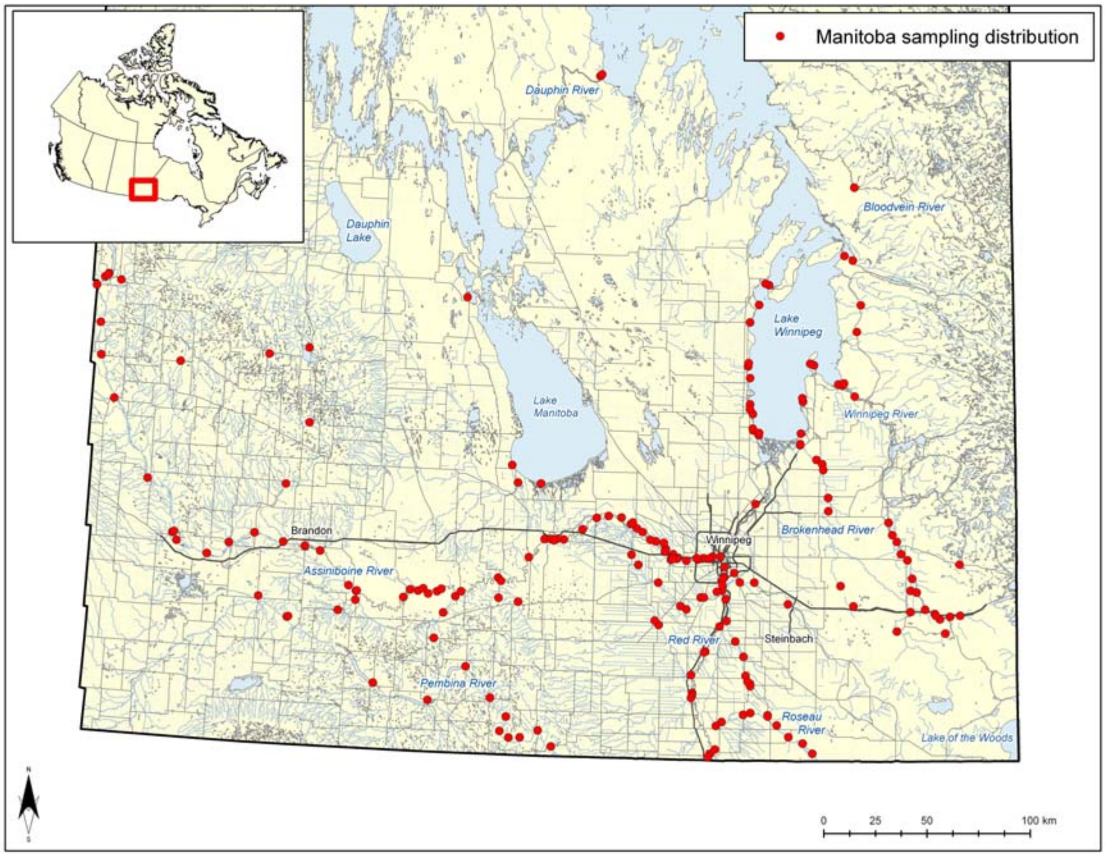

Figure 2. Distribution of all known historic and current freshwater mussel sampling effort in Manitoba.

EASTERN PONDMUSSEL
Common Name – Eastern Pondmussel
Scientific Name – *Ligumia nasuta*
Current COSEWIC Status & Year of Designation – Endangered, April 2007
COSEWIC Reason for Designation – “This was one of the most common species of freshwater mussel in the lower Great Lakes prior to the invasion of the Zebra Mussel (*Dreissena polymorpha*) in the late 1980s. Zebra Mussels attach to the shells of native freshwater mussels in the hundreds or even thousands, causing the native mussels to suffocate or die from lack of food. Over 90% of historical records for the species are in waters that are now infested with Zebra Mussels and therefore uninhabitable. The species has declined dramatically and now occurs as two small, widely separated populations, one in the delta area of Lake St. Clair and one in a tributary of the upper St. Lawrence River. There is evidence that declines may be continuing at one location. Although Zebra Mussels appear to be declining in some areas, their impacts on this species may be irreversible if insufficient breeding adults have survived. Climate change is likely to cause a drop in water levels in the delta and further reduce the amount of habitat available to the mussel. Recent surveys in Lake St. Clair, which were conducted as a collaborative effort between Environment Canada and the Walpole Island First Nation, resulted in the identification of a significant refuge for this species within First Nation territory. The refuge is being managed by the First Nation for the protection of this and other aquatic Species at Risk with which it co-occurs.”
SARA Schedule – No schedule
Range in Canada – Ontario

Species Information

Eastern Pondmussel (*Ligumia nasuta*) is a medium-sized mussel with an average shell length of about 70 mm (COSEWIC 2007). Maximum shell size in Canada has been approximated to be 102 mm (F. Schueler, unpubl. data). The shell is characterized as being thin, narrow and elongate with a distinctive, bluntly-pointed posterior end (Metcalfe-Smith *et al.* 2005; COSEWIC 2007). Although sexual dimorphism is subtle, females can be distinguished from males by a swelling along the posterior ventral margin (Metcalfe-Smith *et al.* 2005; COSEWIC 2007). The exterior of the shell varies in colour from yellowish- or greenish-black in juveniles to dark brown or black in adults with a concentration of narrow green rays at the posterior end (COSEWIC 2007). The nacre is described as purple, pink or silvery-white (Metcalfe-Smith *et al.* 2005; COSEWIC 2007).

Eastern Pondmussel was included in a study completed by Zanatta and Murphy (2006) investigating the evolution of active host-attraction strategies in freshwater mussels. Results from this genetic analysis, using mitochondrial DNA sequencing, suggested that Eastern Pondmussel was closely related to members of *Potamilus* and *Leptodea*, and not closely related to Black Sandshell (*Ligumia recta*). In light of these results, the authors suggested that Eastern Pondmussel should be re-designated into an existing or newly described genus (Zanatta and Murphy 2006).

The key threat limiting the occurrence of Eastern Pondmussel in Canada is believed to be the introduction of the invading Zebra Mussel. This introduction has been attributed to the rapid devastation of the Eastern Pondmussel populations of the Great Lakes and its connecting channels. This species, which is characterized as a lake-species, was once found throughout the Great Lakes proper including Lake Ontario, Lake Erie, Lake St. Clair, Niagara River, Welland River, and the lower reaches of a few major tributaries (Figure 3). Prior to 1990, it was considered to be the fourth most common species of freshwater mussel in the Great Lakes (COSEWIC 2007). Eastern Pondmussel has now been lost from the majority of its former range, but still occurs in the Lake St. Clair delta, in Cedar Creek (an inlet located in the Long Point National Wildlife Area), in Turkey Point Marshes and in Lyn Creek (a tributary of the St. Lawrence River).

Current Status

Beaver Lake

Three fresh whole shells from Beaver Lake were recorded in 1998 (F. Schueler, unpubl. data). An additional weathered shell was collected from this area in 2006 (F. Schueler, unpubl. data). Although not formally sampled, this site has since been revisited in 2006 and it was noted that Beaver Lake was infested with Zebra Mussel (F. Schueler, Bishops Mills Natural History Centre, pers. comm.).

Grand River

The first record of Eastern Pondmussel from the Grand River dates back to 1934 when three fresh whole shells were recorded near Dunnville. Subsequent to this record, five fresh whole shells were recorded in 1963 approximately 1 km downstream from the original historic site. More recently, one fresh valve was recorded from McKenzie Creek in 1995. There are no records of live individuals from this river system.

Great Lakes and Connecting Channels

Lake Ontario

In Lake Ontario, the majority of Eastern Pondmussel records originated from the Bay of Quinte watershed, including areas in and around Prince Edward County. These areas included the Moira River, Consecon Lake, East Lake, Hay Bay and Bay of Quinte proper. It was also found in scattered locations along the north shore of Lake Ontario, including the mouth of Pickering Creek, Hanlon's Point (near Toronto, Ontario) and Hamilton Harbour. The last live record of Eastern Pondmussel in Lake Ontario dates back to 1996 when 14 live individuals were recorded from Consecon Lake. It was noted at time of capture that no Zebra Mussel were present. This site, along with numerous other historic Eastern Pondmussel sites were revisited in 2005, and all areas were found to be infested with Zebra Mussel and not a single live unionid was found (COSEWIC 2007). It is believed that Eastern Pondmussel no longer inhabits these formally occupied areas.

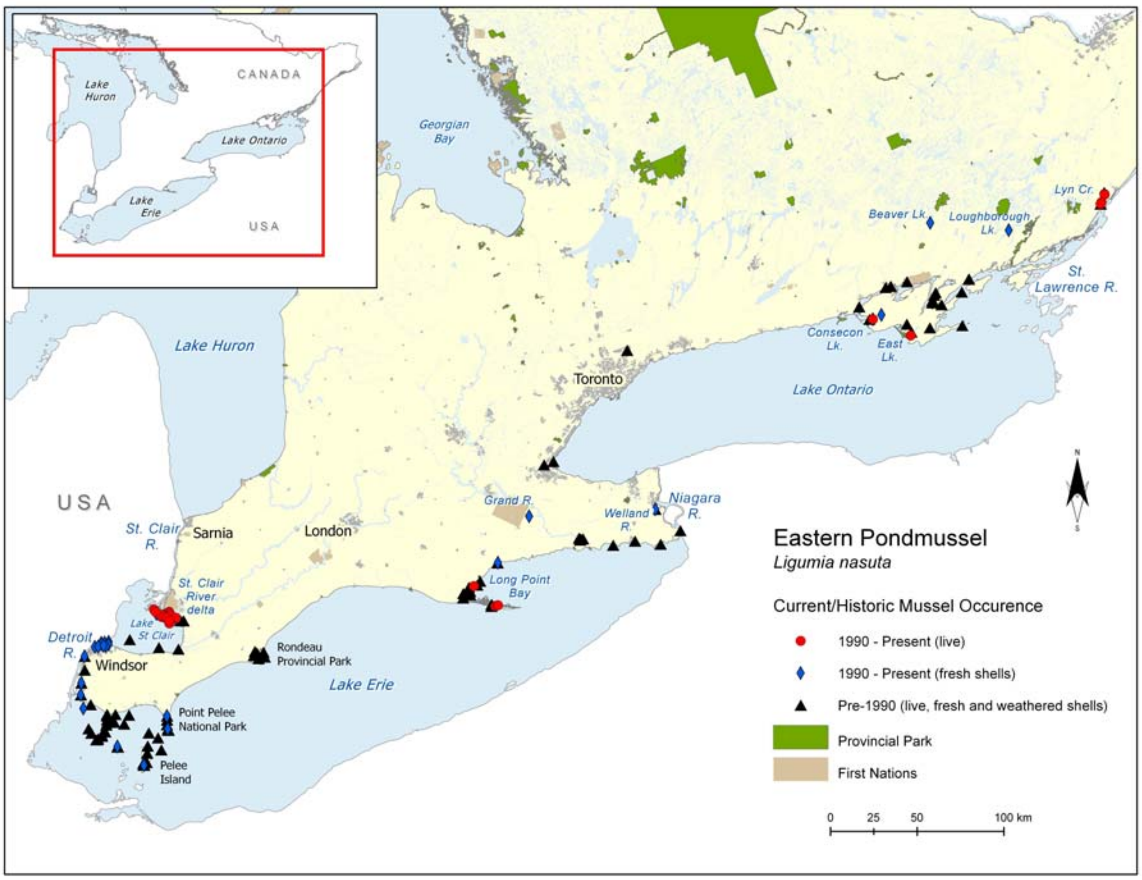

Figure 3. *Current and historic distribution of Eastern Pondmussel in Canada.*

Lake Erie

Eastern Pondmussel also flourished throughout Lake Erie, and its connecting channels, with records from the Niagara River, Welland River; along the north shore of Lake Erie from Crystal Beach, Port Colbourne, the mouth of the Grand River, Port Dover, Port Rowan, Long Point Bay and Rondeau Bay; numerous locations from the western basin including Point Pelee, Pelee Island, Colchester, Middle Sister Island, East Sister Island and Holiday Beach. Eastern Pondmussel distribution also included the Detroit River at Windsor and Amherstberg. Many of the historical Eastern Pondmussel sites have been revisited since the Zebra Mussel invasion and no live Eastern Pondmussel specimens, and in many cases no live unionids, were found (COSEWIC 2007).

Lake St. Clair

Eastern Pondmussel was historically recorded in the offshore waters of Lake St. Clair and in the Detroit River. Lake St. Clair has been intensively surveyed for unionids since the Zebra Mussel invasion and it is believed that Eastern Pondmussel has been extirpated from the offshore area of Lake St. Clair since 1994 (Nalepa *et al.* 1996). Similarly, unionid surveys of the Detroit River from 1997-98 indicated that Eastern Pondmussel is also no longer present in this system (Schloesser *et al.* 2006).

<u>Loughborough Lake</u>

One weathered valve (102 mm) and one weathered shell fragment were collected from Loughborough Lake at the Missouri (Co Rd 10) bridge in eastern Ontario in 2009 (F. Schueler, unpubl. data). This location has not been formally sampled and the 2009 record is the only known record from this area, although it was noted at this time that the area was infested with Zebra Mussel.

<u>Lyn Creek</u>

In 2005, two fresh valves and one weathered whole Eastern Pondmussel were found in Golden Creek, a tributary of Lyn Creek (tributary of the upper St. Lawrence River) (F. Schueler, unpubl. data). Lyn Creek was revisited in 2006 and live Eastern Pondmussel were recorded by means of an observational study at seven sites, yielding a total of 42 live individuals. Additional observational studies were completed at new sites, as well as previously visited sites between 2007 and 2009 and noted the presence of live individuals at all but one location. A formal timed-search survey was completed at one site in 2009, and recorded the presence of 10 live Eastern Pondmussel. It is believe that a population of Eastern Pondmussel inhabits an 8 km stretch of Lyn Creek.

<u>Long Point Bay – Cedar Creek and Turkey Point Marsh</u>

Sampling at three sites in Cedar Creek (a small inlet located within the Long Point National Wildlife Area boundaries) in August 2008, resulted in the capture of 21 Eastern Pondmussel (J. Gilbert, unpubl. data). The same area was revisited in September of the same year and an additional 23 individuals were recorded (J. Gilbert, unpubl. data). Turkey Point Marsh (north shore of Long Point Bay) was sampled in the summer of 2008 and four live individuals were recorded at a single site (J. Gilbert, unpubl. data). The presence of live individuals at Cedar Creek and Turkey Point Marsh marks the first time live Eastern Pondmussel have been recorded from Lake Erie since 1979.

<u>Mill Dam (Lake Ontario)</u>

A historic record from 1860 of 15 fresh whole shells exists from Mill Dam (near Markham). There has been no record of any additional individuals in this area since 1860.

<u>St. Clair River Delta</u>

The St. Clair River delta represents the largest remaining Eastern Pondmussel population in Canada. Many of the Eastern Pondmussel records from this location are found within the Walpole Island First Nation territory. Although a fresh whole shell was recorded near the St. Clair River delta in 1965, the first live animal was not recorded until 1999. The St. Clair River delta represents a significant refuge site for Eastern Pondmussel and other native unionids from the Zebra Mussel invasion (Zanatta *et al.* 2002). It is believed that the shallow depth of the delta as well as its high level of connectivity with the lake proper is discouraging the settlement and survival of Zebra Mussel (Zanatta *et al.* 2002). From 1999 to 2001, Zanatta *et al.* (2002) surveyed numerous sites in the nearshore area of Lake St. Clair and found live mussels at many of these sites, including Eastern Pondmussel, which was found at 16 sites. Metcalfe-Smith *et al*. (2004) surveyed 15 sites in the Canadian waters of the delta in 2003 and 2005 and found live Eastern Pondmussel at 6 of these sites. Since 1999, 310 live Eastern Pondmussel have been sampled from the St. Clair River delta.

<u>Sydenham River</u>

A single Eastern Pondmussel record exists for the Sydenham River from 1991, although there is no information available on whether this record consists of a live individual, or a fresh or weathered shell.

<u>Whitefish Lake (Lake Ontario)</u>

A single weathered Eastern Pondmussel valve was observed from Whitefish Lake in 1995. Whitefish Lake is part of the Lake Ontario portion of the Rideau Canal system. No additional sampling has occurred in this area.

FAWNSFOOT

Common Name – Fawnsfoot
Scientific Name – *Truncilla donaciformis*
Current COSEWIC Status & Year of Designation – Endangered, April 2008
COSEWIC Reason for Designation – “This freshwater mussel is widely distributed in central North America, with the northern portion of its range extending into the Lake Erie, Lake St. Clair and lower Lake Huron drainages of southwestern Ontario. It appears to have always been a rare species in Canada, representing < 5% of the freshwater mussel community in terms of abundance wherever it occurs. Approximately 86% of historical records are in waters that are now infested with Zebra Mussels and therefore uninhabitable. Zebra Mussels, which were accidentally introduced into the Great Lakes, attach to the shells of native freshwater mussels, causing them to suffocate or die from lack of food. The species has declined dramatically and has been lost from four historical locations resulting in a 51% reduction in its range. It is now found in only five widely separated locations, two of which represent single specimens. In two locations, the species’ distribution may be limited by the presence of dams that restrict the movements of the freshwater drum, the presumed fish host of the juvenile mussels. Poor water quality resulting from rural and urban influences poses an additional continuing threat.”
SARA Schedule – No schedule
Range in Canada – Ontario

<u>**Species Information**</u>

Fawnsfoot (*Truncilla donaciformis*) is considered a small freshwater mussel with a average adult length in Ontario of approximately 35 mm (Metcalfe-Smith *et al.* 2005). The maximum shell size for this species is reported to be 52 mm (DFO, unpubl. data). The shell shape has been described as moderately thick, oval to triangular with a rounded anterior end and a pointed posterior end (Metcalfe-Smith *et al.* 2005). The posterior ridge is described as being dorsally flattened (COSEWIC 2008). Shell coloration is yellow to greenish-brown with numerous obvious dark green rays, which are broken forming chevron-shaped markings (Metcalfe-Smith *et al.* 2005).

Fawnsfoot is not easily misidentified for most other Canadian freshwater mussel species as its chevron-shaped markings, and relatively small size are unmistakably characteristic of this species (COSEWIC 2008). Deertoe (*Truncilla truncata*), the only other member of the genus *Truncilla* found in Ontario, is also characterized by the presence of chevron-shaped markings on the shell, although markings on the Deertoe are noticeably thinner in comparison to those of Fawnsfoot (Metcalfe-Smith *et al.* 2005). In addition adult Deertoe can grow to be approximately twice as large as adult Fawnsfoot (Deertoe maximum size is approximately 95 mm; Metcalfe-Smith *et al.* 2005). There is currently no information on the genetic structure of the North American populations of Fawnsfoot.

