Species at Risk Act
Recovery Strategy Series

Recovery Strategy for the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean in Canada

Original publication **2006**
1st amendment **2019**

Fisheries and Oceans Canada
Pêches et Océans Canada
Canada

About the *Species at Risk Act* recovery strategy series

What is the *Species at Risk Act* (SARA)?

SARA is the Act developed by the federal government as a key contribution to the common national effort to protect and conserve species at risk in Canada. SARA came into force in 2003 and one of its purposes is *"to provide for the recovery of wildlife species that are extirpated, endangered or threatened as a result of human activity."*

What is recovery?

In the context of species at risk conservation, **recovery** is the process by which the decline of an endangered, threatened, or extirpated species is arrested or reversed and threats are removed or reduced to improve the likelihood of the species' persistence in the wild. A species will be considered **recovered** when its long-term persistence in the wild has been secured.

What is a recovery strategy?

A recovery strategy is a planning document that identifies what needs to be done to arrest or reverse the decline of a species. It sets goals and objectives and identifies the main areas of activities to be undertaken. Detailed planning is done at the action plan stage.

Recovery strategy development is a commitment of all provinces and territories and of three federal agencies — Environment and Climate Change Canada, Parks Canada Agency, and Fisheries and Oceans Canada — under the Accord for the Protection of Species at Risk. Sections 37-46 of SARA outline both the required content and the process for developing recovery strategies published in this series.

Depending on the status of the species and when it was assessed, a recovery strategy has to be developed within one to two years after the species is added to the List of Wildlife Species at Risk. Three to four years is allowed for those species that were automatically listed when SARA came into force.

What's next?

In most cases, one or more action plans will be developed to define and guide implementation of the recovery strategy. Nevertheless, directions set in the recovery strategy are sufficient to begin involving communities, land users, and conservationists in recovery implementation. Cost-effective measures to prevent the reduction or loss of the species should not be postponed for lack of full scientific certainty.

The series

This series presents the recovery strategies prepared or adopted by the federal government under SARA. New documents will be added regularly as species get listed and as strategies are updated.

To learn more

To learn more about the *Species at Risk Act* and recovery initiatives, please consult the SAR Public Registry.

Recovery Strategy for the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean in Canada

2019

Original publication date: 2006

1st amendment: 2019
Critical habitat identified

Previous versions of this Recovery Strategy can be found on the Species at Risk Public Registry

Recommended citation

DFO. 2019. Recovery Strategy For Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean in Canada. In *Species at Risk Act* Recovery Strategy Series. Ottawa: Fisheries and Oceans Canada. ix + 96 p.

Additional copies:

You can download additional copies from the SAR Public Registry

Cover illustration: Clockwise from upper left: male Northern Riffleshell, male Snuffbox, Round Pigtoe, Salamander Mussel, male Rayed Bean (centre). Images courtesy Environment and Climate Change Canada.

Également disponible en français sous le titre
«Programme de rétablissement de l'épioblasme ventrue, l'épioblasme tricorne, le pleurobème écarlate, la mulette du Necturus et la villeuse haricot au Canada»

ISBN 978-0-660-28196-4
Cat. no. En3-4/16-2019E-PDF

PREFACE

The federal, provincial, and territorial government signatories under the Accord for the Protection of Species at Risk (1996) agreed to establish complementary legislation and programs that provide for effective protection of species at risk throughout Canada. Under the *Species at Risk Act* (S.C. 2002, c.29) (SARA), the federal competent ministers are responsible for the preparation of recovery strategies for listed Extirpated, Endangered, and Threatened species and are required to report on progress within five years.

The Minister of Fisheries and Oceans is the competent minister for the recovery of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean and has prepared this strategy, as per section 37 of SARA. It has been prepared in cooperation and consultation with:

- Jurisdictions – Environment and Climate Change Canada, Ontario Ministry of Natural Resources and Forestry
- Aboriginal groups – Southern First Nations Secretariat, London Chiefs Council, Six Nations of the Grand, Chippewas of Stoney and Kettle Point, Aamjiwnaang First Nation, Chippewas of Sarnia, Caldwell First Nation, Moravian of Thames First Nation, Chippewas of the Thames, Oneida, Munsee-Delaware First Nation, Mississauga of New Credit First Nation, Metis Nation of Ontario
- Environmental non-government groups – Ausable-Bayfield Conservation Authority, Grand River Conservation Authority, Maitland Valley Conservation Authority, St. Clair Region Conservation Authority, Upper Thames River Conservation Authority, Lower Thames Valley Conservation Authority, University of Guelph, University of Toronto/Royal Ontario Museum, McMaster University, Iowa State University

Success in the recovery of these species depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in this strategy and will not be achieved by Fisheries and Oceans Canada, or any other jurisdiction alone. All Canadians are invited to join in supporting and implementing this strategy for the benefit of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean and Canadian society as a whole.

This recovery strategy will be followed by one or more action plans that will provide information on recovery measures to be taken by Fisheries and Oceans Canada and other jurisdictions and/or organizations involved in the conservation of these species. Implementation of this strategy is subject to appropriations, priorities, and budgetary constraints of the participating jurisdictions and organizations.

ACKNOWLEDGMENTS

Fisheries and Oceans Canada would like to thank the following authors: T.J. Morris, M. Burridge, K. McNichols-O'Rourke, S. Staton, A. Doherty, and A. Boyko. The following organizations, who had representatives on the Ontario Freshwater Mussel Recovery Team, offered their support in the development and/or updating of this recovery strategy: Environment and Climate Change Canada, Ontario Ministry of Natural Resources and Forestry, University of Guelph, University of Toronto/Royal Ontario Museum, McMaster University, Ausable-Bayfield Conservation Authority, Grand River Conservation Authority, Maitland Valley Conservation Authority, St. Clair Region Conservation Authority, Upper Thames River Conservation Authority, and Lower Thames Valley Conservation Authority. Maps produced by Adriana Rivas-Ruiz (Fisheries and Oceans Canada).

EXECUTIVE SUMMARY

Freshwater mussels are among the world's most imperilled taxa with declines reported on a global scale. The rich unionid fauna of North America has been hit particularly hard with over 70% of the approximately 300 species showing evidence of declines with many now considered rare, endangered, threatened or imperilled. Canada is home to 55 unionid species, 41 of which can be found in the province of Ontario with 18 species having Canadian distributions restricted to this province. The rivers of southwestern Ontario, primarily those draining into Lake St. Clair and Lake Erie, are home to the richest unionid assemblages in Canada. The Sydenham River has historically been considered to be the richest unionid river in all of Canada (Clarke 1992) with a total species count of 35; however, recent evidence suggests that the Thames River had an historical species count of 35 and the Grand River had an historical count of 34 species.

Threats to the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are many and varied. The main reason for the declines in lake populations, including the Lake St. Clair and Lake Erie populations, is the presence of the invasive Zebra Mussel. Zebra Mussel attach to the shells of native mussels and act to inhibit feeding, respiration, excretion and locomotion. Populations of Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean from river habitats are subject to different threats than lake populations, with the primary threats being declining water quality and the loss of habitat. The watersheds in southwestern Ontario, where Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are still found, are predominantly agricultural with high nutrient and sediment inputs to the watercourse from adjacent lands. The obligate parasitic nature of the reproductive cycle of these five species necessitates a consideration of threats to the host species as well as the direct threats to the mussel.

The original recovery strategy (finalized in 2006) was developed by the Ontario Freshwater Mussel Recovery Team; it was updated in 2012 by Fisheries and Oceans Canada to include the identification of critical habitat, and to update the species and distribution information, with further input from the recovery team.

The long-term goals of the strategy are:

i. To prevent the extirpation of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean in Canada;
ii. To maintain/return healthy self-sustaining Northern Riffleshell populations in the Ausable and Sydenham rivers, and to reintroduce healthy self-sustaining populations to the Thames River and the St. Clair River delta;
iii. To maintain/return healthy self-sustaining populations of Snuffbox in the Ausable and Sydenham rivers, and to reintroduce healthy self-sustaining populations to the Grand and Thames rivers;
iv. To maintain/return healthy self-sustaining populations of Round Pigtoe in the Sydenham River, Bear Creek, and the St. Clair River delta, and to reintroduce healthy self-sustaining populations to the Thames and Grand rivers;
v. To maintain/return healthy self-sustaining populations of Salamander Mussel in the Sydenham River; and,
vi. To maintain/return healthy self-sustaining populations of Rayed Bean in the Sydenham and Thames rivers.

These populations can only be considered recovered when they have returned to historically estimated ranges and/or population densities and are showing signs of reproduction and recruitment. The Detroit River, Lake St. Clair proper, Lake Erie and the Niagara River are specifically excluded from the recovery goal as these areas of the Great Lakes have been devastated by dreissenid mussels and no longer provide suitable habitat for freshwater mussels.

The following specific short-term recovery objectives have been identified to assist with meeting the long-term recovery goal:

i. Determine extent, abundance and population demographics of existing populations;
ii. Determine/confirm host fishes, their distributions and abundances;
iii. Define key habitat requirements to identify critical habitat;
iv. Establish a long-term monitoring program for the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean, their habitats and those of their hosts;
v. Identify threats, evaluate their relative impacts and implement remedial actions to reduce their effects;
vi. Examine the feasibility of relocations, reintroductions and artificial propagation; and,
vii. Increase awareness of the significance of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean and their status as a Canadian species at risk.