As for Eastern Pondmussel, the key threat limiting the occurrence of Fawnsfoot in Canada is believed to be the introduction, and subsequent invasion of the dreissenid mussels (Zebra Mussel and Quagga Mussel) in the Great Lakes. Historic records of Fawnsfoot are available from Lake St. Clair, Lake Erie and the Detroit River, all of which are now infested by dreissenid mussels. Fawnsfoot has now been lost from much of its range, but can still be found in the Grand, Sydenham and Thames rivers (Figure 4); although it is believed that Fawnsfoot distribution in these river systems is restricted by the distribution of their presumed host species, Freshwater Drum (*Aplodinotus grunniens*) (COSEWIC 2008). In addition to these locations, a single Fawnsfoot record exists for both the St. Clair River delta (2003) and the Saugeen River (2005).

Current Status

Grand River

There are a total of eight historic Fawnsfoot records from the Grand River, the most recent being 1997 when 11 live individuals were recorded (Metcalfe-Smith *et al.* 2000a). All Fawnsfoot records are from the extreme lower portion of the Grand River between the mouth of Port Maitland and the Byng Conservation Area at Dunnville (COSEWIC 2008). The location of the 1997 records has been since revisited, although a formal sampling event has not occurred, and no additional Fawnsfoot were located.

Great Lakes and Connecting Channels

Although Fawnsfoot has always been rare in any historic sampling event in which it was present, it is believed that this species no longer occurs at any of its formally occupied areas in Lake St. Clair, Lake Erie and the Detroit River (COSEWIC 2008). One of the earliest records of Fawnsfoot in Canada was collected from Lake St. Clair in 1934. There is one additional record of Fawnsfoot, consisting of four live individuals, from Lake St. Clair proper which was collected in 1986. This is the last time Fawnsfoot was recorded from the offshore waters Lake St. Clair. The first collection of Fawnsfoot from Lake Erie dates back to 1951. There are sparse records of both fresh and weathered shells collected from Lake Erie from 1951 to the late 1980s; although the presence of live individuals was very rare throughout this time period. It was estimated by Nalepa *et al.* (1991) that Fawnsfoot had disappeared from the Lake Erie basin by 1961. The first record of Fawnsfoot in the Detroit River is dated 1982, when a single live individual was collected (Schloesser *et al.* 1998). This record represents the first and only live individual to be collected from this system. Fawnsfoot is now considered to be extirpated from its entire former range in Lake St. Clair, Lake Erie and the Detroit River.

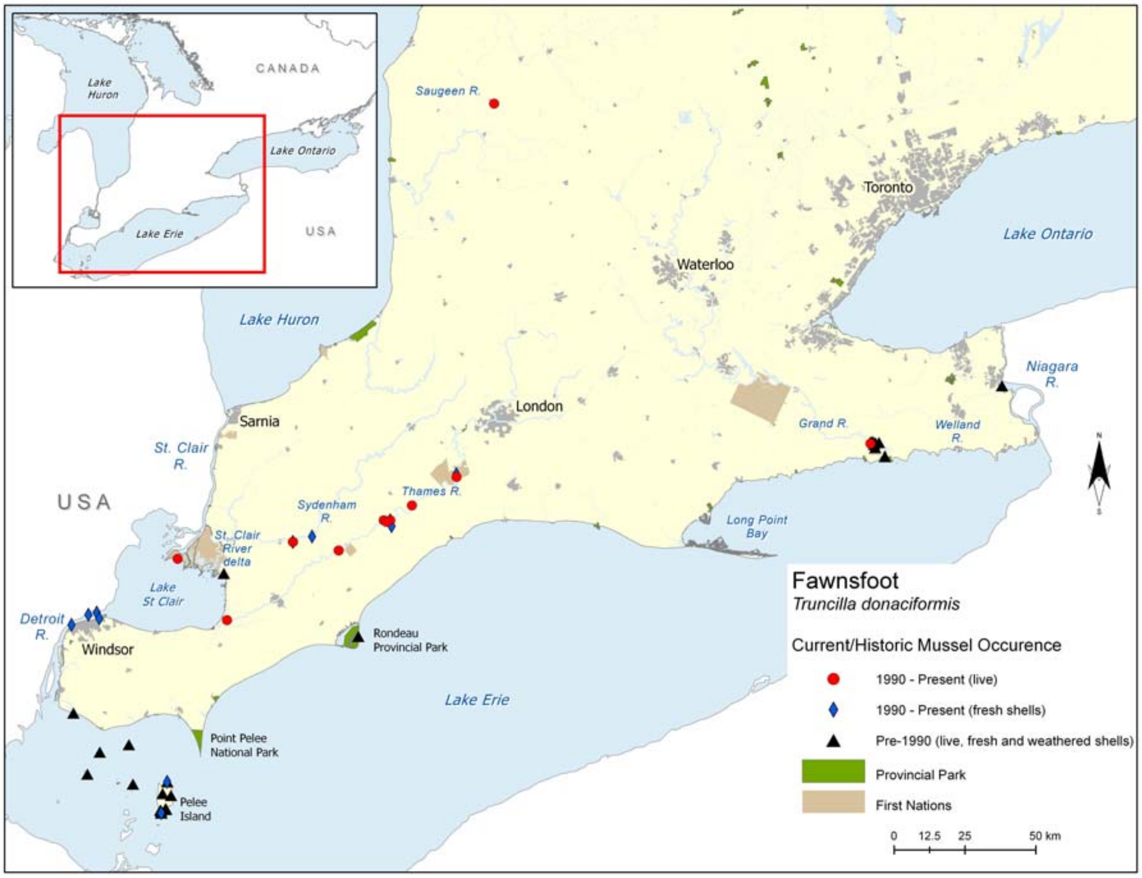

Figure 4. *Current and historic distribution of Fawnsfoot in Canada.*

Saugeen River

The first, and only record of Fawnsfoot from the Lake Huron drainage dates to 2005 when a single individual was collected during a benthic invertebrate assessment from Muskrat Creek (a tributary of the Teeswater River) in the Saugeen River watershed (COSEWIC 2008). Prior sampling in this system targeting freshwater mussels did not detect the presence of Fawnsfoot. In 2006, subsequent to this discovery, a survey was completed in this watershed. The survey was unsuccessful at detecting any additional Fawnsfoot.

St. Clair River Delta

Substantial sampling for freshwater mussels has been completed in the St. Clair River delta (Zanatta *et al.* 2002; Metcalfe-Smith *et al.* 2004) and only a single Fawnsfoot has been recorded in the Canadian portion of the delta. This single individual was found in 2003 at the mouth of Pocket Bay.

Sydenham River

Fawnsfoot was first discovered in the Sydenham River in 1991 when a single fresh whole shell was reported. Subsequent mussel surveys in this river from 1997 to 2003 (Metcalfe-Smith *et al.* 2003; Metcalfe-Smith *et al.* 2007b) yielded the capture of 27 live individuals, in addition to five fresh whole shells.

Thames River

The first live Fawnsfoot specimen was not found in the Thames River until 2005, when timed-search surveys and a subsequent quadrat excavation recorded the presence of 23 live individuals. Until 2005 only one single Fawnsfoot valve had been recorded for this system. Two additional quadrat excavation surveys were completed in 2010 and a total of 45 live individuals were recorded. Fawnsfoot is believed to be relatively widespread in the lower portion of the Thames River, and its presence in the lower portion of this system was verified in 2010 when a single live Fawnsfoot was captured during a fish trawling study near the mouth of the river. It is thought that the Thames River Fawnsfoot population may represent the largest remaining population in Canada (COSEWIC 2008).

MAPLELEAF
Common Name – Mapleleaf
Scientific Name – *Quadrula quadrula* (Rafinesque, 1820)
Designatable Units (DU): Great Lakes – Western St. Lawrence population (referred to as Ontario DU) and Saskatchewan – Nelson population (referred to as Manitoba DU)
Current COSEWIC Status & Year of Designation (Ontario DU) – Threatened, April 2006
COSEWIC Reason for Designation (Ontario DU) – "This heavy shelled mussel that is shaped like a maple leaf, has a very small area of occupancy in watersheds dominated by agriculture with past and continuing declines due to habitat loss and degradation. Although the mussel has been lost from the Great Lakes and connecting channels due to Zebra Mussels, the numbers of mature individuals appear to be very large in two of the watersheds and three of five watersheds have recovery teams in place for aquatic species at risk. Zebra Mussels continue to be a potential threat in watersheds that have numerous impoundments."
Current COSEWIC Status & Year of Designation (Manitoba DU) – Endangered, April 2006
COSEWIC Reason for Designation (Manitoba DU) – "Small area of occupancy; all localities but one are in one system, the Red Assiniboine drainage, and a major event could extirpate the population; no evidence for recruitment (few small individuals); numerous threats including degrading water quality from agriculture, domestic waste, commercial and industrial activities."
SARA Schedule – No schedule
Range in Canada – Ontario, Manitoba

Species Information

Mapleleaf (*Quadrula quadrula*) is a medium to large freshwater mussel species with an average adult length of 90 mm (Metcalfe-Smith *et al.* 2005). In Ontario, Mapleleaf have been recorded up to 135 mm (Zanatta, unpubl. data), while adult shell length in Manitoba have been reported up to 121 mm (Carney 2003). The shell is described as being moderately inflated, quadrate in outline with a rounded anterior end and a squared or truncated posterior end (Metcalfe-Smith *et al.* 2005; COSEWIC 2006a). A characteristic of Mapleleaf is the presence of two bands of raised nodules radiating in a V-shape from the umbo to the ventral margin (COSEWIC 2006a). The first row is centrally located, while the second is located on the posterior ridge. A shallow groove separates the two rows of nodules.

The shell color is described as ranging from yellowish green to greenish brown to light brown to dark brown (older individuals occupying the darker extreme of this spectrum; COSEWIC 2006a). The nacre is generally pearly white with obvious iridescence at the posterior end (Metcalfe-Smith *et al.* 2005).

Mapleleaf is most often confused with the only other member of the genus *Quadrula* in Ontario, Pimpleback (*Quadrula pustolusa*); although, these two species are distinguishable by their nodular pattern and shell shape. The nodules on Mapleleaf are restricted to two bands, and the shell shape is quadrate; whereas the nodules are more irregularly distributed on Pimpleback and the shell shape is rounded (Metcalfe-Smith *et al.* 2005). It should be noted that Pimpleback does not occur in Manitoba waters and Mapleleaf should not be confused with any mussel species present in this province.

Mapleleaf is considered to be a long-lived mussel species (COSEWIC 2006a). This is supported by age estimates resulting from shell sections taken from the Assiniboine River Mapleleaf population, where individuals were found to live up to 64 years with an average age of 22.1 (n=47; J. Carney, unpubl. data). Similarly, Mapleleaf sampled from the Thames (n=20) and Ruscom rivers (n=2) in Ontario were aged, using the same shell sectioning method, resulting in a maximum age of approximately 45 years (DFO, unpubl. data).

A recent genetic analysis on Mapleleaf throughout its distribution in the United States, Ontario and Manitoba indicated that both Canadian populations share the majority of their haplotypes with some populations from the United States, suggesting that all Canadian populations are subsets derived from the American populations (COSEWIC 2006a). However, the Ontario and Manitoba Mapleleaf populations both have unique haploytypes, meaning that each population has genetic information that is not shared with any other region (COSEWIC 2006a). Additional genetic research is currently underway examining the population structure and post-glacial reinvasion pathways for Mapleleaf into the Great Lakes (D. Zanatta, unpubl. data).

Similar to most other Great Lakes freshwater mussels, the key threat limiting the occurrence and survival of Mapleleaf in Ontario is related to the presence of dreissenid mussels. Fortunately, Zebra Mussel are not known to be present in any of the systems where Mapleleaf are found in Manitoba. In this province, the major limiting factor for Mapleleaf is decreased water quality from agricultural practices, and urban and industrial pollution (COSEWIC 2006a).

Current Status

The Canadian distribution of Mapleleaf has been separated into two designatable units based on the criteria outlined by COSEWIC[1]. Specifically, reasons for separation include unique haplotypes (i.e., genetic separation) and geographic distance (i.e., separation by distance) (COSEWIC 2006a). The Manitoba populations are considered a part of the Hudson Bay watershed whereas the Ontario populations stem from the Great Lakes-St. Lawrence watershed (COSEWIC 2006a). In addition, both populations occupy distinct eco-geographic regions, in that the Manitoba populations occupy the Saskatchewan-Nelson Ecological Freshwater Area and the Ontario populations occupy the Great Lakes-Western St. Lawrence Ecological Area (COSEWIC 2006a).

Ontario

Ausable River

Mapleleaf was first detected in the Ausable River in 2002 with the capture of nine live individuals (Figure 5). Subsequent to this discovery, Mapleleaf was recorded at three additional sites in 2004 (n=9). The original site sampled in 2002 was revisited in 2006 and Mapleleaf was again located, this time in greater numbers [n=19; Ausable-Bayfield Conservation Authority (ABCA), unpubl. data]. An additional two sites were sampled in 2008 and 2009, yielding the capture of one and seven live individuals, respectively (ABCA, unpubl. data). These Ausable

[1] http://www.cosewic.gc.ca/eng/sct2/sct2_5_e.cfm

River records, along with the single individual recorded from Bayfield River, represent the only occurrences of Mapleleaf in the Lake Huron drainage.

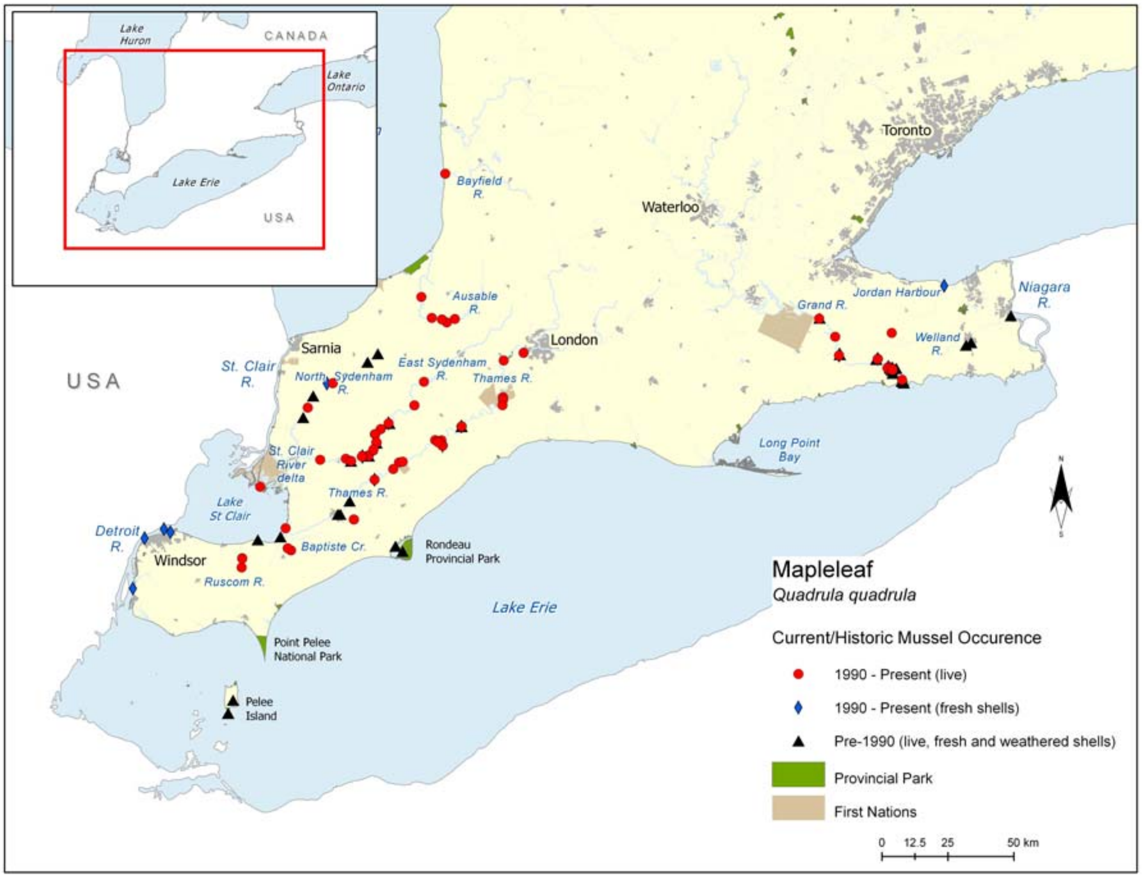

Figure 5. *Current and historic distribution of Mapleleaf in southwestern Ontario.*

Bayfield River

There are no historic records of Mapleleaf from the Bayfield River. A single live Mapleleaf was collected from the Bayfield River in 2007. There has been very limited mussel sampling in the Bayfield River; therefore, it is not possible to determine if a reproducing population of Mapleleaf is present in this system.

Grand River

Historic records dating back as far back as 1885 exist for Mapleleaf in the Grand River. Throughout history Mapleleaf distribution in the Grand River has always occurred in the lower 50 km of this system, ranging from Caledonia to Port Maitland. Numerous sampling events have occurred north of Caledonia and no additional Mapleleaf have been found. It is believed that this 50 km river segment represents the entire distribution of Mapleleaf in the Grand River.

Great Lakes and Connecting Channels

In Ontario Mapleleaf was historically collected from Lake Erie, Lake St. Clair, Detroit River, and Niagara River. Records from Lake Erie indicate that Mapleleaf existed in Rondeau Bay and in the area surrounding Pelee Island. A few historic Mapleleaf records exist from Lake St. Clair although the majority are comprised of shells or single live individual. There are only two Mapleleaf records from the Niagara River that date back to 1934, and three records from the

Detroit River. It appears from these scarce records that Mapleleaf was very rare throughout the Great Lakes proper and their connecting channels even prior to the dreissenid invasion. As is the case with most other freshwater mussels, it is believed that Mapleleaf are now extirpated from the Great Lakes and their connecting channels.

Jordan Harbour

Jordan Harbour represents the first known population of Mapleleaf in Lake Ontario. In the summer of 2010 three fresh valves as well as greater than 100 weathered valves were observed on the north east shore of Jordan Harbour (T. Theysmeyer, Royal Botanical Garden, pers. obs.). No live individuals were recorded during this observational study. There is a need to complete a formal survey of Jordan Harbour as well as suitable habitats in Twenty Mile Creek to determine the size of this Mapleleaf population.

Ruscom River

Ruscom River (a tributary on the south shore of Lake St. Clair) was originally sampled for freshwater mussels in 1999 resulting in the capture of nine live Mapleleaf. It was not possible to determine the status of this population from a single sampling event; therefore, this site was prioritized for sampling in 2010 to determine if a reproducing population was present. Mapleleaf was located in two additional sites during a timed-search survey, yielding a total of 26 live individuals.

St. Clair River Delta

Although Mapleleaf appear to be eradicated from the open water of Lake St. Clair, it has recently been found in both the St. Clair River delta and Ruscom River. Although the St. Clair River delta has been expansively surveyed in the past 10 years, positive detection of Mapleleaf in this area did not occur until 2005 when a single live specimen was recorded from Chematogan Bay during a snorkelling survey.

Sydenham River

The first recorded occurrence of Mapleleaf in the Sydenham River was documented in 1963. Mapleleaf has been noted in this river system from 1960s to present day. The range of Mapleleaf in the Sydenham River occurs from Tupperville to approximately 10 km upstream of Alvinston. Many successful sampling locations along this stretch of the Sydenham River were re-sampled from 1997 to 2009 and continually yielded Mapleleaf captures.

Thames River

Mapleleaf are predominantly present in the middle and lower portions of the Thames River, although a few records do exist in the upper Thames River. The Thames River has been extensively surveyed since the mid 1990s. Recent quadrat excavation surveys have yielded very high numbers of Mapleleaf, the greatest being 225 Mapleleaf recorded during a single site excavation in 2010 (DFO, unpubl. data). The Mapleleaf population in the lower Thames River is thought to be one of the most stable and abundant Mapleleaf populations in Ontario.

Welland River

The Mapleleaf population of the Welland River was represented historical by two records (neither record included the capture of live individuals). General freshwater mussel surveys were completed in the Welland River in 2008, and although Mapleleaf was not found at either historic site, 25 live individuals were recorded from a site approximately 50 rkm (river kilometer) upstream from the historic location. Additional surveys in this area are required to determine the extent of this newly discovered population.

Manitoba

In Manitoba, Mapleleaf has been recorded from the Assiniboine, Bloodvein, Red and Roseau rivers (Figure 6). Unverified reports of Mapleleaf exist for the Brokenhead, LaSalle, Morris, Rat, Seine, Shell rivers as well as Lake Winnipeg. Unfortunately, very limited information is available for these incomplete records; therefore they can not be considered in the following status accounts.

Assiniboine River

The largest known population of Mapleleaf in Manitoba occurs in the Assiniboine River. The first record of Mapleleaf in this system stems from mussel surveys completed from 1959 to 1969. Methods used during these surveys included visual search in clear water, observation through a glass-bottomed viewing box, and searching by hand (Clarke 1973). The method used and the date of capture for Mapleleaf records was not specified. Mapleleaf was again observed during a 1992 scuba diving survey (Scaife and Janusz 1992). Additionally, a total of six live individuals were recorded during a graduate student project in 1995 (Watson 2000). Collections were obtained by employing a raking method and a mini-bullrake. Thus far it was believed that Mapleleaf distribution was restricted to the lower Assiniboine River (below the Portage Diversion). Carney (2003) accounted for an additional 42 live animals during timed-search surveys. Interestingly, during this survey Carney (2003) recorded a single live Mapleleaf at Treherne. These results extend Mapleleaf distribution to the upper Assiniboine River, past the Portage Diversion, which is considered an impassable barrier to upstream movement of fish and a complete barrier for the upstream dispersal of glochidia-infested hosts (COSEWIC 2006a). In 2007, as a consequence of a bridge construction project and subsequent mussel survey and relocation, four live Mapleleaf were recorded near the city of Brandon, providing evidence once again that Mapleleaf distribution spans the Assiniboine River both above and below the Portage Diversion. One additional live individual was capture from a location previously sampled for Mapleleaf during a mussel identification workshop in 2009 (DFO, unpubl. data).

Bloodvein River

A single live Mapleleaf has been recorded for the Bloodvein River, which was observed during a canoe expedition in 2005 (S. Staton, DFO, pers. comm.). There are no known historical mussel surveys from this system to verify the presence of a reproducing population.

Red River

Reports summarized by Clarke (1973) indicate that Mapleleaf were present in the Red River from areas such as Fort Gary, St. Jean Baptiste, Aubigny, Emerson and Winnipeg, although information related to sampling date/year, number of individuals captured, or method of capture are not available. Live individuals have not been recorded in the Red River since the historical account by Clark (1973). It is believed that a viable population of Mapleleaf may persist in the Red River, an assumption based on river geomorphology, Mapleleaf preferred habitat, and the observation many stranded Mapleleaf during a low water event (COSEWIC 2006a; J. Carney, Lakehead University, pers. obs.)

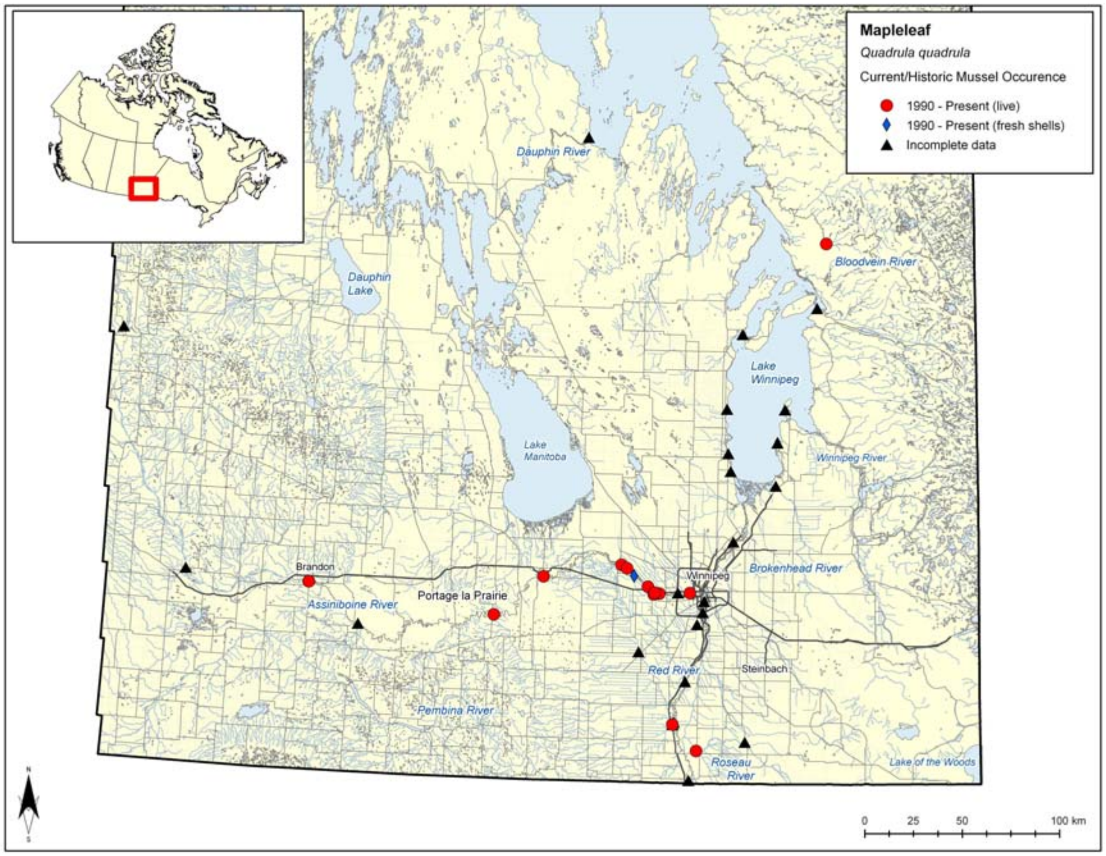

__Figure 6.__ Current and historic distribution of Mapleleaf in Manitoba [some distribution points digitized from distribution map provided in COSEWIC (2006a)].

Roseau River

There is very limited information related to the presence of Mapleleaf in the Roseau River. Knowledge of Mapleleaf in this system is limited to a historic account indicating that Mapleleaf were recorded from Tolstoi (number of live individuals is unknown), and the capture of one live individual in 1992 near Dominion City (J. Carney, unpubl. data). It is currently unknown if a Mapleleaf population persists in the Roseau River.

RAINBOW
Common Name – Rainbow
Scientific Name – *Villosa iris*
Current COSEWIC Status & Year of Designation – Endangered, April 2006
COSEWIC 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."
SARA Schedule – No schedule
Range in Canada – Ontario

Species Information

Rainbow (*Villosa iris*) is a small-sized freshwater mussel with an average shell length of 55 mm (Metcalfe-Smith *et al.* 2005). Adult Rainbow shell lengths have been recorded up to 85 mm in Canada (COSEWIC 2006b). The shell is described as being elliptical, elongate, laterally-compressed in males to moderately inflated in females (Metcalfe-Smith *et al.* 2005). Although sexual dimorphism is subtle, the posterior end of males is described as bluntly pointed, while females are described as rounded (Metcalfe-Smith *et al.* 2005).

The shell is characterized as being smooth with well-marked growth rests (COSEWIC 2006b). The coloration is yellowish green or brown with interrupted dark green rays that are more prominent posteriorly (Metcalfe-Smith *et al.* 2005). Bands may be narrow, wide, or may vary in width over the surface of the shell (Metcalfe-Smith *et al.* 2005). The nacre is generally white with obvious iridescence posteriorly (Metcalfe-Smith *et al.* 2005).

The characteristic small size, interrupted green rays, and narrow elliptical shape of Rainbow enable for easy differentiation of this species from most other Canadian freshwater mussels (COSEWIC 2006b). Rainbow may be confused with juvenile Mucket (*Actinonaias ligamentina*). There is currently no information on the genetic structure of Canadian Rainbow populations.

Rainbow sampled from the Bayfield (n=56), Maitland (n=47), Saugeen (n=61) and Thames rivers (n=15) were sexed and aged using thin shell sections to estimate age of maturity for this species (DFO, unpubl. data). Females ranged from 9 to 48 years of age, providing evidence that Rainbow reach sexual maturity as young as 9 years old.

Unlike other freshwater mussel species found in the Great Lakes, the presence of Zebra Mussel is not a major threat for Rainbow as it is generally found in headwater areas where the threat of Zebra Mussel is comparatively low. Zebra Mussel may pose a greater threat to Rainbow if they become established in reservoirs of impounded rivers (COSEWIC 2006b). Significant threats to this species include increased sediment and nutrient loading, and pollution from urban and agricultural sources.

Current Status

Ausable River

Sparse records of Rainbow exist for the Ausable River since 1998 when a single individual was captured (Figure 7). Timed-search surveys and quadrat sampling since 2002 have yielded an additional 54 live animals, with 16 individuals recorded during a single sampling event.

Bayfield River

The first occurrence of Rainbow in Bayfield River is represented by a single fresh shell collection from 2005. A formal survey of Bayfield River was complete in 2007 over a two-day period and yielded a total 28 live individuals (DFO, unpubl. data). This formal survey represents the only known sampling focused on freshwater mussels in the Bayfield River.

Grand River

Although there are quite a few historic records of Rainbow in the Grand River, the overall abundance of this species in this system is quite low. The first recorded occurrence of Rainbow in the Grand River dates back to 1890 (COSEWIC 2006b). Since 1970 there have been a total of 27 live individuals recorded from this system with only 11 live individuals recorded over the past 10 years. However, there have been numerous records of fresh shells over this same period from tributaries of the Grand River, such as Conestogo River and Mallet River (A. Timmerman, Ontario Ministry of Natural Resources, unpubl. data). Although historic Rainbow records indicate that its distribution extends to the lower reaches of the Grand River, a live Rainbow has not been observed in this section of the Grand River since 1971 (Kidd 1973).

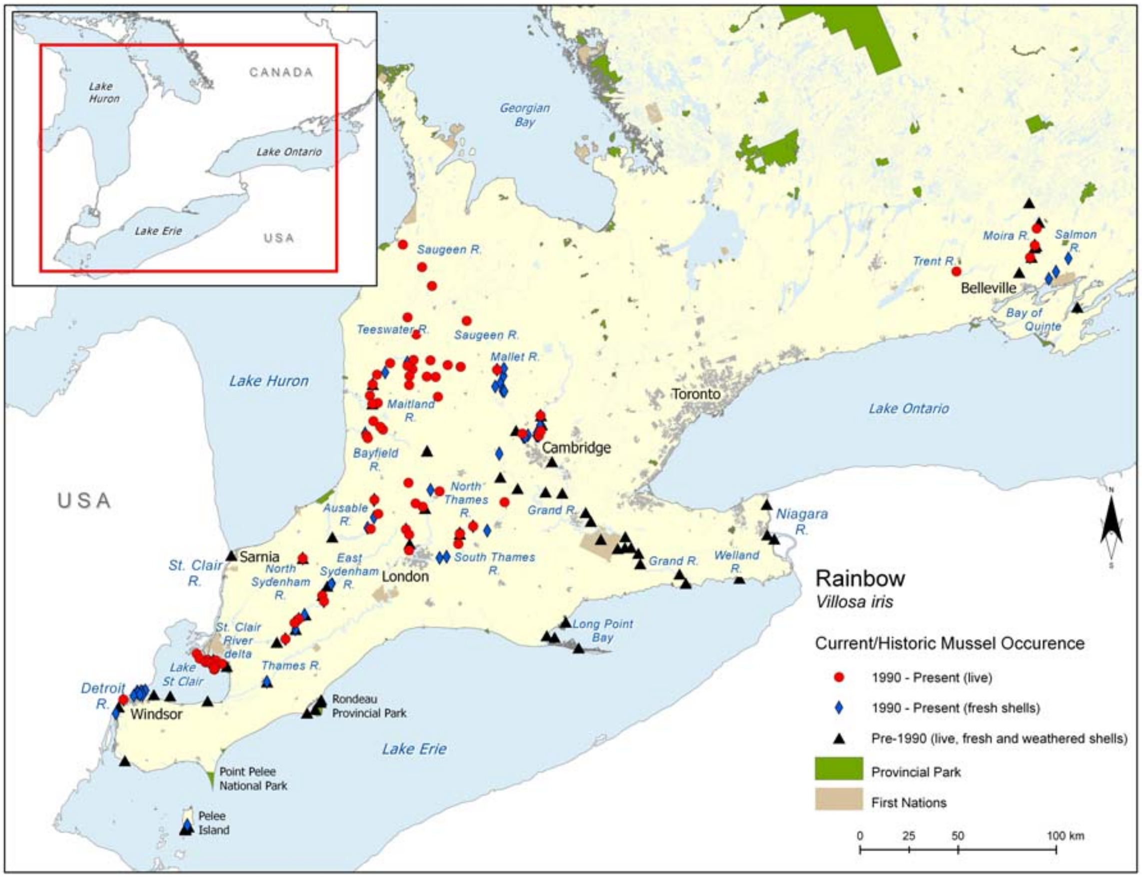

Figure 7. *Current and historic distribution of Rainbow in Canada.*

<u>Great Lakes and Connecting Channels</u>

Historically, Rainbow was found in the nearshore area of Lake Erie (Long Point Bay, Rondeau Bay), Lake Ontario and Lake St. Clair (south shore), as well as throughout the Niagara River, Detroit River and a single location in the St. Clair River. The last occurrence of a live Rainbow from any of these systems was recorded in 1992 when three individuals were sampled from the Detroit River. Surveys have occurred post-dreissenid mussel invasion at all historic Rainbow sites. It is believed that Rainbow, along with the three previously discussed freshwater mussels, is now extirpated from the Great Lakes and its major connecting channels.

<u>Maitland River</u>

Notwithstanding a few historic records from the 1930s, Rainbow had not been recorded from the Maitland River until 1998. Extensive sampling of this system over the past 10 years has yielded greater than 700 live individuals from 19 unique sites. It is believed that the Maitland Rainbow population represents the largest remaining population of this species in Canada (COSEWIC 2006b).

Moira, Salmon and Trent Rivers

The known distribution of Rainbow in eastern Ontario is limited to three river systems: Moira, Trent and Salmon rivers. It should be noted that there has been very limited historic and current freshwater mussel sampling throughout these three systems. A total of 32 (1996), 2 (1996) and 0 live individuals have been collected from the Moira, Trent and Salmon rivers, respectively. Additional shoreline searches were completed in the Salmon River between 2005-2010 and greater than 100 weathered, and a few fresh shells were observed (F. Schueler, pers. obs.; S. Reid, pers. obs.). Additional quantitative sampling is required throughout eastern Ontario to gain a better understanding of the freshwater mussel community in this area.

Saugeen River

Rainbow was not observed from the Saugeen River until 1993 with the capture of a single live individual. Since this first record, an additional 53 live individuals have been sampled at 10 unique sites, including sites in the main branch, the south Saugeen River and one of the Saugeen River tributaries, the Teeswater River.

St. Clair River Delta

Live Rainbow have sporadically been observed in the St. Clair River delta since 1999, although they are generally found in low numbers, leading one to believe that small isolated populations may exist throughout the delta (COSEWIC 2006b). Sampling completed by Metcalfe-Smith *et al.* (2004) noted that Rainbow were far more common in nearshore waters of the United States than in Canada.

Sydenham River

Infrequent observation of Rainbow in the Sydenham River has occurred since the mid 1960s. Since the first observation of this species in 1963, a total of 22 live individuals have been recorded. Unfortunately, quantitative surveys, and increased sampling effort, completed in 2002-2003 only resulted in the capture of seven live individuals (Metcalfe-Smith *et al.* 2003). Rainbow is believed to be rare throughout the Sydenham River.

Thames River

The majority of Rainbow records from the Thames River are restricted to the upper reaches and tributaries of the upper and lower Thames. Timed-search surveys completed in 2004-2005 throughout these areas were successful in locating greater than 90 live individuals (Morris and Edwards 2007).

HABITAT REQUIREMENTS

GLOCHIDIUM AND JUVENILE

To fully understand the habitat requirements of freshwater mussels, we must first understand their unique life cycle. During the spawning period, males located upstream release sperm into the water column. Females subsequently utilize their gills to filter the sperm from the water column, and the sperm is deposited in the posterior portion of the female gill, in a specialized region, where the ova are fertilized. The fertilized ova are held until they reach a larval stage. Although some freshwater mussels are obviously sexually dimorphic (mature females characterized by a swelling of the posterior-ventral margin), female Eastern Pondmussel, Fawnsfoot, Mapleleaf and Rainbow only differ slightly in shell shape from their male counterparts, and are often difficult to differentiate.