The recovery team has identified a variety of approaches that are necessary to ensure that the objectives are met. These approaches have been organized into four categories: Research and Monitoring, Management, Stewardship, and Awareness.

Using the best available information, critical habitat has been identified for riverine populations of the five mussel species within the following watersheds:

- Sydenham River (Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean)
- Ausable River (Northern Riffleshell and Snuffbox)
- Bear Creek (Round Pigtoe)
- Thames River (Round Pigtoe and Rayed Bean)
- Grand River (Round Pigtoe)

Additional areas of potential critical habitat for these species in the St. Clair River delta will be considered in collaboration with Walpole Island First Nation. A schedule of studies has been developed that outlines the necessary steps to obtain the information to further refine these critical habitat descriptions.

The approaches outlined in this strategy to achieve the recovery of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are best accomplished through cooperation with the existing ecosystem recovery teams. In watersheds with existing ecosystem teams, implementation of recovery actions should be coordinated to confirm that recovery activities are beneficial to all species at risk and to eliminate the possible duplication of efforts. Where ecosystem recovery teams are absent, Recovery Implementation Groups (RIGs) may be struck to facilitate the carrying out of recovery actions. Evaluation of the success of recovery actions will be achieved primarily through the routine monitoring programs established to track changes in population demographics and habitat quality and extent; however, RIGs will also incorporate specific milestones into an action plan(s) for the recovery strategy. The entire recovery strategy will be reported on every five years to evaluate the progress towards achieving the goals and objectives and to incorporate new information.

TABLE OF CONTENTS

INTRODUCTION

Freshwater mussels are among the world's most imperilled taxa with declines reported on a global scale (Bogan 1993; Lydeard et al. 2004). The rich unionid fauna of North America has been hit particularly hard with over 70% of the approximately 300 species showing evidence of declines with many now considered rare, endangered, threatened or imperilled (Allan and Flecker 1993; Williams et al. 1993). Canada is home to 55 unionid species, 41 of which can be found in the province of Ontario, with 18 species having Canadian distributions restricted to this province. The rivers of southwestern Ontario, primarily those draining into Lake St. Clair and Lake Erie, are home to the richest unionid assemblages in Canada. The Sydenham River has historically been considered to be the richest unionid river in all of Canada (Clarke 1992) with a total species count of 35 (Metcalfe-Smith et al. 2003); however, recent evidence suggests that the Thames River (McNichols-O'Rourke et al. 2012) had an historical species count of 35 and the Grand River (Metcalfe-Smith et al. 2000) had an historical count of 34 species. In addition, recent surveys have shown that there are at least 26 mussel species currently occurring in the Ausable River (Baitz et al. 2008).

Despite the historical richness of these rivers, recent events have led to significant declines in the unionid communities of southwestern Ontario. Intensive agricultural activity, expanding urbanization and the introduction of the Zebra Mussel (*Dreissena polymorpha*) have all been implicated in large-scale declines observed in freshwater mussel populations over the last two to three decades (Nalepa 1994; Metcalfe-Smith et al. 2000; Metcalfe-Smith et al. 2003). During this time, three, four and seven species have been lost from the Sydenham, Thames, and Grand rivers, respectively. It is difficult to determine if there have been declines in species diversity in the Ausable River as very few mussels surveys were conducted prior to 1990 (Nelson et al. 2003). These declines, coupled with the near complete collapse of the Great Lakes populations (Nalepa et al. 1996), have led to the designation of 13 Ontario mussel species as Endangered, Threatened or Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

The Ontario Freshwater Mussel Recovery Team (OFMRT) was formed in the spring of 2003 to address concerns about the status of Ontario's freshwater mussel populations and to begin to address the recovery planning obligations under Canada's *Species at Risk Act* (SARA). The Federal *Recovery Strategy for the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel and Rayed Bean in Canada* was developed by the OFMRT using the best available information in an effort to: reduce the impacts of threats; prevent the further loss of individuals or populations; and, if possible, to restore these species to healthy, self-sustaining levels. In recognition of the degree of overlap between these species in both their historical and current distributions, as well as the commonality of threats, the OFMRT has adopted a multi-species approach to the recovery of these species.

1 BACKGROUND

1.1 Northern Riffleshell

1.1.1 Species Information

Common Name: Northern Riffleshell
Scientific Name: *Epioblasma rangiana*
Status: Endangered
Reason for Designation: This small freshwater mussel is restricted to two rivers in southern Ontario. Since the original COSEWIC assessment (2000), a small, possibly reproducing population was discovered in the Ausable River although only 16 live individuals, including one juvenile, have been found over the last 10 years. Recruitment is occurring at several sites along the Sydenham River and the population appears to be stable, but the perceived recovery could be due to increased sampling effort over the past 12 years. The main limiting factor is the availability of shallow, silt-free riffle habitat. Both riverine populations are in areas of intense agriculture and urban and industrial development, subject to siltation and pollution. Only four populations in the world, including the two in Canada, show signs of recruitment.
Occurrence: Ontario
Status History: Designated Endangered in April 1999. Status re-examined and confirmed in May 2000 and April 2010.

The Northern Riffleshell (*Epioblasma rangiana* I. Lea, 1838) (Figure 1) is small- to medium-sized and sexually dimorphic. The males are irregularly ovate, with a wide, shallow sulcus anterior to the posterior ridge. Females are obovate, greatly expanded post-ventrally with the expansion broadly rounded and transversely swollen after about the third year of growth. The beaks are elevated above the hinge line and moderately excavated. The pseudocardinal teeth are small, and the lateral teeth are fairly short and moderately thick.

Figure 1. Northern Riffleshell (*Epioblasma rangiana*).
(Photo courtesy of S. Staton, DFO)

1.1.2 Distribution

Global Range – The global range of the Northern Riffleshell is restricted to North America (Figure 2). In the U.S., Northern Riffleshell historically occurred in Illinois, Indiana, Kentucky, Michigan, Ohio, Pennsylvania, and West Virginia (NatureServe 2015). It was found throughout the Ohio drainage, the Great Lakes drainage including the western basin of Lake Erie, Lake St. Clair, and the Detroit River. In Canada, Northern Riffleshell occurs in southwestern Ontario.

Canadian Range – The Canadian distribution of Northern Riffleshell is limited mainly to a 91 km reach of the East Sydenham River, and 44 km reach of the Ausable River (Figure 3). In 2011, Northern Riffleshell valves were collected from a small stretch of the lower Maitland River; however, no other records of this species exist for the Maitland River and it is unclear whether a population exists at this location (T. Morris, Fisheries and Oceans Canada [DFO], pers. comm.). A single live individual was found in a wetland area of the St. Clair River delta in 1999 (Zanatta et al. 2002); however, this species has not been collected in any survey of the area since then (COSEWIC 2010a).

Percent of Global Range in Canada – Approximately 5% of the Northern Riffleshell's global distribution is currently found in Canada.

Distribution Trend – The range of the Northern Riffleshell has been greatly reduced; it no longer occurs in Indiana (NatureServe 2015), and its range has been drastically reduced in all other areas. The species was extirpated in Illinois but has since been reintroduced in the Vermilion drainage (Mankowski 2010). The current North American distribution represents a range reduction of more than 95%. In Canada, its range once included western Lake Erie, Lake St. Clair and the Detroit, East Sydenham, and Thames rivers in Ontario. It is now limited to a 91 km reach of the East Sydenham River and a 44 km reach of the Ausable River.

1.1.3 Population Status and Abundance

Global Status and Abundance – The Northern Riffleshell is a rare species. Although occasionally abundant, it is usually a minor component of the unionid community (Strayer and Jirka 1997). It is considered globally imperilled (G2T2) and has a national status of imperilled (N2) in the U.S. It is considered presumed extirpated (SX) in one state, critically imperilled (S1) in four states, and imperilled (S2) in one state (NatureServe 2015). Its distribution has undergone dramatic declines in the U.S. and Canada. It has been listed as Endangered under the U.S. *Endangered Species Act* since 1993 and a recovery plan for this species in U.S. waters was published in 1994 (United States Fish and Wildlife Service [USFWS] 1994). The Allegheny River and French Creek in Pennsylvania support the largest remaining populations in the U.S.

Canadian Status and Abundance – Northern Riffleshell is considered critically imperilled nationally (N1) and provincially (S1) (NatureServe 2015). It is assumed to be extirpated in the Detroit River (Schloesser et al. 2006), Lake Erie (Schloesser and Nalepa 1994), and the offshore waters of Lake St. Clair (Nalepa et al. 1996). After several surveys in the East Sydenham River between 1973 and 1991, no live Northern Riffleshell were located (Clarke 1981; Mackie and Topping 1988) and the species was assigned a conservation status of SH (no verified occurrences in the past 20 years) in Ontario by the Natural Heritage Information Centre (NHIC; NHIC 1997). In 1998-1999, Metcalfe-Smith et al. (1999) surveyed 66 sites in the Ausable, East Sydenham, Grand, Maitland, and Thames rivers. As a result of these surveys, the range of Northern Riffleshell has been found to extend over a 91 km reach of the East

Sydenham River between Alvinston and Dawn Mills (Metcalfe-Smith et al. 1999). Due to these findings, the species was down-listed to S1 (extremely rare). More recently, a single live individual was found in a wetland area of the St. Clair River delta in 1999 (Zanatta et al. 2002) and the presence of a reproducing population in the Ausable River was confirmed in 2006 (S. Staton, DFO, pers. comm.). In the fall of 2011, two fresh shells were detected in a small section (approximately 10 km) of the lower Maitland River; however, further targeted sampling at 11 sites in 2012 found no evidence of Northern Riffleshell (Epp et al. 2013).