Freshwater mussels are often categorized in terms of the brooding and glochidial release pattern they employ (Watters and O'Dee 1999). Two categories are long-term brooders (bradytictic) and short-term brooders (tachytictic). Eastern Pondmussel, Fawnsfoot and Rainbow are bradyticitic such that they spawn in late summer, brood their glochidia over the winter and subsequently release their glochidia in early spring (COSEWIC 2006b, 2007, 2008). Conversely, Mapleleaf are considered tachytictic, spawning early in the season, brooding glochidia for a shorter period of time and releasing their glochidia in the same year (COSEWIC 2006a). Regardless of brooding strategy, once females release their glochidia the glochidia must encyst on the gills of an appropriate fish host.

Three host fishes have been identified for Eastern Pondmussel: Brook Stickleback (*Culaea inconstans*), Pumpkinseed (*Lepomis gibbosus*) and Yellow Perch (*Perca flavescens*) (McNichols *et al.* 2008). Laboratory fish host experiments suggest that Yellow Perch is the most likely preferred host yielding significantly greater juvenile mussels (McNichols *et al.* 2008). These newly discovered results are consistent with Stansbery (1961) who suggested Yellow Perch as a possible host based on the similarities in Eastern Pondmussel and Yellow Perch distribution along the Atlantic coast.

The potential host fish for Fawnsfoot has yet to be tested in a laboratory setting but is believed to be Freshwater Drum (*Aplodinotus grunniens*) and/or Sauger (*Sander canadensis*) Both species have been reported as potential hosts for this species in the United States (Clarke 1981). Freshwater Drum are known to occur at all locations Fawnsfoot have been recorded with the exception of the one live Fawnsfoot recorded from Muskrat Creek (Saugeen River watershed). It should be noted that there is also no record of Sauger from this area.

Known fish hosts for Mapleleaf include the Flathead Catfish (*Pylodictus olivaris*), which currently does not occur in Canada, and Channel Catfish (*Ictalurus punctatus*). The distribution of Channel Catfish overlaps that of Mapleleaf in both Ontario and Manitoba. Channel Catfish was first reported as a potential fish host for Mapleleaf when Schwebach *et al.* (2002) observed the successful transformation of Mapleleaf glochidia on this fish host. McNichols *et al.* (2008) recognized Mapleleaf as a potential candidate for fish host identification work but unfortunately did not observe any gravid females during field sample collection and could not complete planned experiments.

Numerous fish hosts have been identified for Rainbow in the United States, including Striped Shiner (*Luxilus chrysocephalus*), Smallmouth Bass (*Micropterus dolomieu*), Largemouth Bass (*Micropterus salmoides*), Green Sunfish (*Lepomis cyanellus*), Greenside Darter (*Etheostoma blennioides*), Rainbow Darter (*Etheostoma caeruleum*) and Yellow Perch, which do occur in Canada, and Streamline Chub (*Erimystax dissimilis*) and Bluebreast Darter (*Etheostoma camurum*), which do not occur in Canada (Watters and O'Dee 1997). From the above mentioned list of potential hosts, Largemouth Bass has now been verified as a host for Rainbow in Ontario (Woolnough *et al.* 2007). Mottled Sculpin (*Cottus bairdi*) and Rock Bass (*Ambloplites rupestris*) have also been identified as successful host species in Rainbow glochidia transformation (Woolnough *et al.* 2007; McNichols *et al.* 2008). In a recent laboratory study by McNichols *et al.* (2008) 21 Rock Bass were infested with Rainbow glochidia and produced 133 juveniles.

Freshwater mussels use a variety of lures to attract their appropriate fish hosts. Many species of freshwater mussels have evolved complex host attraction strategies to increase the probability of encountering a suitable host (Zanatta and Murphy 2006). Eastern Pondmussel uses a visual display to attract its fish host. As described by Corey and Strayer (1999) *in* COSEWIC (2007), Eastern Pondmussel expose their mantle by slightly gaping their valves, and subsequently ripple white papillae to mimic a swimming amphipod. Once a host fish is attracted to, and attacks this lure the female mussel expels its glochidia, facilitating attachment on the gills of the fish. Similarly, the shape and movement of the mantle of the Rainbow is modified to mimic a crawling crayfish (COSEWIC 2006b). Mapleleaf utilizes a slightly different strategy to attract a host fish, in that it utilizes conglutinates (packets of glochidia) (COSEWIC 2006a). These conglutinates may have markings similar to that of prey items to mislead potential fish hosts. Unlike Eastern Pondmussel and Rainbow, the mantle of Mapleleaf does not appear to be modified (COSEWIC 2006a). Very little is known about the display behaviour of Fawnsfoot, although Zanatta and Murphy (2006) reported that physical manipulation caused a valve-gaping display. With Freshwater Drum (a molluscivorous species) in mind, they suggested that consumption of gravid female Fawnsfoot presented a unique route to facilitate the release of glochidia directly inside the mouth of Freshwater Drum. Water would then pass over the gills and provide an opportunity for glochidia to be attached to the gills of the fish host.

Regardless of the method of exposure and attachment, glochidia will remain encysted until they metamorphose into juveniles. Attachment times have been noted for Eastern Pondmussel to range from 11 to 32 days and appear to be water temperature dependent (McNichols *et al.* 2008). For the Mapleleaf, development on the fish host has been noted from 51 to 68 days, with temperature being a key factor in development time (Schwebach *et al.* 2002). Attachment times are unknown for both Fawnsfoot and Rainbow.

Encystment is an obligate step in the life cycle of Eastern Pondmussel, Rainbow, Mapleleaf and Fawnsfoot, and development will not occur in the absence of this phase. The gills of the appropriate host fish can be considered a habitat requirement for the glochidial life stage of these freshwater mussels.

Subsequent to metamorphoses, juvenile freshwater mussels are released from the gills of the fish host and bury themselves in the substrate until maturity. Time to maturity can vary from one mussel species to another and accurate estimates are not known for most species. The proportion of glochidia that survive to the juvenile stage is estimated to be as low as 0.000001% (COSEWIC 2006b, 2007). A survival tactic to overcome this increased level of mortality is to produce very high numbers of glochidia. It is difficult to classify required habitat for juvenile mussels because they are difficult to detect and because they have a tendency to burrow; although, they are generally found when implementing adult mussel survey methods (COSEWIC 2006b). Once sexually mature they emerge from the substrate to participate in gamete exchange (Watters *et al.* 2001).

ADULT

Eastern Pondmussel

Adult Eastern Pondmussel preferred habitat includes both nearshore, sheltered areas of the Great Lakes as well as the slack water of slow-moving rivers (Metcalfe-Smith *et al.* 2005; COSEWIC 2007). Substrate preferences include both mud or sand, while depth preferences have been noted to range from 0.3 to 4.5 m (COSEWIC 2007). Specifically, in Lake St. Clair, Eastern Pondmussel was found on substrates composed of over 95% sand located at the transition zone between emergent wetland and open waters (Metcalfe-Smith *et al.* 2004). In Lyn Creek live Eastern Pondmussel were found in areas described as Zebra Mussel-free streams, in slow moving areas over sand, silt and clay beds (Schueler 2008).

Fawnsfoot
Adult Fawnsfoot are generally found in medium- to large-sized rivers at depths ranging from less than 1 m to greater than 5 m (COSEWIC 2008). Their preferred substrate has been described as sand or mud (COSEWIC 2008), although a few recent surveys have recorded Fawnsfoot on rubble- and gravel-dominated substrate (DFO, unpubl. data).

Mapleleaf
The current distribution of adult Mapleleaf in Canada indicates that this species tends to occur in medium to large rivers (Metcalfe-Smith *et al.* 2005; COSEWIC 2006a). Water flow does not appear to be limiting factor for Mapleleaf as it has been found in both slow- and fast-flowing rivers. Recent surveys have indicated that Mapleleaf preferred substrate is dominated by firmly-packed coarse gravel or rubble, although it can also be found over mud, sand or fine gravel substrates (DFO, unpubl. data). Water velocity values for successful Mapleleaf capture sites from the Assiniboine River ranged from 0.42 to 0.72 m s^{-1} (E. Watson, unpubl. data).

Rainbow
Although Rainbow was once found throughout the nearshore area of the Great Lakes and its connecting channels, Zebra Mussel introduction has restricted this species to small creeks and rivers, and the St. Clair River delta. In river systems it can be found in or near riffles and along the edges of emergent vegetation (Metcalfe-Smith *et al.* 2005). It is generally found in areas with moderate to strong current over a mixture of cobble, gravel, or sand (COSEWIC 2006b).

RESIDENCE
Residence is defined in SARA as “dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating”. Residence is interpreted by DFO as being constructed by the organism. In the context of the above narrative description of habitat requirements during glochidial, juvenile and adult life stages, Eastern Pondmussel, Fawnsfoot, Mapleleaf and Rainbow do not construct residences during their life cycle (DFO 2010).

POPULATION STATUS

Population Status was assessed for Eastern Pondmussel, Fawnsfoot, Mapleleaf and Rainbow. Each population was ranked in terms of its abundance (Abundance Index) and trajectory (Population Trajectory). Population status was only assessed for locations where one or more live individuals, fresh whole shells or fresh valves were recorded since 1990 (i.e., post-Zebra Mussel invasion). All sites included in the Population Status assessment did meet these criteria. The Great Lakes and its connecting channels have not been included in the following population estimates as all four mussel species examined are believed to be extirpated from these areas.

The abundance index was assigned as Extirpated, Low, Medium, High or Unknown, and was based on quantitative density estimates, estimates of population size [obtained through analysis of area of occupancy (AO) and density estimates], a comparison of species density estimates to total unionid estimates at each site (when available), and where possible current density was considered in the framework of historical levels (Table 1). Abundance index categorization was completed on a species-by-species basis and the abundance index assigned to each site is relative to all other sites where the species is known to exist.

Quantitative density estimates were obtained from quadrat surveys as described in COSEWIC (2010). The area of occupancy (AO) was required to determine the estimated population size for each species at each location. The area of occupancy was based on the distribution of all live, fresh whole shell, or fresh valve recorded since 1990 (by species and by location). All records were plotted in a GIS. In riverine systems, the method used to generate the AO varied depending on the available spatial data. For areas where stream polygons exist, waterbodies were clipped 500 m up and downstream of the bounding distribution points (measured using the centerline of the stream geometry) and the subsequent polygons were used to define the AO. In areas where rivers are represented as a single line, the streams were clipped 500 m up and downstream of the bounding distribution points and the total length of the occupied area was then determined by buffering the line using an average stream width. Stream width values were borrowed from survey data (when available). If no stream width data were available, stream width was estimated using available resources in the GIS (such as orthoimagery). For lacustrine locations, and for any riverine location consisting of a single observation, each record was buffered by a 500 m radius. If buffered areas overlapped, they were subsequently joined together (if biologically meaningful to do so) and the size of the buffered area was calculated. Area of occupancy values were multiplied by the density estimates to obtain the estimated population sizes (Table 1a-e). The estimated population sizes were then used to determine the current Abundance Index for each population.

The Population Trajectory was assessed as Decreasing, Stable, Increasing, or Unknown for each population based on the best available knowledge of the current trajectory of the population (Table 2). The number of individuals caught over time for each population was considered. Trends over time were classified as Increasing (an increase in abundance over time), Decreasing (a decrease in abundance over time) and Stable (no change in abundance over time). If insufficient information was available to inform the Population Trajectory, the population was listed as Unknown. Certainty has been associated with the Abundance Index and Population Trajectory rankings and is listed as: 1=quantitative analysis; 2=standardized sampling; 3=expert opinion.

*Table 1. Population estimates for all current (a) Eastern Pondmussel; (b) Fawnsfoot; (c) Mapleleaf (ON DU); (d) Mapleleaf (MB DU); and (e) Rainbow populations in Canada. The Great Lakes and its connecting channels have not been included in the following population estimates as all four mussel species examined are believed to be extirpated from these areas. Note: * indicates that the population is represented by a single live individual; ** indicates that density estimates are only available from a single site, and therefore Standard Error (SE) is not available; NA-information is not available.*

(a) Eastern Pondmussel

Population	Average Total Unionid Density (#/m^2) (SE)	Eastern Pondmussel Density (#/m^2) (SE)	Eastern Pondmussel Area of Occupancy (m^2)	Eastern Pondmussel Estimated Population Size
Beaver Lake	NA	NA	5 470 211	NA
Grand River	NA	NA	15 621	NA
Long Point Bay				
Cedar Creek	NA	NA	793 236	NA
Turkey Point Marshes	NA	NA	525 498	NA
Lyn Creek	NA	NA	211 154	NA
St. Clair River delta	0.079 (± 0.105)	0.008 (± 0.006)	17 540 000	48 521 – 242 513

(b) Fawnsfoot

Population	Average Total Unionid Density (#/m^2) (SE)	Fawnsfoot Density (#/m^2) (SE)	Fawnsfoot Area of Occupancy (m^2)	Fawnsfoot Estimated Population Size
Grand River	NA	NA	35 491	NA
Saugeen River*	NA	NA	3996	NA
St. Clair River Delta*	NA	NA	689 383	NA
Sydenham River	3.010**	0.090**	389 219	35 030
Thames River	5.550 (±0.780)	0.117 (± 0.077)	8070573	322 823 – 1 560 311

(c) Mapleleaf (ON DU)

Population	Average Total Unionid Density (#/m^2) (SE)	Mapleleaf Density (#/m^2) (SE)	Mapleleaf Area of Occupancy (m^2)	Mapleleaf Estimated Population Size
Ausable River	2.065 (± 1.945)	0.135 (± 0.121)	712 637	9977 – 183 005
Bayfield River*	NA	NA	80 287	NA
Grand River	2.253**	0.030**	10 827 716	324 831
Jordan Harbour	NA	NA	492 747	NA
Ruscom River	NA	NA	56 719	NA
St. Clair River Delta*	NA	NA	755 799	NA
Sydenham River	5.826 (± 1.587)	0.210 (± 0.058)	5 800 645	883 191 – 1 553 783
Thames River	5.045 (± 0.748)	0.508 (± 0.187)	11 733 405	3 765 144 – 8 144 262
Welland River	NA	NA	6394	NA

(d) Mapleleaf (MB DU)

Population	Average Total Unionid Density (#/m²) (SE)	Mapleleaf Density (#/m²) (SE)	Mapleleaf Area of Occupancy (m²)	Mapleleaf Estimated Population Size
Assiniboine River	NA	0.080[1]**	33 981 330	NA
Bloodvein River*	NA	NA	71 250	NA
Red River	NA	NA	64 033	NA
Roseau River	NA	NA	45 627	NA

[1] Carney (2004)

(e) Rainbow

Population	Average Total Unionid Density (#/m²) (SE)	Rainbow Density (#/m²) (SE)	Rainbow Area of Occupancy (m²)	Rainbow Estimated Population Size
Ausable River	5.687 (± 3.523)	0.119 (± 0.054)	563 467	36 484 – 97 208
Bayfield River	NA	NA	462 129	NA
Grand River	NA	NA	10 853 482	NA
Maitland River	1.208 (± 0.403)	0.715 (± 0.384)	6 112 182	2 019 365 – 6 715 557
Moira River	NA	NA	1 274 219	NA
Salmon River	NA	NA	622 892	NA
Saugeen River	NA	NA	6 402 870	NA
St. Clair River delta	NA	NA	9 612 469	NA
Sydenham River	8.835 (± 5.285)	0.038 (± 0.026)	6 071 670	74 959 – 389 210
Thames River	5.355 (± 1.755)	0.075 (± 0.025)	13 408 680	670 464 – 1 340 868
Trent River	NA	NA	91 127	NA

The Abundance Index and Population Trajectory values were then combined in the Population Status matrix (Table 3) to determine the Population Status for each population. Population Status was subsequently ranked as Poor, Fair, Good, Unknown or Extirpated (Table 4).