The East Sydenham River population is considered one of the healthiest extant populations of Northern Riffleshell in North America. Currently, it occurs over a 91 km reach of the East Sydenham River at a density of approximately 0.091/m^2 at sites where live individuals were collected (COSEWIC 2010a). Live specimens of Northern Riffleshell occur over a 44 km reach of the Ausable River, where it was found between Arkona and Brinsley at an approximate density of 0.029/m^2 at sites where live specimens were observed (Baitz et al. 2008; COSEWIC 2010a).

Percent of Global Abundance in Canada – Approximately 25% of the global population abundance of the Northern Riffleshell occurs in Canada.

Population Trend – The current Canadian distribution of Northern Riffleshell is restricted to two populations. A small population exists in the Ausable River; however, judging from the large number of dead shells collected, this population may have once been larger than that in the East Sydenham River. The population in the East Sydenham River is the largest remaining reproducing population in Canada.

Figure 2. Global distribution of the Northern Riffleshell (modified from Parmalee and Bogan 1998).

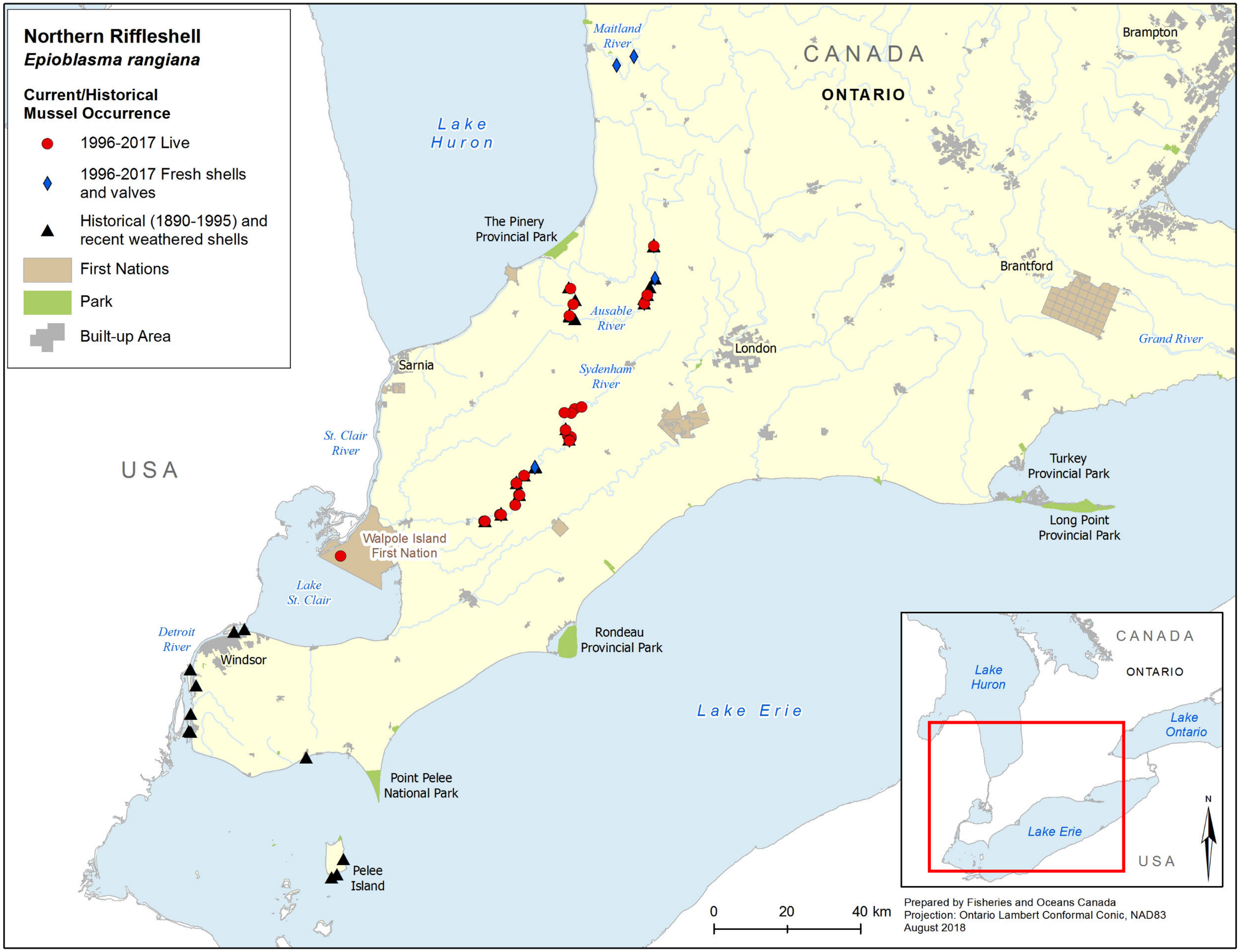

Figure 3. Current distribution of Northern Riffleshell in Canada.

1.1.4 Needs of the Northern Riffleshell

Habitat and Biological Needs

Spawning: The reproductive biology of the Northern Riffleshell follows the general reproductive biology of most mussels. During spawning, male mussels release sperm into the water and females living downstream filter them out of the water with their gills. No information could be found regarding the timing windows of fertilization in this species. Immature juveniles, known as glochidia, develop in the gill marsupia and are released by the female into the water column to undergo a period of parasitism on a suitable host fish species. The Northern Riffleshell is a long-term brooder (bradytictic), and gravid females have been observed from mid-August into October in water temperatures of 18.5 – 26°C in Canada (McNichols et al. 2011). Watters et al. (2009) found gravid females from September until the following June, suggesting the glochidia overwinter in the female mussel. Successful gamete development (and perhaps gamete release) appears to be regulated by water temperature (Galbraith and Vaughn 2009); however, these temperatures have not been recorded for the Northern Riffleshell.

Encysted Glochidial Stage: Further development to the juvenile stage cannot continue without a period of encystment on the host. Females of the genus *Epioblasma*, including the Northern Riffleshell, have developed complex behaviours involving luring mechanisms and the physical capturing of potential hosts to increase the likelihood of successful encystment. The encystment stage timing is unknown. Because the species is bradytictic, the encysted glochidial stage most likely starts in the spring. Laboratory experiments have shown that glochidia can stay encysted on the host between 15 and 31 days (McNichols 2007). There is potential for glochidia to become encysted from mid-August to the following June based on the fact that gravid females have been found during this period (Watters et al. 2009; McNichols et al. 2011). The hookless glochidia become encysted on the gills of the host and are nourished by the host until they metamorphose and break free, settling to the substrate to begin life as free-living juveniles. The glochidial (larval) stage is the most vulnerable and specialized life stage, because: (1) they are most sensitive to contaminant exposure (Gillis et al. 2008; Gillis 2011); and, (2) they must successfully attach to an appropriate host to complete their metamorphosis to the juvenile stage (Bauer 2001). The proportion of glochidia surviving to the juvenile stage is estimated to be as low as 0.000001%. Seven glochidial hosts have been identified for Northern Riffleshell in Canada: Blackside Darter (*Percina maculata*), Brook Stickleback (*Culaea inconstans*), Iowa Darter (*Etheostoma exile*), Johnny Darter (*E. nigrum*), Logperch (*P. caprodes*), Mottled Sculpin (*Cottus bairdii*), and Rainbow Darter (*E. caeruleum*) (McNichols 2007). The Iowa Darter and Mottled Sculpin appear to be the primary host in the laboratory (McNichols et al. 2011). Water temperatures play a large role in determining when metamorphosis and excystment occur; warmer temperatures generally lead to shorter glochidial attachment periods (Watters and O'Dee 1999). There are upper limits that cause glochidial excystment without successful metamorphosis (Dudgeon and Morton 1984). The upper and lower temperature thresholds required for metamorphosis and excystment have not been studied for the Northern Riffleshell; however, laboratory experiments have been successful at 19.5°C (McNichols 2007).

Juvenile: The optimal habitat preferences of juvenile mussels are believed to be different from those of adults, but there have been few studies on this topic (Gordon and Layzer 1989) and further research is required. The juvenile life stage is certainly more vulnerable than the adult stage, because juveniles have very little control over the habitat into which they are released by their host (Wächtler et al. 2001). Because populations of Northern Riffleshell in both the Ausable and East Sydenham rivers show evidence of recruitment, it appears that the quality of the habitat in at least some reaches is suitable. Until the habitat requirements of Northern Riffleshell juveniles are defined, optimal habitat requirements will be described in the adult section below.

Adult: The Northern Riffleshell lives mainly in highly oxygenated riffle areas of rivers (Clarke 1981; Cummings and Mayer 1992). The preferred substrate has been described as rocky and sandy bottoms with firmly packed sand and fine to coarse gravel. Recent observations have confirmed this in the East Sydenham River. The Northern Riffleshell occurs in streams of various sizes and its existence in the western basin of Lake Erie was apparently due to sufficient wave action to produce continuously moving water (USFWS 1994). There is no information on the thermal tolerance of the Northern Riffleshell. The 91 km reach of the East Sydenham River where this species still occurs has a relatively diverse substrate and associated habitat with well-defined riffles and pools, which create exceptional habitat for native mussels (Dextrase et al. 2003).

The quantity of preferred habitat in the Ausable and East Sydenham rivers where Northern Riffleshell still occurs is largely unknown. Because the occupied reach of the East Sydenham River has a relatively low gradient of about 0.4 m/km (Department of Energy and Resources Management 1965), riffle habitat would be expected to constitute only a small proportion of the total habitat. Similar habitat conditions would be expected in the Ausable River, although gradients are somewhat steeper in the lower reaches within the Arkona Gorge. The ability of Northern Riffleshell to tolerate reduced current velocities has not been reported. However, Metcalfe-Smith et al. (unpubl. data) observed at least one individual in an area of preferred substrate with almost no current. Monitoring programs were developed for the Ausable River (Baitz et al. 2008) and East Sydenham River (Metcalfe Smith et al. 2007) in 2006 and 1999-2003, respectively. During these studies, physical characteristics for the different sites examined were measured and it was determined that Northern Riffleshell was found at sites with: (1) water depth between 17 – 22 and 12 – 26 cm (summer depth); and, (2) velocity of 0.16 – 0.27 and 0.17 - 0.31 m/s in the Ausable and East Sydenham rivers, respectively. Substrate type in the East Sydenham River where Northern Riffleshell was found was made up of an average of 16% boulder, 25% rubble, 25% gravel, 19% sand, 11% silt, 0.12% clay, and 0.24% muck (Metcalfe-Smith et al. 2007). In the Ausable River, the substrate showed the highest percentage in gravel (mean 54%) and low percentages (0 – 33%) of boulder (4%), rubble (12%), sand (20%), silt (7%), muck (0%), and clay (1.08%) (Baitz et al. 2008). Further studies are required to determine specific optimal habitat requirements for this species as these percentages are based on three sites in the Ausable River and seven sites in the East Sydenham River. However, these data are the best available information to date. Further research on the identified stretches of both the Ausable and East Sydenham rivers is required to quantify the amount of preferred habitat available and to determine the extent to which sub-optimal habitat may be occupied.

Although the exact food preferences and optimum particle sizes siphoned by adult Northern Riffleshell are unknown, they are probably similar to those of other freshwater mussels (i.e., suspended organic particles such as detritus, bacteria and algae; Strayer et al. 2004). Adults may also engage in some pedal feeding (Nichols et al. 2005).

Limiting Factors

The Northern Riffleshell may be limited by its complex life cycle and by its dispersal mechanism. The dependency on a host for development (as described above) may limit the reproduction of the Northern Riffleshell because any change that affects the host species can also affect the mussel. The availability and health of the host species may also pose a limitation to the Northern Riffleshell. Further research is required to determine specific functional hosts for this species (e.g., distributional overlap between species in their natural environment, and their density).

Like most native freshwater mussels, Northern Riffleshell adults are essentially sessile with movement limited to only a few metres on the river/lake bottom. Although adult movement can be directed upstream or downstream, studies have found a net downstream movement through time (Balfour and Smock 1995; Villella et al. 2004). The primary means for large-scale dispersal, upstream movement, and the invasion of new habitat or evasion of deteriorating habitat, is limited to the encysted glochidial stage on the host fish.

1.2 Snuffbox

1.2.1 Species Information

Common Name: Snuffbox
Scientific Name: *Epioblasma triquetra*
Status: Endangered
Reason for Designation: This small, freshwater mussel is currently found in two rivers in southern Ontario; another population may still survive in the Thames River where one fresh shell was found in 1998. The original COSEWIC assessment (2001) concluded that it had been lost from most of its Canadian range and was confined to the Sydenham River but live mussels from a reproducing population were subsequently found in the Ausable River beginning in 2006. The two remaining populations are in areas of intensive farming and subject to siltation and pollution with siltation being particularly problematic. Invasive Zebra Mussels have rendered much of the historical habitat unsuitable. An invasive fish species, the Round Goby, may pose a new threat by competing with the mussel's two known larval host fishes and by eating juvenile mussels.
Occurrence: Ontario
Status History: Designated Endangered in May 2001. Status re-examined and confirmed in November 2011.

The Snuffbox (*Epioblasma triquetra* Rafinesque, 1820) (Figure 4) does not closely resemble any other mussel in Canada (Clarke 1981). The shell is solid, thick, and triangular in males, somewhat elongate in females. The anterior end is rounded and the posterior end is truncated in males, expanded in females. The ventral margin is slightly curved in males and almost straight in females. The dorsal margin is short and straight. The posterior ridge is high and sharply angled, extended posterioventrally in females. The posterior slope is wide, expanded and sculptured with radial, wavy ribs. The umbos are swollen and elevated above the hinge line, and they turn inward and anteriorly. The beaks are located anterior to the middle of the shell and have a sculpture consisting of three or four faint, double-looped ridges. The shell is yellowish to yellowish green, and is marked with numerous dark green rays that are often broken, appearing as triangular or chevron-shaped spots. The shell surface is smooth (excluding the posterior slope), except for occasional concentric growth rests. Each valve has two pseudocardinal teeth that are ragged, compressed, and relatively thin. There are two lateral teeth in the left valve and one in the right that are short, straight, elevated, and serrated (Watson et al. 2000a).

Figure 4. Snuffbox (*Epioblasma triquetra*).
(Photo credit S. Staton, DFO)

1.2.2 Distribution

Global Range – The Snuffbox currently occurs in Alabama, Arkansas, Illinois, Indiana, Kentucky, Michigan, Minnesota, Mississippi, Missouri, Nebraska, New York, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, Wisconsin, and Ontario (NatureServe 2015) (Figure 5). Historically, it was known to occur in 19 states throughout the Ohio-Mississippi River drainage and in the Great Lakes drainage in Lake Erie, Lake St. Clair, and tributaries of lakes Erie, Huron, Michigan, and St. Clair. In the U.S., Snuffbox is thought to be extant in only 37 of the 99 streams for which historical records are available (Watson et al. 2000a).

Canadian Range – In Canada, Snuffbox was historically known from the province of Ontario in the Ausable, East Sydenham, Grand, Niagara, and Thames rivers, Lake Erie and Lake St. Clair (Watson et al. 2000a). The two remaining populations of Snuffbox are located in the Ausable and East Sydenham rivers (Figure 6).

Percent of Global Range in Canada – Less than 5% of the species' global distribution is found in Canada.

Distribution Trend – The range of the Snuffbox has been significantly reduced as it has been extirpated from Iowa and Kansas (NatureServe 2015) and possibly Mississippi and New York. It is also believed to be extirpated from the Grand, Niagara, and Thames rivers, Lake Erie and Lake St. Clair. Remaining populations are small and geographically isolated from one another, and not all of them are healthy and reproducing. The rate of change in geographical distribution is not available, but it has been lost from 60% of formerly occupied streams.

1.2.3 Population Status and Abundance

Global Status and Abundance – The Snuffbox is considered globally vulnerable (G3) and has a national status of vulnerable (N3) in the U.S. It is considered critically imperilled (S1) in 12 states, possibly extirpated (SH) in one state, and presumed extirpated (SX) in two states (NatureServe 2015). The Snuffbox was listed as Endangered under the U.S. federal *Endangered Species Act* on February 13, 2012 (USFWS 2012a). No abundance estimates are available for the global population (Dextrase et al. 2003). The Snuffbox typically occurs in low numbers in mussel communities, representing < 1% of the mussel assemblage; however, it can be locally abundant. The largest remaining population in North America is found in the Clinton River, Michigan, where it was the dominant species in 1992. It is estimated that there are fewer than 50 reproducing, extant occurrences of the Snuffbox in North America (The Nature Conservancy [TNC] 2000). Most populations have become small and geographically isolated from one another.

Canadian Status and Abundance – Snuffbox is considered critically imperilled nationally (N1) and provincially (S1) (NatureServe 2015). It is currently known to occur only in a 93 km reach of the East Sydenham River as well as at five sites within a 91 km reach of the Ausable River. It has likely been extirpated from the Detroit, Grand, and Thames rivers and lakes Erie and St. Clair. Intensive quantitative surveys were conducted between 1999 and 2003 throughout 12 sites within the historical Canadian range of Snuffbox: 17 live individuals were found (Metcalfe-Smith et al. 2000) within a 93 km reach of the East Sydenham River (COSEWIC 2011a). From 2002 – 2009, sections of the East Sydenham River were surveyed again during searches for gravid females and the total number of live animals captured was over 200 (J. Ackerman, University of Guelph [UG], unpubl. data). In 2006, quantitative surveys at seven different sites in the Ausable River were completed and 26 live Snuffbox were found at four of these, making this the second reproducing population in Canada (Baitz et al. 2008). Densities at these sites averaged 0.09 animals/m^2 ranging from 0.01 – 0.25 /m^2 (Baitz et al. 2008).

Percent of Global Abundance in Canada – Global population abundance estimates are not available but Canadian populations likely represent less than 5% of the global abundance.

Population Trend – Snuffbox populations in the East Sydenham River appear to be declining (Metcalfe-Smith et al. 2007). Current and historical catch rates show a decline between 1963-1973 and 1997-1999 (Watson et al. 2000a). Baseline data were collected for Snuffbox at seven sites on the Ausable River and until this study, the status was unknown (Baitz et al. 2008). Further data are required to determine if this population is declining, stable, or expanding.

Figure 5. Global distribution of the Snuffbox (modified from Parmalee and Bogan 1998).