*Table 2. Abundance Index and Population Trajectory of each (a) Eastern Pondmussel; (b) Fawnsfoot; (c) Mapleleaf (ON DU); (d) Mapleleaf (MB DU); and (e) Rainbow population in Canada. Certainty has been associated with the Abundance Index and Population Trajectory rankings and is listed as: 1=quantitative analysis; 2=standardized sampling; 3=expert opinion. * indicates that the population is represented by a single live individual.*

(a) Eastern Pondmussel

Population	Abundance Index	Certainty	Population Trajectory	Certainty
Beaver Lake	Unknown	3	Unknown	3
Grand River	Unknown	3	Unknown	3
Great Lakes and connecting channels	Extirpated	2	-	-
Long Point Bay	Low	2	Unknown	3
Lyn Creek	Low	3	Unknown	3
St. Clair River delta	Medium	1	Unknown	3

(b) Fawnsfoot

Population	Abundance Index	Certainty	Population Trajectory	Certainty
Grand River	Low	3	Unknown	3
Great Lakes and connecting channels	Extirpated	2	-	-
Saugeen River*	Low	3	Unknown	3
St. Clair River delta*	Low	1	Unknown	3
Sydenham River	Medium	1	Unknown	3
Thames River	High	1	Unknown	3

(c) Mapleleaf (ON DU)

Population	Abundance Index	Certainty	Population Trajectory	Certainty
Ausable River	Medium	2	Unknown	3
Bayfield River*	Low	3	Unknown	3
Grand River	High	2	Unknown	3
Great Lakes and connecting channels	Extirpated	2	-	-
Ruscom River	Medium	2	Unknown	3
St. Clair River delta*	Low	1	Unknown	3
Sydenham River	High	1	Stable	3
Thames River	High	1	Stable	3
Welland River	Low	2	Unknown	3

(d) Mapleleaf (MB DU)

Population	Abundance Index	Certainty	Population Trajectory	Certainty
Assiniboine River	Low	2	Unknown	3
Bloodvein River*	Unknown	3	Unknown	3
Roseau River	Unknown	3	Unknown	3

(e) Rainbow

Population	Abundance Index	Certainty	Population Trajectory	Certainty
Ausable River	Low	2	Unknown	3
Bayfield River	Low	2	Unknown	3
Grand River	Low	2	Stable	3
Great Lakes and connecting channels	Extirpated	2	-	-
Maitland River	High	2	Stable	3
Moira River	Low	3	Unknown	3
Salmon River	Unknown	3	Unknown	3
Saugeen River	Low	2	Unknown	3
St. Clair River delta	Low	1	Unknown	3
Sydenham River	Low	1	Unknown	3
Thames River	Medium	1	Unknown	3
Trent River	Low	3	Unknown	3

Table 3. *The Population Status matrix combines the Abundance Index and Population Trajectory rankings to establish the Population Status for each Eastern Pondmussel, Fawnsfoot, Mapleleaf, and Rainbow population in Canada. The resulting Population Status has been categorized as Extirpated, Poor, Fair, Good, or Unknown.*

		Population Trajectory			
		Increasing	**Stable**	**Decreasing**	**Unknown**
Abundance Index	**Low**	Poor	Poor	Poor	Poor
	Medium	Fair	Fair	Poor	Poor
	High	Good	Good	Fair	Fair
	Unknown	Unknown	Unknown	Unknown	Unknown
	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated

Table 4. *Population Status of all (a) Eastern Pondmussel; (b) Fawnsfoot; (c) Mapleleaf (ON DU); (d) Mapleleaf (MB DU) and (e) Rainbow populations in Canada, resulting from an analysis of both the Abundance Index and Population Trajectory. Certainty assigned to each Population Status is reflective of the lowest level of certainty associated with either initial parameter (Abundance Index or Population Trajectory). * indicates that the population is represented by a single live individual.*

(a) Eastern Pondmussel

Population	Population Status	Certainty
Beaver Lake	Unknown	3
Grand River	Unknown	3
Great Lakes and connecting channels	Extirpated	2
Long Point Bay	Poor	3
Lyn Creek	Poor	3
St. Clair River delta	Poor	3

(b) Fawnsfoot

Population	Population Status	Certainty
Grand River	Poor	3
Great Lakes and connecting channels	Extirpated	2
Saugeen River*	Poor	3
St. Clair River delta*	Poor	3
Sydenham River	Poor	3
Thames River	Fair	3

(c) Mapleleaf (ON DU)

Population	Population Status	Certainty
Ausable River	Poor	3
Bayfield River*	Poor	3
Grand River	Fair	3
Great Lakes and connecting channels	Extirpated	2
Ruscom River	Poor	3
St. Clair River delta*	Poor	3
Sydenham River	Good	3
Thames River	Good	3
Welland River	Poor	3

(d) Mapleleaf (MB DU)

Population	Population Status	Certainty
Assiniboine River	Poor	3
Bloodvein River*	Unknown	3
Roseau River	Unknown	3

(e) Rainbow

Population	Population Status	Certainty
Ausable River	Poor	3
Bayfield River	Poor	3
Grand River	Poor	3
Great Lakes and connecting channels	Extirpated	2
Maitland River	Good	3
Moira River	Poor	3
Salmon River	Unknown	3
Saugeen River	Poor	3
St. Clair River delta	Poor	3
Sydenham River	Poor	3
Thames River	Poor	3
Trent River	Poor	3

THREATS

In the past 30 years, species diversity and abundance of native freshwater mussels has declined throughout Canada and the United States (Williams *et al.* 1993). It appears that the greatest limiting factors to the stabilization and growth of freshwater mussel populations in Canada are largely attributed to the introduction and establishment of dreissenid mussels and decreases in the quality of available freshwater mussel habitat. The historic vast distribution of freshwater mussels in the Great Lakes and its connecting channels has been devastated by the introduction of dreissenid mussels, and many of the areas once inhabited by freshwater mussels no longer provide suitable habitat.

In addition, there is evidence that decreases in water quality, specifically increased turbidity and suspended solids, increased nutrient loading, and increased levels of contaminants and toxic substance are also limiting the distribution of freshwater mussels. These declines in water quality are the result of activities such as dam construction and impoundments, channel modifications (e.g., channelization, dredging, snagging) and land-use practices (e.g., farming, mining, construction) (Bogan 1993; Williams *et al.* 1993; Watters 2000). Impoundments typically result in siltation, stagnation, loss of shallow water habitat, pollutant accumulation and nutrient-poor water, while dams alter flow and temperature regimes and separate mussels from their fish hosts (Bogan 1993; Watters 2000). Channelization, dredging and snagging activities result in the disruption of the riffle-run-pool sequence, as well as the alteration of circulation patterns and substrate composition (Watters 2000). Mussels caught in the path of the dredge are destroyed while silt and suspended solids generated by these activities may travel downstream and adversely affect other mussel populations (Watters 2000). Sediments stirred up during channelization or dredging activities can result in the re-suspension of contaminants, increased concentrations of inorganic plant nutrients, reduced rates of photosynthesis and increased biochemical oxygen demand (Watters 2000). Land-use practices such as farming, logging, mining and construction usually result in the runoff of sediments, pollutants and salt into streams (Bogan 1993; Watters 2000).

Toxic chemicals from both point and non-point sources, especially agriculture, are believed to be one of the major threats to mussel populations today (Strayer and Fetterman 1999). Fuller (1974) investigated the effects of heavy metals on mussels and concluded that substances such as arsenic, cadmium, chlorine, copper, mercury and zinc can be toxic to freshwater mussels because mussels can accumulate these substances from their environment. Due to the obligate nature of the mussel reproductive cycle, any threat leading to the separation of mussel and fish host during reproduction can be detrimental to the mussel population. Direct threats to the host, such as barriers to movement, and recreational activities, such as angling and harvesting pressures, will have cumulative effects on the mussel population.

It is important to note that these threats may not always act independently; rather, one threat may directly affect another, or the interaction between two threats may introduce an interaction effect. It is quite difficult to quantify these interactions; therefore, each threat will be discussed independently.

EXOTIC SPECIES

Dreissenid mussels, Zebra Mussel and Quagga Mussel, have severely affected native, lacustrine freshwater mussel populations. The invasion and spread of these invasive species throughout the Great Lakes and their tributaries has decimated many native freshwater mussel populations (Schloesser and Nalepa 1994; Nalepa *et al.* 1996; Ricciardi *et al.* 1996; Schloesser *et al.* 1996; Schloesser *et al.* 1998; Zanatta *et al.* 2002). They have destroyed the lacustrine habitat historically inhabited by Eastern Pondmussel, Fawnsfoot, Mapleleaf, and Rainbow in Lake St. Clair (Nalepa *et al.* 1996), Lake Erie (Schloesser and Nalepa 1994) and Lake Ontario (F. Schueler, Bishops Mills Natural History Centre, pers. comm.). Zebra Mussel compete with native mussel species for space and food and can attach to freshwater mussel shells, impairing movement, burrowing, feeding, respiration, reproduction and other physiological activities (Mackie 1991; Haag *et al.* 1993; Baker and Hornbach 1997). This typically results in the death of the unionid mussel. Zebra Mussel exhibit rapid population growth and are able to eliminate entire unionid populations in a very short time.

This threat is particularly relevant to remnant freshwater mussel populations occupying the St. Clair delta, which is currently acting as a refuge for native freshwater mussels (Metcalfe-Smith *et al.* 2007a; McGoldrick *et al.* 2009). Zebra Mussel are not only a threat for lacustrine freshwater mussel populations but do pose a threat to riverine populations should they become established in reservoirs. Impoundments behind reservoirs act to increase water retention times, allowing time for Zebra Mussel veligers to settle and act as a seed population. Infestation may occur if water retention time is greater than the life span of the larval stage of the Zebra Mussel (G. Mackie, University of Guelph Emeritus, pers. comm.). This increases susceptibility to invasion by these exotics (Metcalfe-Smith *et al.* 2000b). Zebra Mussel have already been reported in two reservoirs on the Thames River (UTRCA 2003), and have been noted to occur throughout the lower Thames River from Fanshawe Reservoir to the mouth of the river (Morris and Edwards 2007). Another highly susceptible population is that of the Grand River, which is heavily impounded with a total of 34 dams/weirs (GRCA 1998). Zebra Mussel infestation in the Luther, Belwood, Guelph, Conestogo reservoirs could seriously impact the freshwater mussel populations of the Grand River (Metcalfe-Smith *et al.* 2000a).

Although all four mussel species discussed in this document have been substantially impacted by Zebra Mussel, Eastern Pondmussel may be the species most greatly affected. It is estimated that greater than 90% of historic records of Eastern Pondmussel are from areas that are now heavily invested with Zebra Mussel (COSEWIC 2007). In addition, the results of an unpublished study on the impacts of Zebra Mussel on native mussels in Lake St. Clair indicated that Eastern Pondmussel had the lowest rate of survival, and carried the heaviest load of Zebra Mussel relative to their size (Hunter pers. comm. *in* COSEWIC 2007). In addition, Eastern Pondmussel was once found in eastern Lake Ontario with records of live individuals from Consecon Lake and East Lake as recent as 1996. Both lakes were revisited in 2005 and 2006 and it was found that the lakes were heavily infested with Zebra Mussel and no live unionids, of any species, were present (COSEWIC 2007; F. Schueler, Bishops Mills Natural History Centre, pers. comm.). Fortunately, it is not likely that Zebra Mussel will affect the Lyn Creek population of Eastern Pondmussel, as introduction into this system would have to begin at Graham, Centre or Temperance lakes and enter Lambs Pond by spreading through ditches, which is believed to be an unlikely route of invasion (F. Schueler, Bishops Mills Natural History Centre, pers. comm.).

TURBIDITY AND SEDIMENT LOADING

Increases in turbidity, and the subsequent decrease in silt-free habitats has reduced the quantity and quality freshwater habitat across southwestern Ontario. Increased siltation affects freshwater mussels by clogging siphons, hindering the intake of oxygen and impeding reproductive functions (Strayer and Fetterman 1999). Increased suspended solids in the water column can clog the gill structures and ultimately suffocate the mussel. Furthermore, the reproductive cycle of many freshwater mussels require a visual predator to be attracted to a lure, and subsequently become infested with glochidia. Increased siltation would decrease the likelihood that the fish host will be able to locate the mussel.

Increased sediment loading is often associated with increased agricultural land use. Increased agricultural land use can also lead to riparian vegetation clearing or unrestricted livestock access to the river leading to poor water quality with increased sediment loads (WQB 1989a). Agricultural practices and increased tile drainage results in large inputs of sediments to the watercourse (COSEWIC 2008). On a much smaller scale, in-water projects without sedimentation controls may cause temporary turbidity increases in the waterway.

Portions of the Thames and Sydenham rivers flow through areas of prime agricultural land in southwestern Ontario. It is estimated that over 85%, 78%, and 88% of the land in the Sydenham River, upper Thames River and lower Thames River is used for agricultural purposes and large extents of these rivers have little to no riparian vegetation (Dextrase *et al.* 2003; Taylor *et al.* 2004). Dextrase *et al*. (2003) reported suspended solid levels in the Sydenham River to be as high as 900 mg L^{-1}, which would undoubtedly negatively affect the freshwater mussel assemblage. The upper Thames River (where Rainbow are present) is considered to be moderately turbid, while the lower Thames River (where Mapleleaf and Fawnsfoot are present) is considered to be highly turbid (COSEWIC 2006a).

Another watershed greatly affected by increased turbidity is the Grand River. It is believed that poor water quality and increased sediment loads in this watershed have resulted from riparian vegetation clearing and increased livestock access to the river (WQB 1989a). Agricultural land use in the Grand River increased from 68% in 1976 to 75% in 1998 and it is believed that the effects of this increase will more greatly affect species found in the lower Grand River, such as Mapleleaf (COSEWIC 2006a).

The Ausable River watershed is an example of a watershed that has been drastically altered. It is estimated that by 1983 85% of the land in this watershed had been converted from forest and lowland vegetation to agricultural land, and that 70% of the land is now in tile drainage (Nelson *et al.* 2003). Also there are 21 dams in this system causing sediment retention upstream and scouring downstream (COSEWIC 2006a).

In Manitoba, the Assiniboine, Red, and Roseau rivers are found within what is considered to be one of the most altered biomes (tall-grass to mixed-prairie; Meffe and Carroll 1997). Most of the land within this biome has been converted to agricultural, urban and industrial lands. Uncontrolled access of cattle herds to the rivers has been noted as a major source of damage to the river banks (COSEWIC 2006a).

Areas considered to be less affected by this threat include the St. Clair River delta (as it is afforded protections by the Walpole Island First Nation territory), Lyn Creek (as this creek is surrounded by relatively undisturbed habitat; F. Schueler, Bishops Mills Natural History Centre, pers. comm.), and Cedar Creek in Long Point Bay (as this area is found within the Long Point National Wildlife Area).

CONTAMINANTS AND TOXIC SUBSTANCES

Freshwater mussel life history characteristics also make them particularly sensitive to increased levels of sediment contamination and water pollution. Adult mussels feed primarily by filter feeding, while juveniles remain buried deep in the sediment feeding on particles associated with the sediment. The glochidial stage has also been shown to be sensitive to heavy metals, acidity and salinity (COSEWIC 2008) Toxic chemicals from both point and non-point sources, especially agriculture, are believed to be one of the major threats to mussel populations today (Strayer and Fetterman 1999).

The effects of heavy metals on mussels have been reviewed by Fuller (1974) and he concluded that substances such as arsenic, cadmium, chlorine, copper, mercury and zinc can be toxic to freshwater mussels because they accumulate these substances from their environment. There is also an ever-growing body of literature indicating that freshwater mussels are sensitive to ammonia (Augspurger *et al.* 2003; Bartsch *et al.* 2003; Mummert *et al.* 2003). Studies have indicated that the juvenile stage is the most vulnerable to ammonia exposure (COSEWIC 2006a).

In the Grand River, Mackie (1996) indicated that much of the harm to the freshwater mussel assemblage was attributed to anthropogenic stressors below urban centers, such as sewage pollution. In addition, increased agricultural activities lead to increased levels of pesticides and fertilizers running off the land into the river (COSEWIC 2006a). In the Thames River, mean ammonia concentrations exceed federal guidelines in all sub-basins (Morris *et al.* 2008). While mean concentrations of copper exceed guidelines in several sub-basins (Metcalfe-Smith *et al.* 2000b).

NUTRIENT LOADING

Agriculture, the primary land use in many southwestern Ontario watersheds, appears to be contributing to poor water quality through agricultural runoff and manure seepage (GRCA 1997; ARRT 2005; TRRT 2005; Veliz *et al.* 2007). Particularly relevant to freshwater mussels are the indirect effects of increased nutrient loading, such that, increases in nutrient levels can lead to increased algal growth. Once algal masses senesce, the oxygen supply in the water column is used for the decomposition process, leading to decreased levels of available oxygen. Strayer and Fetterman (1999) identified increased nutrient loads from non-point sources, and especially from agricultural activities as a primary threat to freshwater mussels.

Phosphorus and nitrogen loadings in the Thames River watershed are some of the highest loadings for the entire Great Lakes basin (WQB 1989b). Tile drainage, wastewater drains, manure storage and spreading has contributed to poor water quality in this system (TRRT 2005). Specifically, the lower Thames River, where Fawnsfoot and Mapleleaf occur, faces increased pressure from agricultural activities. Similarly, the Sydenham River has shown high nutrient levels with total phosphorus levels often exceeding the provincial water quality objective (Dextrase *et al.* 2003). Concentrations of total phosphorus, associated with agricultural runoff, continues to increase in the east branch, affecting Rainbow and Mapleleaf (COSEWIC 2006a, 2006b). Likewise, water quality data collected from the Ausable River, potentially affecting Mapleleaf and Rainbow populations, show that total phosphorus levels are often above the provincial water quality objective, and that nitrate levels also exceed guidelines (COSEWIC 2006a).

It has been noted that the major concern in the Red River and Assiniboine River drainage is non-point sources nutrient enrichment from agricultural runoff (Manitoba Conservation 2000). An analysis of water quality data from the Red River and Assiniboine river drainages indicated that there have been significant increases in both total nitrogen and total phosphorus over the past 30 years (Jones and Armstrong 2001). Increases in phosphorus ranged from 29% to 62% for the Red and Assiniboine rivers, respectively, while increases in nitrogen ranged from 54% to 57% for the Red and Assiniboine rivers, respectively (Jones and Armstrong 2001). A subsequent study by Bourne *et al*. (2002) indicated that from 1994 to 2001 the Assiniboine River carried, on average, 3682 and 637 tonnes per year of total nitrogen and total phosphorus, respectively. Comparatively, the Red River carried, on average 15301 and 4269 tonnes per year of total nitrogen and total phosphorus, respectively (Bourne *et al.* 2002). These elevated levels of both nitrogen and phosphorus may be limiting the survival of Mapleleaf in these systems.

ALTERED FLOW REGIMES

The presence of impoundments and dams on freshwater streams and rivers has been shown to negatively affect mussel communities (Vaughn and Taylor 1999; Parmalee and Polhemus 2004). Impoundments typically result in siltation, stagnation, loss of shallow water habitat, pollutant accumulation and water of poor quality due to high nutrient concentrations, while dams alter flow and can affect the natural thermal profile (Bogan 1993; Vaughn and Taylor 1999; Watters 2000). In addition, poor management of water control structures can potentially dewater areas, leading to unsuitable habitat for mussels as the bottom of the watercourse may become exposed. Dams can also cause sediment retention upstream and scouring downstream. Increased pressures from urbanization can include increased water taking from rivers as well as storm water management that greatly alter flow regimes surrounding urbanized centers. Man-made alterations to the environment have also been detrimental to mussel communities (Watters 2000). For example, channelization, dredging and snagging activities result in the disruption of the riffle-run-pool sequence, as well as alterations to circulation patterns and substrate composition (Watters 2000). Increased tile drainage, resulting from the conversion of forest-covered land to agricultural, allows for large inputs of sediments into the watercourse.

A total of 21 dams in the Ausable River watershed may be altering flow regimes in this system and negatively affecting freshwater mussels (COSEWIC 2006b). The Thames River is another severely altered system with a total of 173 water control structures (e.g., dams and weirs) in the upper watershed and 65 in the lower (COSEWIC 2006a). A large water control dam, the Portage Diversion, on the Assiniboine River diverts water from the Assiniboine River north to Lake Manitoba (COSEWIC 2006a). It is quite plausible that a water control structure of this magnitude is negatively affecting mussel habitat in this system although the effects are currently unknown.

HABITAT REMOVAL AND ALTERATION

Physical loss of freshwater mussel habitat can occur as a result of many activities, such as dredging, infilling, construction of impoundments, marinas and docks, and channelization. Although there is no quantitative information available regarding the number of freshwater mussel affected by these human activities, removal or alteration of preferred habitat could have a direct effect on the recovery or survival of freshwater mussels.