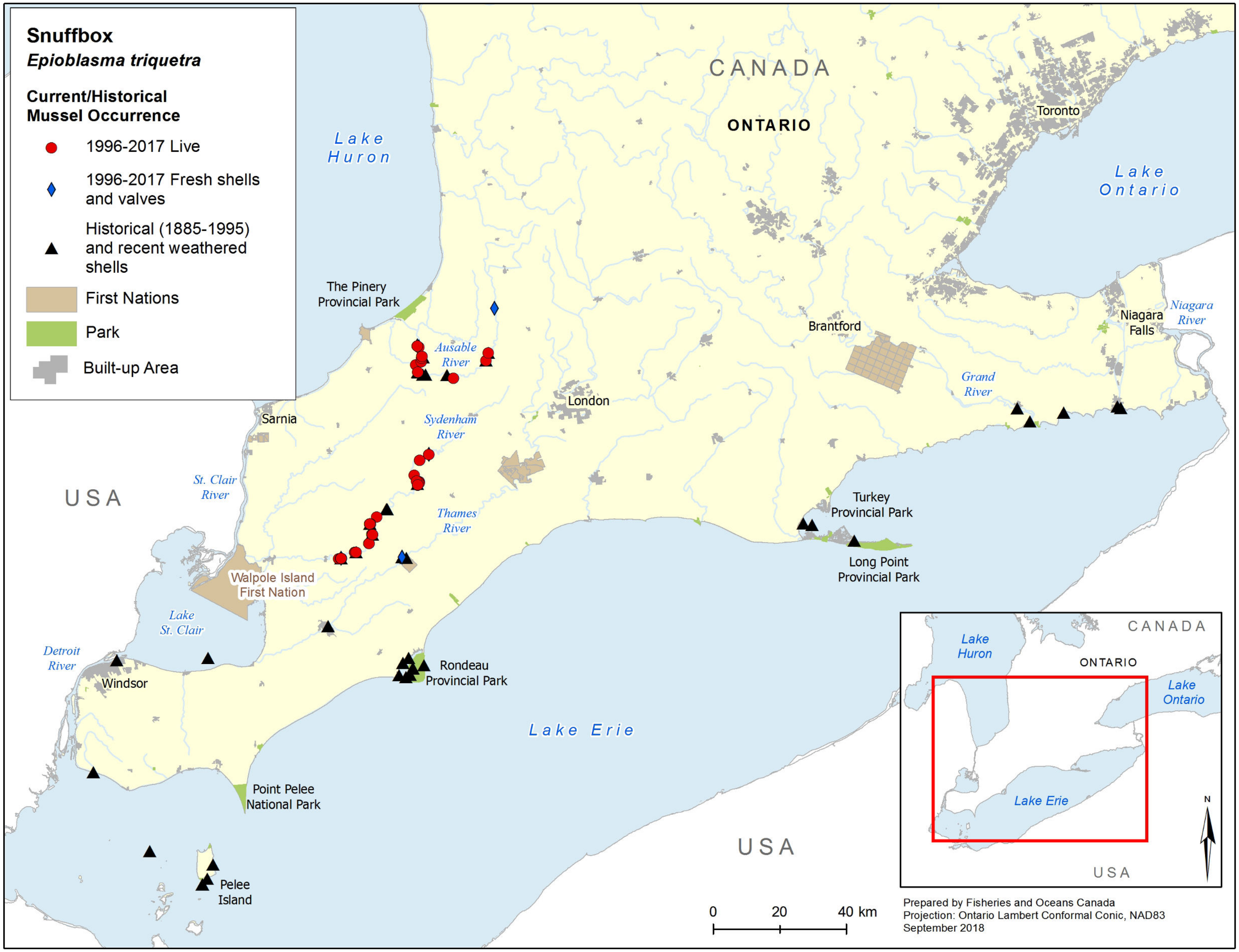

Figure 6. Distribution of Snuffbox in Canada.

1.2.4 Needs of the Snuffbox

Habitat and Biological Needs

Spawning: The reproductive biology of the Snuffbox follows the general reproductive biology of most mussels – refer to Section 1.1.4. (Needs of the Northern Riffleshell) for the general reproductive biology of freshwater mussels. Fertilization is thought to occur in late summer as eggs are observed in early September (Watters et al. 2009); however, specific time frames for this stage of reproduction require further research. The Snuffbox is a long-term brooder and gravid females have been observed from mid-August through late September in water temperatures of 14.5 – 26°C in Canada (McNichols 2007). Watters et al. (2009) found gravid females from September until the following June, suggesting the glochidia overwinter in the female mussel. Water temperatures required for successful gamete development (and perhaps gamete release) have not been recorded for the Snuffbox.

Encysted Glochidial Stage: Refer to Section 1.1.4. (Needs of the Northern Riffleshell) for general information on freshwater mussel glochidia. Female Snuffbox have developed specialized structures including a mantle lure and shell denticles that permit a unique method of host capture, increasing the likelihood of successful encystment (Barnhart et al. 2008). Glochidia are held by the female over winter for release the following spring or summer. The timing for the encysted glochidial stage is suspected to be from spring to August based on Watters et al. (2009); however, glochidia may overwinter on the host if infested later in the year. To confirm this, further research is required. Laboratory experiments have shown that glochidia can stay encysted on the host between 20 and 84 days (McNichols 2007). In nature, this length of time could be longer or shorter depending on environmental conditions such as water temperature. There is potential for glochidia to become encysted from mid-August to the following June based on the fact that gravid females have been found during this period (McNichols 2007; Watters et al. 2009). In early host fish infestation experiments, a total of five Snuffbox juveniles transformed on Brook Stickleback, Iowa Darter, Largemouth Bass (*Micropterus salmoides*), Mottled Sculpin, and Rainbow Darter; however, due to the extremely small number of juveniles, these data should be interpreted with caution especially due to the specific host capture method used by the Snuffbox to infest its host (McNichols and Mackie 2002; McNichols and Mackie 2004; Barnhart et al. 2008). On the other hand, thousands of Snuffbox juveniles have transformed on the Logperch (McNichols 2007). Therefore, it is considered the primary and most likely functional (distributional overlap with Snuffbox) host of Snuffbox (McNichols 2007; Schwalb et al. 2011). The upper and lower temperature thresholds required for metamorphosis and excystment have not been studied for the Snuffbox; however, laboratory experiments were successful at 19.5°C (McNichols 2007).

Juvenile: Refer to Section 1.1.4. (Needs of the Northern Riffleshell) for general information on juvenile freshwater mussels. Because populations of Snuffbox in both the Ausable and East Sydenham rivers show evidence of recruitment, it appears that the quality of the habitat in at least some reaches is suitable. Until the habitat requirements of Snuffbox juveniles are defined, optimal habitat requirements will be described in the adult section below.

Adult: The Snuffbox is typically found in riffle areas or shoals (runs) in small- to medium-sized rivers and streams (van der Schalie 1938; Dennis 1984). Its substrate preference has been described as anything from sand (Clarke 1981) to gravel, cobble, and boulder (Buchanan 1980). It has been reported at depths of 0.5 – 2.5 m (Baker 1928; Buchanan 1980), and is found in areas with swift currents. Monitoring programs for the Ausable River (Baitz et al. 2008) and East

Sydenham River (Metcalfe Smith et al. 2007) were developed in 2006 and 1999-2003, respectively. During these surveys, physical characteristics were measured and it was determined that Snuffbox was found at sites with: (1) water depth between 18 – 31 and 12 – 26 cm (summer depth); and, (2) a velocity of 0.03 – 0.38 and 0.16 – 0.31 m/s in the Ausable and East Sydenham rivers, respectively. Buchanan (1980) measured bottom velocities of 0.36 – 0.51 m/s at collection sites in the Meramac River basin, Missouri. Many of the historical records for this species in Canada come from Lake Erie where it probably inhabited wave-washed shoals. The Snuffbox is usually found entirely buried in the substrate (Buchanan 1980), or with only the posterior slope exposed to view (Ortmann 1919). Substrate type in the East Sydenham River where Snuffbox was found was made up of an average of 13% boulder, 23% rubble, 28% gravel, 22% sand, 11% silt, 0.12% clay, and 0.40% muck (Metcalfe-Smith et al. 2007). In the Ausable River, the substrate showed the highest percentage of gravel (52 – 62%) and low percentages (0 – 33%) of boulder (0 – 7%), rubble (1 – 25%), sand (10 – 25%), silt (20 – 10%), muck (0.07 – 3%), and clay (0 – 13.04%) (Baitz et al. 2008). Further studies are required to determine specific optimal habitat requirements for this species as these percentages are based on seven sites in the Ausable River and nine sites in the East Sydenham River. However, these data are the best available information to date.

There is no direct information on the thermal tolerance of the Snuffbox; however, water temperatures at sites where live specimens were found in the East Sydenham River between 2002 and 2010 (summer and fall temperatures) were between 14.5 – 26°C.

Lifespan and age at sexual maturity are not known for the Snuffbox; however, it has been estimated that it matures at 5 – 10 years of age based on gravid females collected from the Clinch River (Dennis 1987) and Powell River (Yeager and Saylor 1995).

Although the exact food preferences and optimum particle sizes siphoned by adult Snuffbox are unknown, they are probably similar to those of other freshwater mussels (i.e., suspended organic particles such as detritus, bacteria, and algae; Strayer et al. 2004). Adults may also engage in some pedal feeding (Nichols et al. 2005).