FISH HOSTS

The obligate glochidial encystment stage necessitates access to a suitable fish host. Therefore, the distribution of many freshwater mussel species is limited by the distribution of its fish host(s). If host fish populations decline, recruitment will not occur, and the mussel species may become functionally extinct (Bogan 1993). Due to the obligate nature of the mussel reproductive cycle, any threat leading to the separation of mussel and fish host during reproduction can be detrimental to the mussel population. Movement is minimal in adult freshwater mussels and therefore mussels rely on fish host for dispersal into new habitats, and ultimately for genetic exchange with other populations. Please see 'Habitat Requirements' for a complete discussion on suitable fish hosts for each species.

Threats to fish hosts include barriers to movement such as impoundments and dams which limits the fish host's dispersal ability. For example, improvements of the Grand River mussel community have been linked to the addition of fish ladders in this system, allowing for mussel dispersal via the host fish (Metcalfe-Smith *et al.* 2000a). The presence of dams on this river system had been historically flagged as a central threat to the overall health of the freshwater mussel assemblage in this system (Kidd 1973). Freshwater Drum, believed to be the host fish for Fawnsfoot, may be particularly affected by the threat of dams and barriers to movement. A study by Watters (1996) observed that the distributions of two freshwater mussel species in Indiana, Ohio and West Virginia were limited by the presence of small dams that restricted Freshwater Drum dispersal. Similarly, Fawnsfoot distribution upstream in the Fox River system (Illinois) appears to be limited by Freshwater Drum movement past a low-head dam (Tiemann *et al.* 2007). It is thought that the presence of the first dam on the Thames River at Springbank Park, which represents a temporary barrier to fish passage from mid-may to early November (Reid and Mandrak 2006), is limiting the presence of Freshwater Drum, and subsequently Fawnsfoot in this system (COSEWIC 2008). The known fish host for Mapleleaf is Channel Catfish, which is considered to be a common species in both Ontario and Manitoba (COSEWIC 2006a). Therefore, the fish-mussel host interaction is not thought to be limiting the presence of Mapleleaf throughout its Canadian range.

Additional fish host threats include decreased water quality, which can create an uninhabitable environment for the fish host, or in cases where the fish host is a visual predator, the fish will not be attracted to the mussel's lure and infestation will not occur. A detailed discussion on the activities resulting in decreased water quality can be found in the 'Turbidity and Sediment Loading' section of this document.

PREDATION AND HARVESTING

Known freshwater mussel predators include a variety of fish species, muskrat (*Ondatra zibethicus*), mink (*Mustela vison*) and raccoon (*Procyon lotor*) (Fuller 1974; Neves and Odom 1989; Tyrrell and Hornbach 1998). The direct impacts that these predators may have on Canadian freshwater mussel populations have not been investigated and are currently unknown; although, it is believed that if the threat of predation were to occur the impact that this threat would have on the mussel assemblage would be quite low.

In addition to predation, harvesting freshwater mussels for human consumption has been highlighted as a potential concern. To date, there have been no reported incidences where Eastern Pondmussel, Fawnsfoot, Mapleleaf, or Rainbow have been harvested for human consumption (J. Barkley, DFO, pers. comm.). Thus far, Wavy-rayed Lampmussel (*Lampsilis fasciola*) is the only species of freshwater mussel currently listed under the *SARA* that has been recorded to be harvested for human consumption (J. Barkley, DFO, pers. comm.).

RECREATIONAL ACTIVITIES

Recreational activities, such as driving all-terrain vehicles (ATVs) through streams, boating, fishing, and kayaking may negatively impact mussel beds. ATVs are noted as a potential threat to mussel beds in the Thames, Ausable and Sydenham rivers where ATVs travel up and down the rivers, crushing mussel beds. Propeller channels from recreational boats, speed boats, and jet skies have been noted through the mussel beds in the St. Clair River delta (D. McGoldrick, Environment Canada, pers. comm.). Fly fisherman may be crushing mussel beds as they fish throughout the rivers. The paddling action from canoeist or kayakers in shallow waters may disturb the riverbed, dislodging mussels that are subsequently carried downstream to potentially unsuitable habitat (Metcalfe-Smith *et al.* 2000b). In addition, beach maintenance practices that include the removal and destruction of mussels should be revised to incorporate the relocation of the collected mussels.

CLIMATE CHANGE

Through discussion on the effects of climate change on aquatic species, impacts such as decreases in water levels, increases in water and air temperatures, increases in the frequency of extreme weather events, and emergence of diseases have been highlighted, all of which may negatively impact native freshwater mussels (Lemmen and Warren 2004). Although the various climate models provide differing predictions on the long-term effects of climate change, many scenarios indicate that there will be a drop in water levels (COSEWIC 2007). Impacts of decreased water levels will be particularly important to those freshwater mussel populations occupying the shallow sand flats of the St. Clair River delta (COSEWIC 2007). It is predicted that decreases in water levels will either cause the freshwater mussels in this area to become locally extinct, or force their movement into deeper waters where they are likely to be out-competed by Zebra Mussel. Since the effects of climate change on freshwater mussels are speculative, it is difficult to determine the likelihood and impact of this threat on each population; therefore, the threat of climate change is not included in the following population-specific Threat Level analysis.

THREAT LEVEL

Each threat was ranked in terms of the Threat Likelihood and Threat Impact for all locations where it is believed that a population of Eastern Pondmussel, Fawnsfoot, Mapleleaf or Rainbow may exist. The criteria used to determine whether a site would be included in the Population Status assessment, in that only locations where one or more live individuals, fresh whole shells or fresh valves were recorded since 1990 (i.e., post-Zebra Mussel invasion) were included in the assessment, was also applied to the Threat Level analysis. The only exception to this rule was Mapleleaf in the Red River. A detailed explanation of why this site is included can be found under the Population Status heading. The Threat Likelihood was assigned as Known, Likely, Unlikely, or Unknown, and the Threat Impact was assigned as High, Medium, Low, or Unknown (Table 5, 6). Threat Likelihood was classified for the extent of the known distribution of any of the four listed mussel species for each location. If location-specific information was not available, knowledge of the threat throughout the watershed was applied. Location-specific information was used to categorize the Threat Impact for each location. If location-specific information was not available the highest Threat Impact ranking for all known locations was used. If more than one species was found in the same location, the Threat Impact for that location may be all species present at that location. In situations were the biology differs between mussel species, or that various mussel species are thought to be impacted at different levels by the same threat, the Threat Impact was separated by species. Certainty of the Threat Impact was classified and is based on: 1= causative studies; 2=correlative studies; and, 3=expert opinion. The Threat Likelihood and Threat Impact for each location were subsequently combined in the Threat Level matrix (Table 7) resulting in the final Threat Level for each location (Table 8).

It should be noted that the Great Lakes and their connecting channels were not considered in the Threat Level evaluation, as it has been shown that these areas have been devastated by the introduction of Zebra Mussel and it is highly unlikely that these areas will be the focus of any recovery efforts.

Table 5. *Definition of terms used to describe Threat Likelihood and Threat Impact.*

Term	Definition
Threat Likelihood	
Known (K)	This threat has been recorded to occur at site X.
Likely (L)	There is a > 50% chance of this threat occurring at site X.
Unlikely (U)	There is a < 50% chance of this threat occurring at site X.
Unknown (UK)	There are no data or prior knowledge of this threat occurring at site X.
Threat Impact	
High (H)	If threat was to occur, it would jeopardize the survival or recovery of this population.
Medium (M)	If threat was to occur, it would likely jeopardize the survival or recovery of this population.
Low (L)	If threat was to occur, it would be unlikely to jeopardize the survival or recovery of this population.
Unknown (UK)	There is no prior knowledge, literature or data to guide the assessment of the impact if it were to occur.

Table 6. *Threat Likelihood and Threat Impact for all locations in Canada where it is believed that a population of Eastern Pondmussel (EPM), Fawnsfoot (FF), Mapleleaf (ML) or Rainbow (RB) may exist. The Threat Likelihood was assigned as Known (K), Likely (L), Unlikely (U), or Unknown (UK), and the Threat Impact was assigned as High (H), Medium (M), Low (L), or Unknown (UK). Certainty is associated with Threat Impact (TI) and is based on the best available data (1= causative studies; 2=correlative studies; and 3=expert opinion). References (Ref) are provided and the complete list of references appears subsequent to the table. Species presence is indicated for each location by means of species code, which appears below the site name. Gray cells indicate that the threat is not applicable to the population due to the nature of the aquatic system where the site is located. Locations appear based on the geographical location (west to east).*

Manitoba

	Assiniboine River				Red River				Roseau River				Bloodvein River			
	ML				ML				ML				ML			
	TLH	TI	C	Ref	TLH	TI	C	Ref	TLH	TI	C	Ref	TLH	TI	C	Ref
Exotic species	U	H	3	24,25	L	H	3	25	U	H	3	25	U	H	3	25
Turbidity and sediment loading	K	M	3	8,25	K	M	3	8,24	K	M	3	8	U	M	3	12,24
Contaminants and toxic substances	K	H	3	8	K	H	3	8	U	H	3	8,25	U	H	3	12,24
Nutrient loading	K	L	3	8	K	M	3	8,25	K	M	3	8,25	U	L	3	12
Altered flow regimes	K	M	3	12	K	M	3	12,25	U	M	3	25				
Habitat removal and alterations	K	M	3	12,25	K	M	3	12,25	U	M	3	12	U	M	3	12
Fish hosts (EPM)																
Fish hosts (ML)	U	H	3	8,24	U	H	3	8,24	U	H	3	8,24	U	L	3	12
Fish hosts (FF)																
Fish hosts (RB)																
Predation and harvesting	U	M	3	8,24	U	L	3	12,25	U	L	3	12	U	L	3	12,24
Recreational activities	U	L	3	24	K	L	3	24	K	L	3	25	K	L	3	12

Ontario

	Ruscom River				St. Clair River delta				St. Clair River delta			
	ML				ML, FF				EPM, RB			
	TLH	TI	C	Ref	TLH	TI	C	Ref	TLH	TI	C	Ref
Exotic species	K	H	2	14,16	K	H	2	1,17	K	H	2	1,17
Turbidity and sediment loading	K	M	3	15,24	U	M	3	1	U	H	3	1
Contaminants and toxic substances	K	H	3	15	K	H	3	24	K	H	3	24
Nutrient loading	K	M	3	15	U	M	3	24	U	H	3	24
Altered flow regimes	K	M	3	15,24								
Habitat removal and alterations	L	H	3	14,24	U	H	3	24	U	H	3	24
Fish hosts (EPM)					U	H	3	24	U	H	3	24
Fish hosts (ML)	U	H	3	14	U	H	3	24	U	H	3	24
Fish hosts (FF)					U	H	3	24	U	H	3	24
Fish hosts (RB)					K	H	3	24	K	H	3	24
Predation and harvesting	UK	L	3	14	U	L	3	24	U	L	3	24
Recreational activities	UK	L	3	14	K	L	3	1	K	L	3	1

Ontario (continued)

	Sydenham River				Sydenham River				Upper Thames River			
	RB				ML,FF				RB			
	TLH	TI	C	Ref	TLH	TI	C	Ref	TLH	TI	C	Ref
Exotic species	U	H	2	16,23,24	U	H	2	16,23,24	L	H	2	24
Turbidity and sediment loading	K	H	3	6,8,13,24	K	M	3	6,8,13,24	K	H	3	6,13
Contaminants and toxic substances	K	H	3	6,13,24	K	H	3	6,13,24	K	H	3	6,13
Nutrient loading	K	H	3	6,8,13,24	K	M	3	6,8,13,24	K	H	3	6,13
Altered flow regimes	K	M	3	8	K	M	3	8	K	H	3	13,24
Habitat removal and alterations	K	H	3	24	K	H	3	24	K	H	3	24
Fish hosts (EPM)												
Fish hosts (ML)	U	H	3	24	U	H	3	24	U	H	3	24
Fish hosts (FF)	U	H	3	23	U	H	3	23	U	H	3	24
Fish hosts (RB)	K	H	3	24	K	H	3	24	L	H	3	24
Predation and harvesting	U	L	3	24	U	L	3	24	U	L	3	24
Recreational activities	K	L	3	24	K	L	3	24	K	L	3	24

	Lower Thames River				Ausable River				Ausable River			
	ML,FF				RB				ML			
	TLH	TI	C	Ref	TLH	TI	C	Ref	TLH	TI	C	Ref
Exotic species	K	H	2	7,9,16	U	H	2	10,16	U	H	2	10,16
Turbidity and sediment loading	K	M	3	24	K	H	3	6,8,10, 11,24	K	M	3	6,8,10, 11,24
Contaminants and toxic substances	K	H	3	24	K	H	3	6,10	K	H	3	6,10
Nutrient loading	K	M	3	24	K	H	3	6,10, 11,24	K	M	3	6,10, 11,24
Altered flow regimes	K	M	3	24	K	M	3	11	K	M	3	11
Habitat removal and alterations	K	H	3	24	U	H	3	10,24	U	H	3	10,24
Fish hosts (EPM)												
Fish hosts (ML)	U	H	3	24	U	H	2	10	U	H	2	10
Fish hosts (FF)	U	H	3	24								
Fish hosts (RB)	L	H	3	24	U	H	2	10	U	H	2	10
Predation and harvesting	U	L	3	24	U	L	3	10,24	U	L	3	10,24
Recreational activities	K	L	3	24	K	L	3	10,24	K	L	3	10,24

Ontario (continued)

	Bayfield River				Bayfield River				Maitland River			
	RB				ML				RB			
	TLH	TI	C	Ref	TLH	TI	C	Ref	TLH	TI	C	Ref
Exotic species	U	H	2	10	U	H	2	10	U	H	2	16
Turbidity and sediment loading	K	H	3	6,10,24	K	M	3	6,10,24	K	H	3	6,13
Contaminants and toxic substances	K	H	3	6,10	K	H	3	6,10	K	H	3	6,13
Nutrient loading	K	H	3	6,22,24	K	M	3	6,22,24	K	H	3	6,13
Altered flow regimes	K	H	3	10,24	K	H	3	10,24	L	M	3	24
Habitat removal and alterations	U	H	3	10	U	H	3	10	L	M	3	24
Fish hosts (EPM)												
Fish hosts (ML)	U	H	3	10	U	H	3	10				
Fish hosts (FF)												
Fish hosts (RB)	U	H	3	10	U	H	3	10	U	H	3	24
Predation and harvesting	U	L	3	10,24	U	L	3	10,24	U	L	3	24
Recreational activities	K	L	3	10,24	K	L	3	10,24	K	L	3	24

	Saugeen River				Long Point Bay				Grand River			
	RB,FF				EPM				RB			
	TLH	TI	C	Ref	TLH	TI	C	Ref	TLH	TI	C	Ref
Exotic species	U	H	2	16,24	K	H	2	16	L	H	2	16,24
Turbidity and sediment loading	K	H	3	6,24	U	H	3	24	K	H	2	6,8,13,21,24
Contaminants and toxic substances	K	H	3	6,24	U	H	3	24	K	H	2	6,8,13,24
Nutrient loading	K	H	3	6,13	U	H	3	24	K	H	2	2,3,4,6,8,24
Altered flow regimes	L	M	3	24					K	M	2	5,24
Habitat removal and alterations	K	H	3	24	U	H	3	24	K	H	2	24
Fish hosts (EPM)					U	H	3	24				
Fish hosts (ML)												
Fish hosts (FF)	*											
Fish hosts (RB)	L	H	3	24					K	H	3	20,24
Predation and harvesting	U	L	3	24	U	L	3	24	U	L	3	24
Recreational activities	U	L	3	24	U	L	3	24	K	L	3	24

* Known fish host for Fawnsfoot (Freshwater Drum) does not occur in this system.

Ontario (continued)

	Grand River				Grand River				Jordan Harbour			
	FF,ML				EPM				ML			
	TLH	TI	C	Ref	TLH	TI	C	Ref	TLH	TI	C	Ref
Exotic species	K	H	2	16,24	U	H	2	16,24	K	H	2	16
Turbidity and sediment loading	K	M	2	6,8,13, 21,24	K	H	2	6,8,13, 21,24	K	M	3	26
Contaminants and toxic substances	K	H	2	6,8, 13,24	K	H	2	6,8, 13,24	K	H	3	26,27
Nutrient loading	K	M	2	2,3,4, 6,8,24	K	H	2	2,3,4, 6,8,24	K	M	3	26,27
Altered flow regimes	K	M	2	5,24	K	M	2	5,24				
Habitat removal and alterations	K	H	2	24	K	H	2	24	U	H	3	26
Fish hosts (EPM)					U	H	3	24				
Fish hosts (ML)	K	H	3	20,24					U	H	3	26
Fish hosts (FF)	K	H	3	20,24								
Fish hosts (RB)												
Predation and harvesting	K	L	3	24	K	L	3	24	U	L	3	26
Recreational activities	K	L	3	24	K	L	3	24	U	L	3	26

	Welland River				Trent River				Salmon River			
	ML				RB				RB			
	TLH	TI	C	Ref	TLH	TI	C	Ref	TLH	TI	C	Ref
Exotic species	U	H	2	16	K	H	2	16,18	L	H	2	16,18,19
Turbidity and sediment loading	K	M	3	26	U	H	3	6,24	U	H	3	6,19
Contaminants and toxic	K	H	3	26,27	L	H	3	6,13	U	H	3	6,13,18
Nutrient loading	K	M	3	26,27	U	H	3	6,24	U	H	3	6,19
Altered flow regimes	U	M	3	26	K	H	3	18,24	K	L	3	18,24
Habitat removal and alterations	U	H	3	26	K	H	3	24	U	H	3	19,24
Fish hosts (EPM)												
Fish hosts (ML)	U	H	3	26								
Fish hosts (FF)												
Fish hosts (RB)					K	H	3	24	U	H	3	19
Predation and harvesting	U	L	3	26	UK	L	3	24	U	L	3	19
Recreational activities	K	L	3	26	K	L	3	24	UK	L	3	24

Ontario (continued)

	Moira River				Beaver Lake				Lyn Creek			
	RB				EPM				EPM			
	TLH	TI	C	Ref	TLH	TI	C	Ref	TLH	TI	C	Ref
Exotic species	L	H	2	16,18	K	H	2	24	U	H	2	16,19
Turbidity and sediment loading	U	H	3	6,18	U	H	3	24	U	H	3	19
Contaminants and toxic	L	H	3	6,13,19	UK	H	3	24	U	H	3	19
Nutrient loading	U	H	3	6,24	UK	H	3	24	U	H	3	19
Altered flow regimes	K	M	3	24					U	M	3	19
Habitat removal and alterations	U	H	3	24	U	H	3	24	U	H	3	24
Fish hosts (EPM)					U	H	3	24	U	H	3	19,24
Fish hosts (ML)												
Fish hosts (FF)												
Fish hosts (RB)	U	H	3	24								
Predation and harvesting	U	L	3	24	U	L	3	24	U	L	3	19
Recreational activities	K	L	3	24	K	L	3	24	U	L	3	19