Limiting Factors

The Snuffbox may be limited by its complex life cycle and by its dispersal mechanism. The dependency on a host for development (as described above) may limit the reproduction of the Snuffbox because any change that affects the host species can also affect the mussel. In addition, this species also appears to be specific in its host selection as its primary host is the Logperch due to its broader and more robust frontal bones (Barnhart et al. 2008). Other darter species that have been examined have often died during capture (as their heads have been crushed) or within a few days after capture (Barnhart et al. 2008). The availability and health of the host species may also pose a limitation to the species.

Refer to the Limiting Factors for Northern Riffleshell for information on freshwater mussel dispersal.

1.3 Round Pigtoe

1.3.1 Species Information

Common Name: Round Pigtoe
Scientific Name: *Pleurobema sintoxia*
Status: Endangered
Reason for Designation: This mussel species occupies a small area in the Lake St. Clair watershed and three other watersheds in southern Ontario, where its habitat has been declining in extent and quality. Urban development, agricultural runoff, and impacts from the Zebra Mussel and the Round Goby are threatening the survival of the species in Canada.
Occurrence: Ontario
Status History: Designated Endangered in 2004. Status re-examined and confirmed in May 2014

The Round Pigtoe (*Pleurobema sintoxia* Rafinesque, 1820) (Figure 7) is a medium to large-sized freshwater mussel with a highly variable morphology depending on the habitat. In rivers, this mussel has a compressed, solid and somewhat rectangular shell, with a compressed beak that is slightly elevated and projects forward only slightly beyond the hinge line. The Great Lakes form has a smaller and more inflated shell, with a full beak that is elevated and projects forward, well beyond the hinge line (COSEWIC 2004). The anterior end is rounded and the posterior end is square and truncated. The posterior ridge is rounded, ending in a blunt point. The shell in juveniles is dull tan with distinct green rays that fade as the shell becomes larger. Adults have deep mahogany coloured shells with dark banding and may grow up to 13 cm. The surface is rough with concentric growth rests. There are two pseudocardinal teeth in the left valve that are stout, rectangular, and serrated. There is one pseudocardinal tooth in the right valve that is low and roughened. There are two lateral teeth in the left valve and one in the right that are straight, moderately high, and finely serrated.

Figure 7. Round Pigtoe (*Pleurobema sintoxia*).

(Photo courtesy J.L. Metcalfe-Smith, Environment and Climate Change Canada)

1.3.2 Distribution

Global Range – In the U.S., Round Pigtoe occurs throughout the Mississippi and Ohio drainages in Alabama, Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, New York, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, West Virginia, and Wisconsin (NatureServe 2015). In Canada, Round Pigtoe occurs only in Ontario (Figure 8).

Canadian Range – Round Pigtoe was historically found in Lake Erie, Lake St. Clair and the Detroit, Grand, Niagara, Sydenham, and Thames rivers. Populations that are suspected to be reproducing remain in the St. Clair River delta and the Sydenham River. Remnant populations still exist in the Grand and Thames rivers, as well as Rondeau Bay (Figure 9).

Percent of Global Range in Canada – Less than 5% of the species' global distribution is currently found in Canada.

Distribution Trend – In the U.S., the present range of Round Pigtoe is similar to its historical range, although most large river populations have disappeared in the Upper Midwest. Populations in tributaries of the Mississippi and Ohio rivers still survive. In Canada, it was known from Lake Erie and offshore of Lake St. Clair, but these populations have been lost. The remaining population in the St. Clair River delta is located entirely within the Walpole Island First Nation, where it is the most abundant of the species at risk in this location (T. Morris, DFO, pers. comm. 2015). Round Pigtoe was widespread in the upper and lower Thames River, but is now restricted to a very small (possibly relict) population in McGregor Creek (tributary to the lower Thames) and in the upper reaches of the Middle and South Thames rivers. In the Grand River, Round Pigtoe historically occurred in the lower reaches of the river downstream of Brantford, although shells have occasionally been found higher in the watershed (Metcalfe-Smith et al. 2000). There are nine historical records of Round Pigtoe in the Niagara River; however, a 2001 survey found only fresh and weathered shells and Zebra Mussel was reported to be abundant (COSEWIC 2004). Round Pigtoe is well distributed, although not common, throughout the Sydenham River. In 2014, the Ontario Ministry of Natural Resources and Forestry (OMNRF) found one live Round Pigtoe in Rondeau Bay (OMNRF, unpubl. data); it is unknown whether there is a reproducing population at this location.

1.3.3 Population Status and Abundance

Global Status and Abundance – The Round Pigtoe is broadly distributed but uncommon and rarely, if ever, abundant (COSEWIC 2004). The species is considered apparently secure to secure globally (G4G5) and has a national status of apparently secure to secure (N4N5) in the U.S. It is considered critically imperilled (S1) in four states, and imperilled (S2) in four states (NatureServe 2015). In the U.S., current and historical ranges of Round Pigtoe are similar, although large river populations have mostly disappeared from the Upper Midwest. Many populations still exist in the Mississippi and Ohio drainages. It is not currently listed under the U.S. *Endangered Species Act*.

In the U.S., many populations of Round Pigtoe have declined and there is no evidence of recent recruitment in some areas (COSEWIC 2004).

Canadian Status and Abundance – Round Pigtoe is considered critically imperilled nationally (N1) and provincially (S1) (NatureServe 2015). It has not been seen in Lake Erie offshore since

1951 – 52, or offshore of Lake St. Clair since 1990 (COSEWIC 2004). However, surveys from 1999 – 2001 reported 42 Round Pigtoe from three nearshore sites off Squirrel Island in the St. Clair River delta (Zanatta et al. 2002). Ninety-two other nearshore sites surveyed had no evidence of live specimens. Small pockets of isolated populations may persist in some nearshore areas although, to date, none have been found. Results from recent surveys of the Detroit River and Niagara River indicate that Round Pigtoe is extirpated from these rivers. It has been found in a 48 km stretch of the Grand River; however, low numbers of live specimens, and a lack of small specimens, indicates that reproduction rates are likely declining. The Thames River population is restricted to a very small area (approximately 24 km in length) in the upper reaches of the Middle and South Thames rivers between Thamesford and London. Round Pigtoe has always been rare in the Sydenham River. Forty-five specimens were observed at seven different sites on the East Sydenham River between Rokeby and Dawn Mills (approximately 107 km in length) and one site in the North Sydenham River (COSEWIC 2004).

Percent of Global Abundance in Canada – Less than 5% of the species' global abundance is currently found in Canada.

Population Trend – The current Canadian distribution of Round Pigtoe is restricted to the St. Clair River delta and three southwestern Ontario rivers. The St. Clair River delta has been identified as a possible refuge for unionids from impacts of the Zebra Mussel (Zanatta et al. 2002). Surveys between 1999 and 2001 reported Round Pigtoe from three sites in the St. Clair River delta; however, repeated sampling of the same sites in 2003 reported declines in all three sites. In the Grand River, low numbers of live specimens, and a lack of small specimens, indicates that reproduction rates are likely declining. The Thames River has a relict population (large individuals, no signs of reproduction) in the upper reaches of the Middle Thames as well as a population between Thamesford and the confluence with the South Thames. In the Sydenham River watershed, Round Pigtoe was observed at seven different sites on the East Sydenham River and another site in the North Sydenham River. The size of the specimens sampled indicates recruitment is occurring. The population in the East Sydenham River is considered to be the healthiest in Ontario. Only one live specimen has been found in Rondeau Bay after 1996 and the status of the species at this location is unknown.

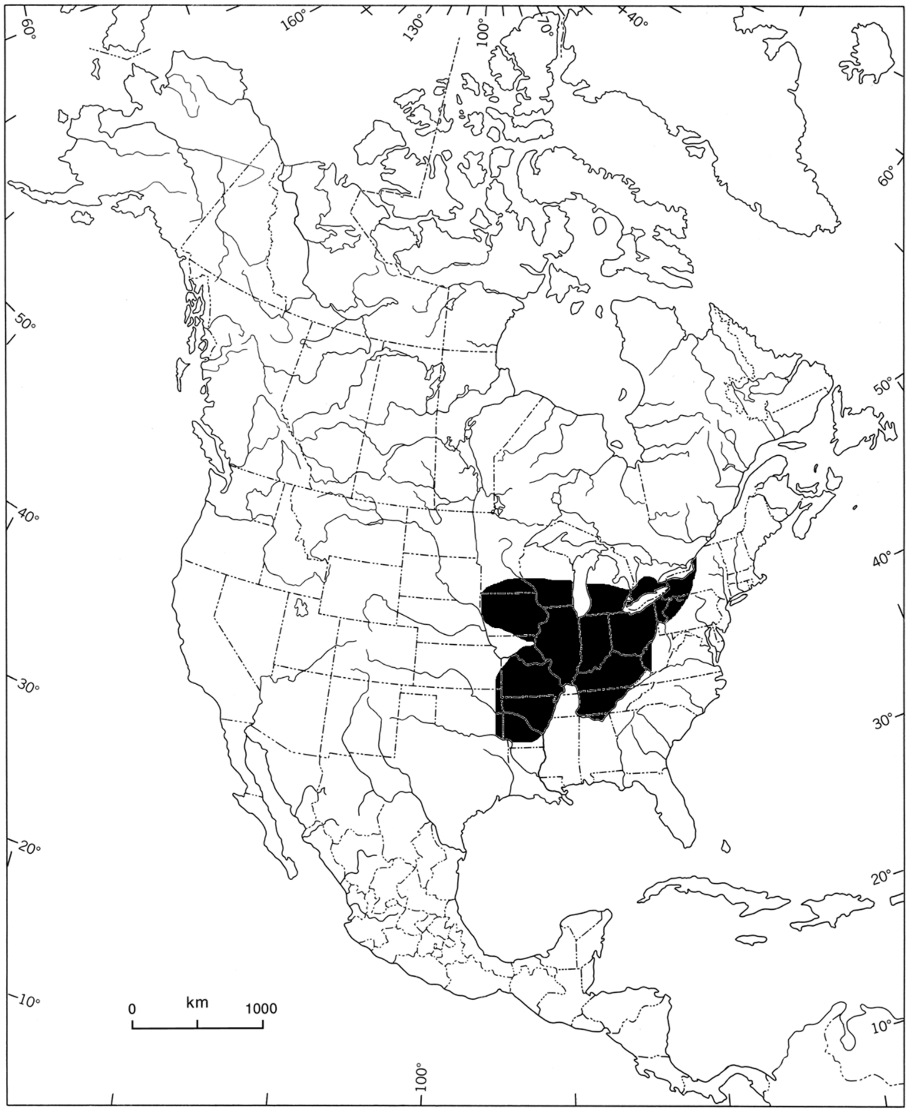

Figure 8. Global distribution of the Round Pigtoe (modified from Parmalee and Bogan 1998).

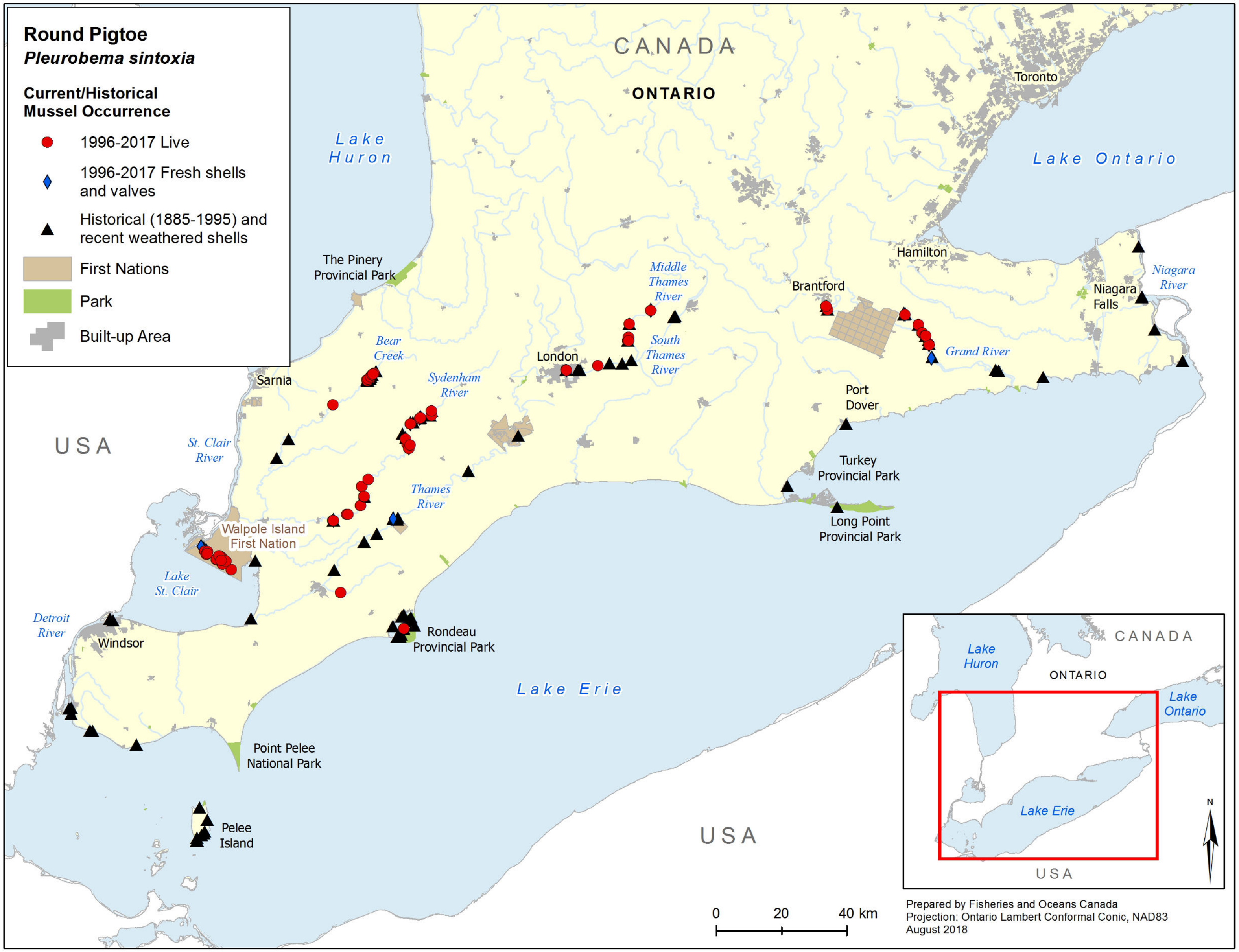

Figure 9. Distribution of Round Pigtoe in Canada.

1.3.4 Needs of the Round Pigtoe

Habitat and Biological Needs

Spawning: Refer to Section 1.1.4. (Needs of the Northern Riffleshell) for the general reproductive biology of freshwater mussels. The Round Pigtoe is a short-term brooder (tachytictic) with eggs appearing in May and glochidia brooding from May to July (Watters et al. 2009). Fertilization occurs before this, but specific time frames are not known for Canadian populations. Water temperatures required for successful gamete development (and perhaps gamete release) have not been recorded for the Round Pigtoe.

Encysted Glochidial Stage: Refer to Section 1.1.4. (Needs of the Northern Riffleshell) for general biology and habitat information on freshwater mussel glochidia. Timing of encystment is unknown, but suspected to be from May to August as females are gravid from May until July. Known host fishes for the Round Pigtoe include the Bluegill (*Lepomis macrochirus*), Bluntnose Minnow (*Pimephales notatus*), Central Stoneroller (*Campostoma anomalum*), Northern Redbelly Dace (*Chrosomus eos*), Southern Redbelly Dace (*C. erythrogaster*), and Spotfin Shiner (*Cyprinella spiloptera*) (Hove 1995; Watters et al. 2005). In Ontario, these species, except the Southern Redbelly Dace, occur within the range of Round Pigtoe and are assumed to serve as glochidial hosts, although no potential hosts have yet been tested in Canada as gravid females have not been located. The upper and lower temperature thresholds required for metamorphosis and excystment have not been studied for the Round Pigtoe.

Juvenile: Refer to Section 1.1.4. (Needs of the Northern Riffleshell) for general biology and habitat information on juvenile freshwater mussels. Because populations of Round Pigtoe in the Sydenham River show evidence of recruitment, it appears that the quality of the habitat in at least some reaches is suitable. Until the habitat requirements of Round Pigtoe juveniles are defined, optimal habitat requirements will be described in the adult section.

Adult: The Round Pigtoe typically occurs in medium to large rivers (van der Schalie 1938; Parmalee and Bogan 1998) but also may occur in lakes (Clarke 1981; Strayer and Jirka 1997). In large rivers, it may be found in mud, sand, and gravel, deeper than 3 m, but also occurs on sand and gravel bars (Gordon and Layzer 1989). In the St. Clair River delta, Round Pigtoe inhabits shallow (< 1 m) nearshore areas with firm, sand bottoms (Zanatta et al. 2002). In smaller rivers, it is often found deeply buried in gravel, cobble, and boulders, in or below riffles with moderate flows (Ortmann 1919; Parmalee and Bogan 1998). A monitoring program for the Sydenham River was developed between 1999 and 2003 (Metcalfe Smith et al. 2007). During these sampling events, physical characteristics for the different sites examined were measured and it was determined that Round Pigtoe was found at sites with: (1) water depth between 12 - 26 cm (summer depth); and, (2) velocity of 0.16 – 0.31 m/s. Substrate type in the Sydenham River where Round Pigtoe was found was made up of an average of 16% boulder, 23% rubble, 27% gravel, 22% sand, 9% silt, 0.25% clay, and 0.54% muck (Metcalfe-Smith et al. 2007). Further studies are required to determine specific optimal habitat requirements for this species as these percentages are based on only seven sites in the East Sydenham River and one site in the North Sydenham River, and do not include any data from the Grand or Thames rivers. However, these are the best available data to date.

There is no direct information on the thermal tolerance of the Round Pigtoe; however, water temperatures at sites where live specimens were found in the Sydenham River watershed

between 2002 and 2010 (summer and fall temperatures) were between 14.5 – 26°C (J. Ackerman, UG, unpubl. data).
The lifespan of the Round Pigtoe has not yet been determined, but other members of the Subfamily Ambleminae are known to live for more than 30 years (Stansbery 1967). Age to maturity for this species is not known, but the juvenile stage for most unionids lasts 2 – 5 years.

Although the exact food preferences and optimum particle sizes siphoned by adult Round Pigtoe are unknown, they are probably similar to those of other freshwater mussels (i.e., suspended organic particles such as detritus, bacteria and algae; Strayer et al. 2004). Adults may also engage in some pedal feeding (Nichols et al. 2005).

Limiting Factors

The Round Pigtoe may be limited by its complex life cycle and by its dispersal mechanism. The dependency on a host for development (as described above) may limit the reproduction of the Round Pigtoe because any change that affects the host species can also affect the mussel. The availability and health of the host species may also pose a limitation to the species. Additional research is needed to identify host species for Round Pigtoe in Canada.