References:

1. COSEWIC (2007) (EPM)
2. Mackie (1996)
3. Morris (2006) (WRLM RS)
4. Morris *et al.* (2008)
5. COSEWIC (2010) (WRLM)
6. Strayer and Fetterman (1999)
7. Maskant (2004) *in* COSEWIC (2006a)
8. COSEWIC (2006a) (ML)
9. COSEWIC (2008) (FF)
10. K. Jean, ABCA, pers. comm.
11. Nelson *et al.* (2003)
12. D. Watkinson, DFO, pers. comm.
13. COSEWIC (2006b) (RB)
14. M. Nelson, Essex Region Conservation Authority (ERCA), pers. comm.
15. Proposed Assessment Report, ERCA (unpubl. data)
16. Strayer (1999)
17. Zanatta *et al.* (2002)
18. S. Reid, Ontario Ministry of Natural Resources, pers. comm.
19. F. Schueler, Bishops Mills Natural History Centre pers. comm.
20. J. Wright, Grand River Conservation Authority (GRCA), pers. comm.
21. Water Quality Branch (1989a)
22. Veliz *et al.* (2007)
23. M. Andreae, St. Clair Region Conservation Authority, pers. comm.
24. 4 Mussel Recovery Potential Assessment Participants, Burlington Art Centre, 19-20 October 2010
25. J. Carney, Lakehead University, pers. comm.
26. J. Baker, Niagara Region Conservation Authority, pers. comm.
27. Niagara Peninsula Conservation Authority (2010)

Table 7. *The Threat Level matrix combines the Threat Likelihood and Threat Impact rankings to establish the Threat Level for each location in Canada where it is believed that a reproducing population of Eastern Pondmussel (EPM), Fawnsfoot (FF), Mapleleaf (ML) or Rainbow (RB) may exist. The resulting Threat Level has been categorized as Poor, Fair, Good, or Unknown.*

		Threat Impact			
		Low (L)	**Medium (M)**	**High (H)**	**Unknown (UK)**
Threat Likelihood	**Known (K)**	Low	Medium	High	Unknown
	Likely (L)	Low	Medium	High	Unknown
	Unlikely (U)	Low	Low	Medium	Unknown
	Unknown (UK)	Unknown	Unknown	Unknown	Unknown

Table 8. *Threat Level for all location in Canada where it is believed that a population of Eastern Pondmussel (EPM), Fawnsfoot (FF), Mapleleaf (ML) or Rainbow (RB) may exist resulting from an analysis of both the Threat Likelihood and Threat Impact. The number in brackets refers to the level of certainty assigned to each Threat Level, which relates to the level of certainty associated with Threat Impact. Certainty has been classified as: 1= causative studies; 2=correlative studies; and 3=expert opinion. Gray cells indicate that the threat is not applicable to the location due to the nature of the aquatic system. Clear cells do not necessarily represent a lack of a relationship between a location and a threat; rather, they indicate that either the Threat Likelihood or Threat Impact was Unknown.*

Manitoba

	Assiniboine River	Red River	Roseau River	Bloodvein River
Threat	**ML**	**ML**	**ML**	**ML**
Exotic species	Medium (3)	High (3)	Medium (3)	Medium (3)
Turbidity and sediment loading	Medium (3)	Medium (3)	Medium (3)	Low (3)
Contaminants and toxic substances	High (3)	High (3)	Medium (3)	Medium (3)
Nutrient loading	Low (3)	Medium (3)	Medium (3)	Low (3)
Altered flow regimes	Medium (3)	Medium (3)	Low (3)	
Habitat removal and alterations	Medium (3)	Medium (3)	Low (3)	Low (3)
Fish hosts (EPM)				
Fish hosts (ML)	Medium (3)	Medium (3)	Medium (3)	Low (3)
Fish hosts (FF)				
Fish hosts (RB)				
Predation and harvesting	Low (3)	Low (3)	Low (3)	Low (3)
Recreational activities	Low (3)	Low (3)	Low (3)	Low (3)

Ontario

	Ruscom River	St. Clair River Delta	St. Clair River Delta	Sydenham River
Threat	**ML**	**ML, FF**	**EPM, RB**	**RB**
Exotic species	High (2)	High (2)	High (2)	Medium (2)
Turbidity and sediment loading	Medium (3)	Low (3)	Medium (3)	High (3)
Contaminants and toxic substances	High (3)	High (3)	High (3)	High (3)
Nutrient loading	Medium (3)	Low (3)	Medium (3)	High (3)
Altered flow regimes	Medium (3)			Medium (3)
Habitat removal and alterations	High (3)	Medium (3)	Medium (3)	High (3)
Fish hosts (EPM)		Medium (3)	Medium (3)	
Fish hosts (ML)	Medium (3)	Medium (3)	Medium (3)	Medium (3)
Fish hosts (FF)		Medium (3)	Medium (3)	Medium (3)
Fish hosts (RB)		High (3)	High (3)	High (3)
Predation and harvesting	Unknown (3)	Low (3)	Low (3)	Low (3)
Recreational activities	Unknown (3)	Low (3)	Low (3)	Low (3)

Ontario (continued)

Threat	Sydenham River ML,FF	Upper Thames River RB	Lower Thames River ML,FF	Ausable River RB
Exotic species	Medium (2)	High (2)	High (2)	Medium (2)
Turbidity and sediment loading	Medium (3)	High (3)	Medium (3)	High (3)
Contaminants and toxic substances	High (3)	High (3)	High (3)	High (3)
Nutrient loading	Medium (3)	High (3)	Medium (3)	High (3)
Altered flow regimes	Medium (3)	High (3)	Medium (3)	Medium (3)
Habitat removal and alterations	High (3)	High (3)	High (3)	Medium (3)
Fish hosts (EPM)				
Fish hosts (ML)	Medium (3)	Medium (3)	Medium (3)	Medium (2)
Fish hosts (FF)	Medium (3)	Medium (3)	Medium (3)	
Fish hosts (RB)	High (3)	High (3)	High (3)	Medium (2)
Predation and harvesting	Low (3)	Low (3)	Low (3)	Low (3)
Recreational activities	Low (3)	Low (3)	Low (3)	Low (3)

Threat	Ausable River ML	Bayfield River RB	Bayfield River ML	Maitland River RB
Exotic species	Medium (2)	Medium (2)	Medium (2)	Medium (2)
Turbidity and sediment loading	Medium (3)	High (3)	Medium (3)	High (3)
Contaminants and toxic substances	High (3)	High (3)	High (3)	High (3)
Nutrient loading	Medium (3)	High (3)	Medium (3)	High (3)
Altered flow regimes	Medium (3)	High (3)	High (3)	Medium (3)
Habitat removal and alterations	Medium (3)	Medium (3)	Medium (3)	Medium (3)
Fish hosts (EPM)				
Fish hosts (ML)	Medium (2)	Medium (3)	Medium (3)	
Fish hosts (FF)				
Fish hosts (RB)	Medium (2)	Medium (3)	Medium (3)	Medium (3)
Predation and harvesting	Low (3)	Low (3)	Low (3)	Low (3)
Recreational activities	Low (3)	Low (3)	Low (3)	Low (3)

Ontario (continued)

Threat	Saugeen River RB,FF	Long Point Bay EPM	Grand River RB	Grand River FF,ML
Exotic species	Medium (2)	High (2)	High (2)	High (2)
Turbidity and sediment loading	High (3)	Medium (3)	High (2)	Medium (2)
Contaminants and toxic substances	High (3)	Medium (3)	High (2)	High (2)
Nutrient loading	High (3)	Medium (3)	High (2)	Medium (2)
Altered flow regimes	Medium (3)		Medium (2)	Medium (2)
Habitat removal and alterations	High (3)	Medium (3)	High (2)	High (2)
Fish hosts (EPM)		Medium (3)		
Fish hosts (ML)				High (3)
Fish hosts (FF)				High (3)
Fish hosts (RB)	High (3)		High (3)	
Predation and harvesting	Low (3)	Low (3)	Low (3)	Low (3)
Recreational activities	Low (3)	Low (3)	Low (3)	Low (3)

Threat	Grand River EPM	Jordan Harbour ML	Welland River ML	Trent River RB
Exotic species	Medium (2)	High (2)	Medium (2)	High (2)
Turbidity and sediment loading	High (2)	Medium (3)	Medium (3)	Medium (3)
Contaminants and toxic substances	High (2)	High (3)	High (3)	High (3)
Nutrient loading	High (2)	Medium (3)	Medium (3)	Medium (3)
Altered flow regimes	Medium (2)		Low (3)	High (3)
Habitat removal and alterations	High (2)	Medium (3)	Medium (3)	High (3)
Fish hosts (EPM)	Medium (3)			
Fish hosts (ML)		Medium (3)	Medium (3)	
Fish hosts (FF)				
Fish hosts (RB)				High (3)
Predation and harvesting	Low (3)	Low (3)	Low (3)	Unknown (3)
Recreational activities	Low (3)	Low (3)	Low (3)	Low (3)

Ontario (continued)

Threat	Salmon River RB	Moira River RB	Beaver Lake EPM
Exotic species	High (2)	High (2)	High (2)
Turbidity and sediment loading	Medium (3)	Medium (3)	Medium (3)
Contaminants and toxic substances	Medium (3)	High (3)	Unknown (3)
Nutrient loading	Medium (3)	Medium (3)	Unknown (3)
Altered flow regimes	Low (3)	Medium (3)	
Habitat removal and alterations	Medium (3)	Medium (3)	Medium (3)
Fish hosts (EPM)			Medium (3)
Fish hosts (ML)			
Fish hosts (FF)			
Fish hosts (RB)	Medium (3)	Medium (3)	
Predation and harvesting	Low (3)	Low (3)	Low (3)
Recreational activities	Unknown (3)	Low (3)	Low (3)

N.B. The Threat Level represents a combination of the current Threat Impact and Threat Likelihood at a location. It does not reflect the potential impact a threat might have on a freshwater mussel population if it was allowed to occur in the future.

MITIGATIONS AND ALTERNATIVES

Numerous threats affecting mussel populations are related to habitat loss or degradation. DFO – Fish Habitat Management has developed generic mitigation measures for 19 Pathways of Effects for the protection of aquatic species at risk in the Ontario Great Lakes Area (Table 9; Coker *et al.* 2010). Additional mitigation and alternative measures related to the introduction of exotic species, disruptions to the mussel-fish host relationship, predation and harvesting, and recreational activities are discussed.

Table 9. *Threats to freshwater mussel populations and the Pathways of Effect associated with each threat. 1 - Vegetation clearing; 2 – Grading; 3 – Excavation; 4 – Use of explosives; 5 – Use of industrial equipment; 6 – Cleaning or maintenance of bridges or other structures; 7 – Riparian planting; 8 – Streamside livestock grazing; 9 – Marine seismic surveys; 10 – Placement of material or structures in water; 11 – Dredging; 12 – Water extraction; 13 – Organic debris management; 14 – Wastewater management; 15 – Addition or removal of aquatic vegetation; 16 – Change in timing, duration and frequency of flow; 17 – Fish passage issues; 18 – Structure removal; 19 – Placement of marine finfish aquaculture site.*

Threats	Pathway(s)
Turbidity and sediment loading	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 18
Contaminants and toxic substances	1, 4, 5 ,6 ,7 ,11 ,12 ,13 ,14, 15, 16 ,18
Nutrient loading	1, 4, 7, 8, 11, 12, 13, 14, 15, 16
Altered flow regimes	10, 11, 12, 16, 18
Habitat removal and alteration	1, 2, 3, 4, 5, 7, 8, 10, 11, 13, 14, 15, 16, 18
Fish hosts (barriers to movement)	10, 16, 17

EXOTIC SPECIES
As discussed in the ‘Threats’ section, exotic species introduction and establishment could have negative effects on freshwater mussel populations.

Mitigation
- Evaluate the likelihood that a waterbody will be invaded by exotic species.
- Watershed monitoring for the presence and abundance of exotic species that may negatively affect freshwater mussel populations, or negatively affect preferred habitat of freshwater mussels.
- Develop and implement plans to address potential risks, impacts, and proposed actions if monitoring detects the arrival or establishment of an exotic species.
- Introduce a public awareness campaign on proper boat cleaning methods when transferring boats from an infested waterway.
- Restrict the use of boats in areas particularly susceptible to Zebra Mussel introduction and infestation (i.e., reservoirs in the Thames and Grand rivers).

Alternatives
- Unauthorized introductions
    - None.
- Authorized introductions
    - Do not carry out introduction where freshwater mussel populations are known to exist.

FISH HOSTS
As discussed in the ‘Threats’ section, increased siltation may be limiting the host’s ability to visually locate the displaying mussel, impeding the transfer of glochidia from the mussel to the fish host. If decreases in visibility resulting from increased siltation are found to be a limiting factor in reproductive success, mitigation pathways related to increased siltation should be implemented (Coker *et al.* 2010).

In addition, decreases in the number of individual host fish or decreases in the area of overlap between host fish and freshwater mussel may be decreasing the likelihood that a fish-mussel encounter will occur.

Mitigation
- Implement a management plan for the appropriate fish host species. This would increase the host’s survival, increasing number of host individuals, creating a healthy host population and subsequently increasing the likelihood that the fish host would encounter a gravid freshwater mussel.
- Immediate release of host fish if caught angling in areas where freshwater mussels of concern are known to occur. Please see distribution maps for each mussel species in the individuals ‘Current Status’ sections and discussion of verified and potential fish hosts in the ‘Habitat Requirements’ section.
- Watershed monitoring, risk assessment, and action plan implementation of potential exotics that may affect the fish hosts. The same steps as proposed above for exotic species should be implemented.

Alternatives

- Seasonal or zonal restrictions applied to fish species known to be used as a host to Eastern Pondmussel, Fawnsfoot, Mapleleaf or Rainbow glochidia.

PREDATION AND HARVESTING

As discussed in the 'Threats' section, muskrat, mink and raccoon may have negative effects on freshwater mussel populations. It should be considered that if this threat was to occur, it would be localized, and have a relatively small impact on the freshwater mussel population. In addition, human harvesting for consumption was also noted as a potential threat to freshwater mussels.

Mitigation

- If predators were identified at a local scale to have an impact on a freshwater mussel population, predator control should be considered.
- A public awareness campaign on the negative effects of freshwater mussel consumption on humans should be introduced.
- Enforcement should be increased in areas where human consumption of freshwater mussels is known to occur.

Alternatives

- None.

RECREATIONAL ACTIVITIES

As discussed in the 'Threats' section, recreational activities such as driving all-terrain vehicles (ATVs) through streams, boating, fly-fishing, beach cleaning, canoeing, and kayaking may negatively impact mussel beds

Mitigation

- Introduction of a public awareness campaign on the negative effects of the above-listed recreational activities on freshwater mussels.

Alternatives

- None.

SOURCES OF UNCERTAINTY

Despite concerted efforts to increase our knowledge of Eastern Pondmussel, Fawnsfoot, Mapleleaf and Rainbow populations in Canada, there are still areas of uncertainty related to their life history. Areas of future research should include studies on natural mortality rates, glochidial attachment times, and the threats limiting the survival of freshwater mussels.

Areas of particular uncertainty are related to the juvenile life stage. Very little information is available regarding the preferred habitat of juvenile freshwater mussels and the survival of individuals from the glochidial stage up to, and including, the juvenile life stage. In addition, it is very difficult to obtain gravid females in the field which would provide increased knowledge on fecundity and reproductive capacity. Furthermore, locating gravid females would also allow for fish host experiments on species in which this relationship has yet to be studied.

Additional studies on habitat requirements are imperative to determine critical habitat for all life stages of these freshwater mussels. Additional studies on the preferred habitat of these species may also help to determine possible candidate areas for relocation. Additionally, field work should be completed in all locations where only a few individuals have been located to determine whether or not a reproducing population exists, and if so, to determine the species density at that location. As well, additional quantitative field work should be completed in areas that have yet to be examined. There is a need for additional inventory work which would inform the population status assessment. This type of work is particularly important in Manitoba, eastern Ontario, and the lower portion of many of the major southwestern Ontario rivers where there has been very limited sampling.

Supplementary laboratory experiments, and if feasible field experiments, should be completed to determine fish hosts for all freshwater mussel species currently at risk. For example, the fish host for Fawnsfoot is thought to be Freshwater Drum based on information available from southern populations. Laboratory experiments, using samples from Canadian populations, should be completed to verify the usage of Freshwater Drum as fish host for Fawnsfoot. Also, Channel Catfish has been verified as the fish host for Mapleleaf, and it has been suggested that other members of the catfish family present in Canada [e.g., Brown Bullhead, (*Ameiurus nebulosus*)] may also be acting as a host. The potential relationship between Mapleleaf and other members of the catfish family should be tested. Many of the fish hosts for Rainbow have been verified in the United States. Currently in Canada, only Rock Bass, Largemouth Bass, and Mottled Sculpin have been verified as a successful host during laboratory experiments. Glochidial attachment experiments should be completed for all other potential Rainbow fish hosts. Once a host has been identified for a species, it is important to determine its distribution, abundance and the overall health of the population of the fish host. Knowledge of the fish hosts that these freshwater mussel species at risk use during their obligate glochidial stage may help provide insight on reasons for their decline. It is necessary to determine host distribution and abundance, and to quantify the amount of overlap between the mussel and host fish populations.

Numerous threats have been identified for Eastern Pondmussel, Fawnsfoot, Mapleleaf and Rainbow populations in Canada, although the severity of these threats is currently unknown. There is a need for more causative studies to evaluate the impact of each threat on each population with greater certainty. In the literature, the threat impacts are generally discussed at a broad level (i.e., mussel community level). It is important to further our knowledge on threat likelihood and impact at the species level. Research is currently underway to determine the direct and indirect effects that Round Goby *(Neogobius melanostomus*) may have on native freshwater mussels. This type of species-specific threat research of exotic species on native mussels is needed to better inform decisions on the management of exotic species. Although predation is listed as a potential threat to native mussels, the level of predation by raccoons and other predators is currently unknown. Research is needed to determine the level to which native mussels are preyed on. Once we gain a better understanding on the level of predation, the distribution of predators should be compared to that of mussels of concern to determine the distributional overlap.

REFERENCES

Manitoba Conservation. 2000. Development of a Nutrient Management Strategy for Surface Waters in Southern Manitoba. Water Quality Management Section, Manitoba Conservation, Winnipeg, MB. Information Bulletin 2000-2E. 10 p.

ARRT (Ausable River Recovery Team). 2005. Recovery strategy for species at risk in the Ausable River: An ecosystem approach, 2005-2010. Draft Recovery Strategy submitted to RENEW Secretariat. 129 p.

Augspurger, T., A.E. Keller, M.C. Black, W.D. Cope, and F.J. Dwyer. 2003. Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. Environ. Toxicol. Chem. 22:2569-2575.

Baker, S.M. and D.J. Hornbach. 1997. Acute physiological effects of Zebra Mussel (*Dreissena polymorpha*) infestation on two unionid mussels, *Actinonaias ligamentina* and *Amblema plicata*. Can. J. Fish. Aquat. Sci. 54:512-519.

Bartsch, M.R., T.J. Newton, J.W. Allran, J.A. O'Donnel, and W.B. Richardson. 2003. Effects of pore-water ammonia on in situ survival and growth of juvenile mussels (*Lampsilis cardium*) in the St. Croix riverway, Wisconsin, USA. Environ. Toxicol. Chem. 22:2561-2568.

Bogan, A.E. 1993. Freshwater bivalve extinctions (Mollusca: Unionidae): A search for causes. Am. Zool. 33:599-609.

Bourne, A., N. Armstrong, and G. Jones. 2002. A preliminary estimate of total nitrogen and total phosphorus loading to streams in Manitoba, Canada. Water Quality Management Section. Manitoba Conservation Report No. 2002 - 04. 49 p.

Carney, J.P. 2003. Freshwater mussels (Mollusca: Unionidae) in the Assiniboine, Souris and Pembina Rivers, Manitoba: demographics, reproduction and parasitism. Data report submitted to the Province of Manitoba Conservation Data Centre. 56 p.

Carney, J.P. 2004. A survey of the freshwater mussel (Bivalvia: Unionidae) fauna of the Assiniboine River in Spruce Woods Provincial Park. Data report submitted to the Province of Manitoba Conservation Department and Manitoba Parks.14 p.

Clarke, A.H. 1973. The freshwater molluscs of the Canadian Interior Basin. Malacologia 13:1-509.

Clarke, A.H. 1981. The Freshwater Molluscs of Canada. National Museums of Canada, Ottawa, Ontario, Canada, 446 p.

Coker, G.A., D.L. Ming, and N.E. Mandrak 2010. Mitigation guide for the protection of fishes and fish habitat to accompany the species at risk recovery potential assessments conducted by Fisheries and Oceans Canada (DFO) in Central and Arctic Region. Version 1.0. Can. Manuscr. Rep. Fish. Aquat. Sci. 2904. vi + 40 p.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006a. COSEWIC assessment and status report on the Mapleleaf mussel, *Quadrula quadrula* (Saskatchewan - Nelson population and Great Lakes - Western St. Lawrence population) in Canada. vii + 58 p.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006b. COSEWIC assessment and update status report on the Rainbow mussel (*Villosa iris*) in Canada. vii + 38 p.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2007. COSEWIC assessment and update status report on the Eastern Pondmussel (*Ligumia nasuta*) in Canada. vii + 34 p.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2008. COSEWIC assessment and update status report on the Fawnsfoot (*Truncilla donaciformis*) in Canada. vii + 39 p.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2010. COSEWIC assessment and update status report on the Wavyrayed Lampmussel (*Lampsilis fasciola*) in Canada. xiv + 67 p.

Dextrase, A.J., S.K. Staton, and J.l. Metcalfe-Smith. 2003. National recovery strategy for species at risk in the Sydenham River: an ecosystem approach. National Recovery Plan No. 25. Recovery of Nationally Endangered Wildlife (RENEW). Ottawa, Ontario, Canada. 73 p.

DFO. 2007. Revised protocol for conducting recovery potential assessments. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/39.

DFO. 2010. Guidelines for terms and concepts used in the species at risk program. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/065.

Fuller, S.L.H. 1974. Clams and Mussels (Mollusca: Bivalvia). *In* Pollution Ecology of Freshwater Invertebrates. *Edited by* J. Hart, C.W. and S.L.H. Fuller. Academic Press, New York, NY., USA. p. 215-273.

GRCA Grand River Conservation Authority. 1997. State of the Grand River watershed. Focus on watershed issues 1996-1997.

GRCA (Grand River Conservation Authority). 1998. State of the watershed report: background report on the health of the Grand River watershed, 1996-97. 143 p.

Haag, W.R., D.J. Berg, D.W. Garton, and J.L. Farris. 1993. Reduced survival and fitness in native bivalves in response to fouling by the introduced Zebra Mussel (*Dreissena polymorpha*) in western Lake Erie. Can. J. Fish. Aquat. Sci. 50:13-19.

Jones, G. and N. Armstrong. 2001. Long-term trends in total nitrogen and total phosphorus concentrations in Manitoba streams. Water Quality Management Section, Water Branch, Manitoba Conservation, Winnipeg, MB. Manitoba Conservation Report No. 2001-07.154 p.

Kidd, B.T. 1973. Unionidae of the Grand River drainage, Ontario, Canada. Carleton University, Ottawa, Ontario. 172 p.

Lemmen, D.S. and F.J. Warren. 2004. Climate change impacts and adaptation: A Canadian perspective. Natural Resources Canada, Ottawa, Ontario, Canada. 174 p.

Mackie, G.L. 1991. Biology of the exotic Zebra Mussel, *Dreissena polymorpha*, in relation to native bivalves and its potential impact in Lake St. Clair. Hydrobiologia 219:251-268.

Mackie, G.L. 1996. Diversity and status of Unionidae (Bivalvia) in the Grand River, a tributary of Lake Erie, and its drainage basin. Prepared for Lands and Natural Heritage Branch, Ontario Ministry of Natural Resources, Peterborough, Ontario. 39 p.

McGoldrick, D.J., J.L. Metcalfe-Smith, D.W. Schloesser, T.J. Newton, M.T. Arts, G.L. Mackie, E.M. Monroe, J. Biberhofer, and K. Johnson. 2009. Characteristics of a refuge for native freshwater mussels (Bivalvia: Unionidae) in Lake St. Clair. J. Great Lakes Res. 35 137-146.

McNichols, K.A., D.T. Zanatta, C.C. Wilson, and J.D. Ackerman. 2008. Investigating research gaps for recovery of Unionid mussel species at risk in Canada. 2008/09 Final Report (Project # 1509). 2008 Final Report prepared for Endangered Species Recovery Fund, World Wildlife Canada. 23 p.

Meffe, G.K. and C.R. Carroll. 1997. Principles of Conservation Biology, 2nd ed. Sinauer Associates Inc. Sunderland Massachusetts, U.S.A., 729 p.

Metcalfe-Smith, J.L., S.K. Staton, G.L. Mackie, and N.M. Lane. 1998. Selection of candidate species of freshwater mussels (Bivalvia: Unionidae) to be considered for national status designation by COSEWIC. Can. Field-Nat. 112:425-440.

Metcalfe-Smith, J.L., G.L. Mackie, J. Di Maio, and S.K. Staton. 2000a. Changes over time in the diversity and distribution of freshwater mussels (Unionidae) in the Grand River, southwestern Ontario. J. Great Lakes Res. 26:445-459.

Metcalfe-Smith, J.L., S.K. Staton, and E.L. West. 2000b. Status of the Wavy-rayed Lampmussel, *Lampsilis fasciola* (Bivalvia: Unionidae), in Ontario and Canada. Can. Field-Nat. 114:457-470.

Metcalfe-Smith, J.L., J. Di Maio, S.K. Staton, and S.R. De Solla. 2003. Status of the freshwater mussel communities of the Sydenham River, Ontario, Canada. Am. Midl. Nat. 150:37-50.

Metcalfe-Smith, J.L., D.J. McGoldrick, M. Williams, D.W. Schloesser, J. Biberhofer, G.L. Mackie, M.T. Arts, D.T. Zanatta, K. Johnson, P. Marangelo, and T.D. Spencer. 2004. Status of a refuge for native freshwater mussels (Unionidae) from the impacts of the exotic Zebra Mussel (*Dreissena polymorpha*) in the delta area of Lake St. Clair. Technical Note, Environment Canada, National Water Research Institute, Burlington, Ontario, Canada. 47 p. + appendices.

Metcalfe-Smith, J.L., A. MacKenzie, I. Carmichael, and D.J. McGoldrick. 2005. Photo Field Guide to the Freshwater Mussels of Ontario. St. Thomas, Ontario, Canada. 60 p.

Metcalfe-Smith, J.L., D.J. McGoldrick, C.R. Jacobs, J. Biberhofer, M.T. Arts, G.L. Mackie, V.S. Jackson, D.W. Schloesser, T.J. Newton, E.M. Monroe, and M.D. Drebenstedt. 2007a. Creation of managed refuge sites for native freshwater mussels to mitigate impacts of the exotic Zebra Mussel in the delta area of Lake St. Clair. Environment Canada, Burlington, Ontario. Canada. vi + 50 p.

Metcalfe-Smith, J.L., D.J. McGoldrick, D.T. Zanatta, and L. Grapentine. 2007b. Development of a monitoring program for tracking the recovery of endangered freshwater mussels in the Sydenham River, Ontario. WSTD Contribution, Environment Canada, Water Science and Technology Directorate, Burlington, Ontario, Canada. 40 p. + appendices.

Morris, T.J. 2006. Recovery strategy for the Wavy-rayed Lampmussel (*Lampsilis fasciola*) in Canada. Species at Risk Act Recovery Strategy Series, Fisheries and Oceans Canada. viii + 43 p.

Morris, T.J. and A. Edwards. 2007. Freshwater mussel communities of the Thames River, Ontario: 2004-2005. Can. Manuscr. Rep. Fish. Aquat. Sci. 2810. v + 30 p.

Morris, T.J., D.J. McGoldrick, J.L. Metcalfe-Smith, D.T. Zanatta, and P.L. Gillis. 2008. Pre-COSEWIC assessment of the Wavyrayed Lampmussel (*Lampsilis fasciola*). DFO Can. Sci. Advis. Sec. Res. Doc. 2008/083. v + 39 p.

Mummert, A.K., R.J. Neves, T.J. Newcomb, and D.S. Cherry. 2003. Sensitivity of juvenile freshwater mussels (*Lampsilis fasciola*, *Villosa iris*) to total and un-ionized ammonia. Environ. Toxicol. Chem. 22:2545-2553.

Nalepa, T.F., B.A. Manny, J.C. Roth, S.C. Mozley, and D.W. Schloesser. 1991. Long-term decline in freshwater mussels (Bivalvia: Unionidae) of the western basin of Lake Erie. J. Great Lakes Res. 17:214-219.

Nalepa, T.F., D.J. Hartson, G.W. Gostenik, D.L. Fanslow, and G.A. Lang. 1996. Changes in the freshwater mussel community of Lake St. Clair from Unionidae to *Dreissena polymorpha* in eight years. J. Great Lakes Res. 22:354-369.

Nelson, M.. M. Veliz, S. Staton, and E. Dolmage. 2003. Towards a recovery strategy for species at risk in the Ausable River: Synthesis of background information. Final Report prepared for the Ausable River Recovery Team. 92 p.

Neves, R.J. and M.C. Odom. 1989. Muskrat predation on endangered freshwater mussels in Virginia. J. Wildl. Manage. 53:934-941.

NPCA (Niagara Peninsula Conservation Authority). 2010. Water Quality Monitoring Program 2009: Annual Report. Welland Ontario Canada. iii + 35 p.

Parmalee, P.W. and R.R. Polhemus. 2004. Prehistoric and pre-impoundment populations of freshwater mussels (Bivalvia: Unionidae) in the South Fork Holston River, Tennessee. Southeast. Nat. 3:231-240.

Reid, S.M. and N.E. Mandrak. 2006. Evaluation of potential impact of Springbank Dam restoration on Black Redhorse (*Moxostoma duquesnei*) and other sucker species in the Thames River. Can. Tech. Rep. Fish. Aquat. Sci. 2670:32 p.

Ricciardi, A., F.G. Whoriskey, and J.B. Rasmussen. 1996. Impact of the Dreissena invasion on native unionid bivalves in the upper St. Lawrence River. Can. J. Fish. Aquat.Sci. 53:1434-1444.

Scaife, B. and L. Janusz. 1992. A survey of freshwater mussels on the Assiniboine River, September 1992. Fisheries Branch MS Report No. 92-02, Manitoba Department of Natural Resources, Manitoba. 24 p.

Schloesser, D.W. and T.F. Nalepa. 1994. Dramatic decline of unionid bivalves in offshore waters of western Lake Erie after infestation by the Zebra Mussel, *Dreissena polymorpha*. Can. J. Fish. Aquat. Sci. 51:2234-2242.

Schloesser, D.W., T.F. Nalepa, and G.L. Mackie. 1996. Zebra Mussel infestation of unionid bivalves (Unionidae) in North America. Am. Zool. 36:300-310.

Schloesser, D.W., W.P. Kovalak, G.D. Longton, K.L. Ohnesorg, and R.D. Smithee. 1998. Impact of zebra and quagga mussels (*Dreissena spp.*) on freshwater unionids (Bivalvia: Unionidae) in the Detroit River of the Great Lakes. Am. Midl. Nat. 140:299-313.

Schloesser, D.W., J.L. Metcalfe-Smith, W.P. Kovalak, G.D. Longton, and R.D. Smithee. 2006. Extirpation of freshwater mussels (Bivalvia: Unionidae) following the invasion of dreissenid mussels in an interconnecting river of the Laurentian Great Lakes. Am. Midl. Nat. 155:307-320.

Schueler, F.W. 2008. A plan for continuing the Unionid survey of the Lyn/Jones Creek system (30 April 2008) & A plan for finding persisting *Ligumia nasuta* in habitats similar to that where it has been found in the Lyn/Golden Creek (23 June 2008). 10 p.

Schwebach, M., D. Schriever, V. Kanodia, N. Dillon, M. Hove, M. McGill, C. Nelson, J. Thomas, and A. Kapuscinski. 2002. Channel catfish is a suitable host for Mapleleaf glochidia. Ellipsaria 4:12-13.

Stansbery, D.H. 1961. The naiades (Mollusca, Pelecypoda, Unionacea) of Fishery Bay, South Bass Island, Lake Erie. Sterkiana 5:1-37.

Strayer, D.L. 1999. Effects of alien species on freshwater mollusks in North America. J. N. Am. Benthol. Soc. 18:74-98.

Strayer, D.L. and A.R. Fetterman. 1999. Changes in the distribution of freshwater mussels (Unionidae) in the upper Susquehanna River basin, 1955-1965 to 1996-1997. Am. Midl. Nat. 142:328-339.

Taylor, I., B. Cudmore, C. MacCrimmon, S. Madzia, and S. Hohn. 2004. The Thames River Watershed: Synthesis Report (draft). Prepared for the Thames River Recovery Team. 74 p.

Tiemann, J.S., H.R. Dodd, N. Owens, and D.H. Wahl. 2007. Effects of lowhead dams on unionids in the fox river, Illinois. Northeast. Nat. 14:125-138.

TRRT (Thames River Recovery Team). 2005. Recovery strategy of the Thames River aquatic ecosystem: 2005 - 2010. 146 p.

Tyrrell, M. and D.J. Hornbach. 1998. Selective predation by muskrats on freshwater mussels in 2 Minnesota rivers. J. N. Am. Benthol. Soc. 17:301-310.

UTRCA (Upper Thames River Conservation Authority). 2003. Zebra Mussels found in Fanshawe Reservoir.

Vaughn, C.C. and C.M. Taylor. 1999. Impoundments and the decline of freshwater mussels: A case study of an extinction gradient. Conserv. Biol. 13:912-920.

Veliz, M., H. Brock, and J. Neary. 2007. Ausable Bayfield Conservation Authority Watershed Report Card 2007. Ausable Bayfield Conservation Authority. Exeter, Ontario. 104 p.

Watson, E.T. 2000. Distribution and life history of the Unionidae (Bivalvia: Mollusca) in the Assiniboine River drainage in Manitoba, with special reference to *Anodontoides ferussacianus*. University of Manitoba, Winnipeg, Manitoba. 159 p.

Watters, G.T. 1996. Small dams as barriers to freshwater mussels (Bivalvia: Unionoida) and their hosts. Biol. Conserv. 75:79-85.

Watters, G.T. 2000. Freshwater mussels and water quality: A review of the effects of hydrologic and instream habitat alterations. First Freshwater Mollusk Conservation Society Symposium. Ohio Biological Survey. 261-274.

Watters, G.T. and S.H. O’Dee. 1997. Potential hosts for Villosa iris (Lea, 1829). Triannual Unionid Report. 12:7.

Watters, G.T. and S. O'Dee. 1999. Glochidia of the freshwater mussel *Lampsilis* overwintering on fish hosts. J. Mollus. Stud. 65:453-459.

Watters, G.T., S.H. O’Dee, and S. Chordas III. 2001. Patterns of vertical migration in freshwater mussels (Bivalvia: Unionidae). J. Freshwater Ecol. 16:541-549.

Williams, J.D., M.L. Warren, K.S. Cummings, J.L. Harris, and R.J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18:6-22.

Woolnough, D.A., K.A. McNichols, A.N. Schwalb, J.D. Ackerman, and G.L. Mackie. 2007. Endangered Unionid mussels in Ontario (ESR1 1350). Final report prepared for the Endangered Species Recovery Fund. 12 p.

WQB (Water Quality Branch). 1989a. The application of an interdisciplinary approach to the selection of potential water quality sampling sites in the Grand River basin. Environment Canada, Water Quality Branch, Ontario Region: 111 p.

WQB (Water Quality Branch). 1989b. The application of an interdisciplinary approach to the selection of potential water quality sampling sites in the Thames River basin. Environment Canada, Water Quality Branch, Ontario Region: 122 p.

Zanatta, D.T., G.L. Mackie, J.L. Metcalfe-Smith, and D.A. Woolnough. 2002. A refuge for native freshwater mussels (Bivalvia: Unionidae) from impacts of the exotic Zebra Mussel (*Dreissena polymorpha*) in Lake St. Clair. J. Great Lakes Res. 28:479-489.

Zanatta, D.T. and R.W. Murphy. 2006. Evolution of active host-attraction strategies in the freshwater mussel tribe Lampsilini (Bivalvia: Unionidae). Mol. Phylogenet. Evol. 41:195-208.