Refer to the Limiting Factors for Northern Riffleshell for information on freshwater mussel dispersal.

1.4 Salamander Mussel[1]

1.4.1 Species Information

Common Name: Salamander Mussel
Scientific Name: *Simpsonaias ambigua*
Status: Endangered
Reason for Designation: This freshwater mussel was reported from two rivers in southern Ontario in 1998. Surveys since the original COSEWIC assessment (2001) have found live individuals still along the Sydenham River. Despite extensive additional sampling, the half-shell found in 1998 is the only evidence of this species along the Thames River. Habitat quality continues to decline from intense agriculture, urban development, and pollution from point and non-point sources. In addition, this mussel only uses the Mudpuppy, a salamander, as its host; threats to the salamander are also threats to the mussel.
Occurrence: Ontario
Status History: Designated Endangered in May 2001. Status re-examined and confirmed in May 2011.

The Salamander Mussel (*Simpsonaias ambigua* Say, 1825) (Figure 10) is a small freshwater mussel that is distinguished from other mussels by its elongate elliptical shell shape, incomplete hinge teeth, double-looped beak sculpture, and rayless, brown periostracum. The shell is thin,

[1] Formerly known as the Mudpuppy Mussel.

fragile, and compressed in males to slightly inflated posteriorly in females. It is much thicker anteriorly than posteriorly. The anterior and posterior ends are rounded; the dorsal and ventral margins are nearly straight and parallel. The posterior ridge is rounded. The beaks are located approximately one-quarter of the distance from anterior to posterior, and are slightly elevated above the hinge line and somewhat compressed. Beak sculpture consists of four to five double-looped ridges. The periostracum (shell surface) is smooth, yellowish tan to dark brown in colour, and rayless. Pseudocardinal teeth are very small, low, and rounded (one in each valve). Lateral teeth are absent (Watson et al. 2000b).

Figure 10. Salamander Mussel (*Simpsonaias ambigua*).
(Photo Credit: D. Zanatta, University of Toronto)

1.4.2 Distribution

Global Range – The Salamander Mussel currently occurs in Arkansas, Illinois, Indiana, Kentucky, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, Tennessee, West Virginia, Wisconsin, and Ontario (NatureServe 2015) (Figure 11). Historically, it was found in the Lake Erie, Lake Huron, and Lake St. Clair drainages as well as the Cumberland, upper Mississippi, and Ohio river systems (Clarke 1985).

Canadian Range – There are only three historical records for Salamander Mussel in Canada: two from the East Sydenham River in the mid-1960s and one from the Detroit River in 1934. Salamander Mussel currently occurs only in the East Sydenham River in Ontario, although a single fresh valve was found in the Thames River in the city of London in 1998, and three live specimens were found in the St. Clair River delta in 1999; no live animals or shells have been found at these two locations since the original records (Figure 12). It has been suggested that Salamander Mussel is at the northern-most limit of its range in the Great Lakes region and may be naturally rare.

Percent of Global Range in Canada – Less than 5% of the species' global distribution is currently found in Canada.

Distribution Trend – Salamander Mussel is no longer found in 60% of formerly occupied rivers and streams in the U.S. and is extirpated from Iowa (NatureServe 2015), and possibly New York, Tennessee, and Michigan. In Canada, it was historically known from the Detroit and North Sydenham rivers, but recent surveys indicate that it now occurs only in the East Sydenham River.

1.4.3 Population Status and Abundance

Global Status and Abundance – In the U.S., extant populations are known from 12 states and its range appears to be declining in most jurisdictions. Salamander Mussel is thought to be present in only 32 of the 80 rivers and streams for which historical records are available. It is considered vulnerable globally (G3) and has a national status of N3 in the U.S. It is considered presumed extirpated (SX) in one state, possibly extirpated (SH) in one state, critically imperilled (S1) in seven states, and imperilled (S2) in three states (NatureServe 2015).

Canadian Status and Abundance – Salamander Mussel is considered critically imperilled nationally (N1) and provincially (S1) (NatureServe 2015). In Ontario, Salamander Mussel had been ranked SH (historical; no occurrences verified in the past 20 years) by the NHIC until the late 1990s. Intensive surveys conducted on tributaries of Lake Erie, lower Lake Huron, and Lake St. Clair in 1997 – 1999 (Metcalfe-Smith et al. 1998, 1999) produced a total of 90 specimens from eight different sites on the East Sydenham River, one site in the St. Clair River delta, and one site on the Thames River. The largest remaining population of Salamander Mussel in Ontario is restricted to the middle reach of the East Sydenham River. Three live specimens were found in the St. Clair River delta in 1999 although no additional specimens have been found from this area recently. A single fresh valve was reported from the Thames River in 1998. Further surveys in this watershed have produced no signs of living or dead animals in the Thames River. Based on these findings, Salamander Mussel was down-listed from SH to S1 in Ontario.

Percent of Global Abundance in Canada – Less than 5% of the species' global distribution is currently found in Canada. Population abundance estimates are not available.

Population Trend – Salamander Mussel is no longer found in 60% of formerly occupied rivers and streams in the U.S. and is extirpated from Iowa (NatureServe 2015), and possibly from New York, Tennessee, and Michigan. In Canada, it now occurs only in the East Sydenham River. Live animals were collected from eight different sites within a 73 km reach of the East Sydenham River in 1997 – 1999. The broad range of sizes of live specimens and fresh shells indicated that there is ongoing recruitment.

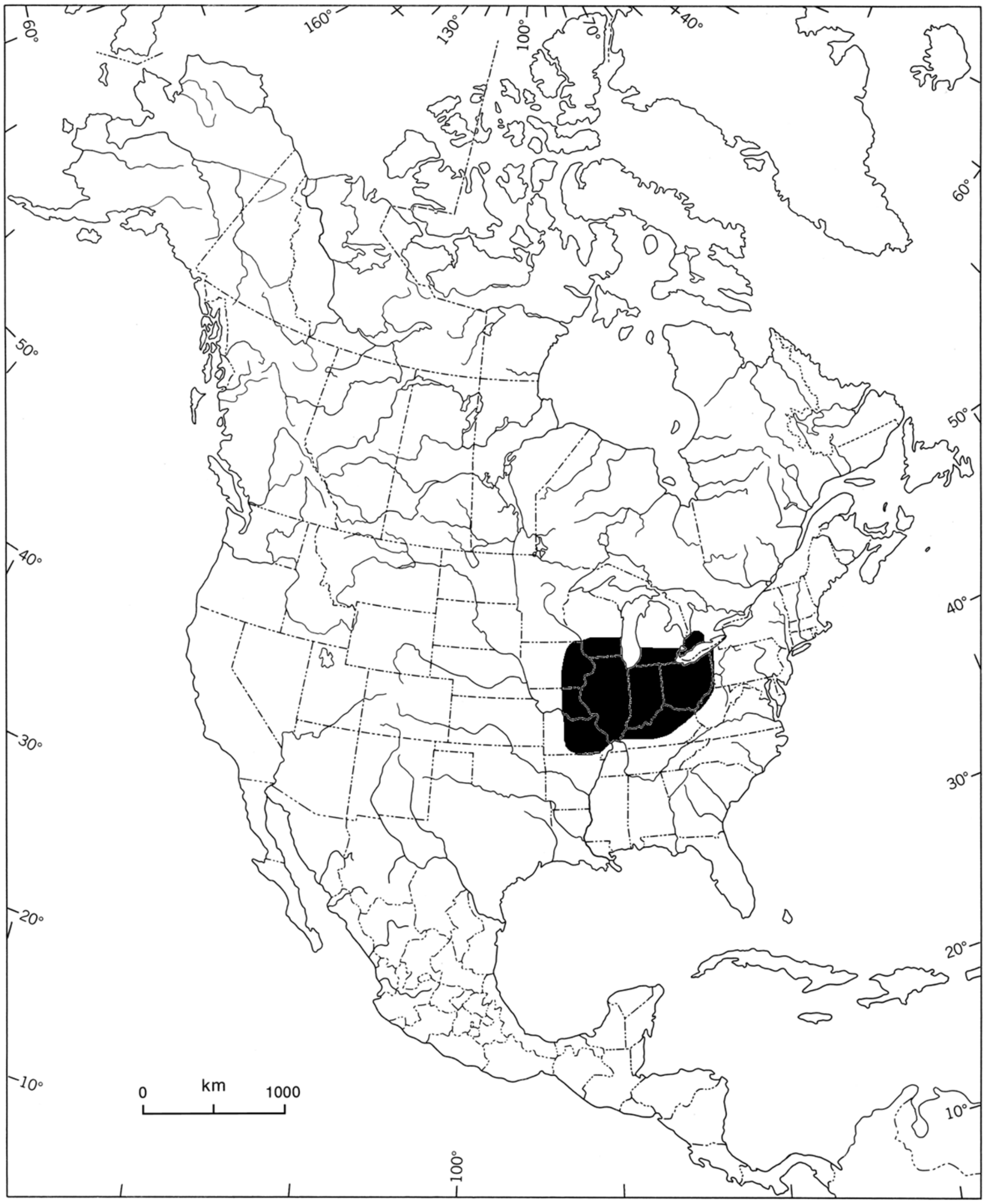

Figure 11. Global distribution of the Salamander Mussel (modified from Parmalee and Bogan 1998).

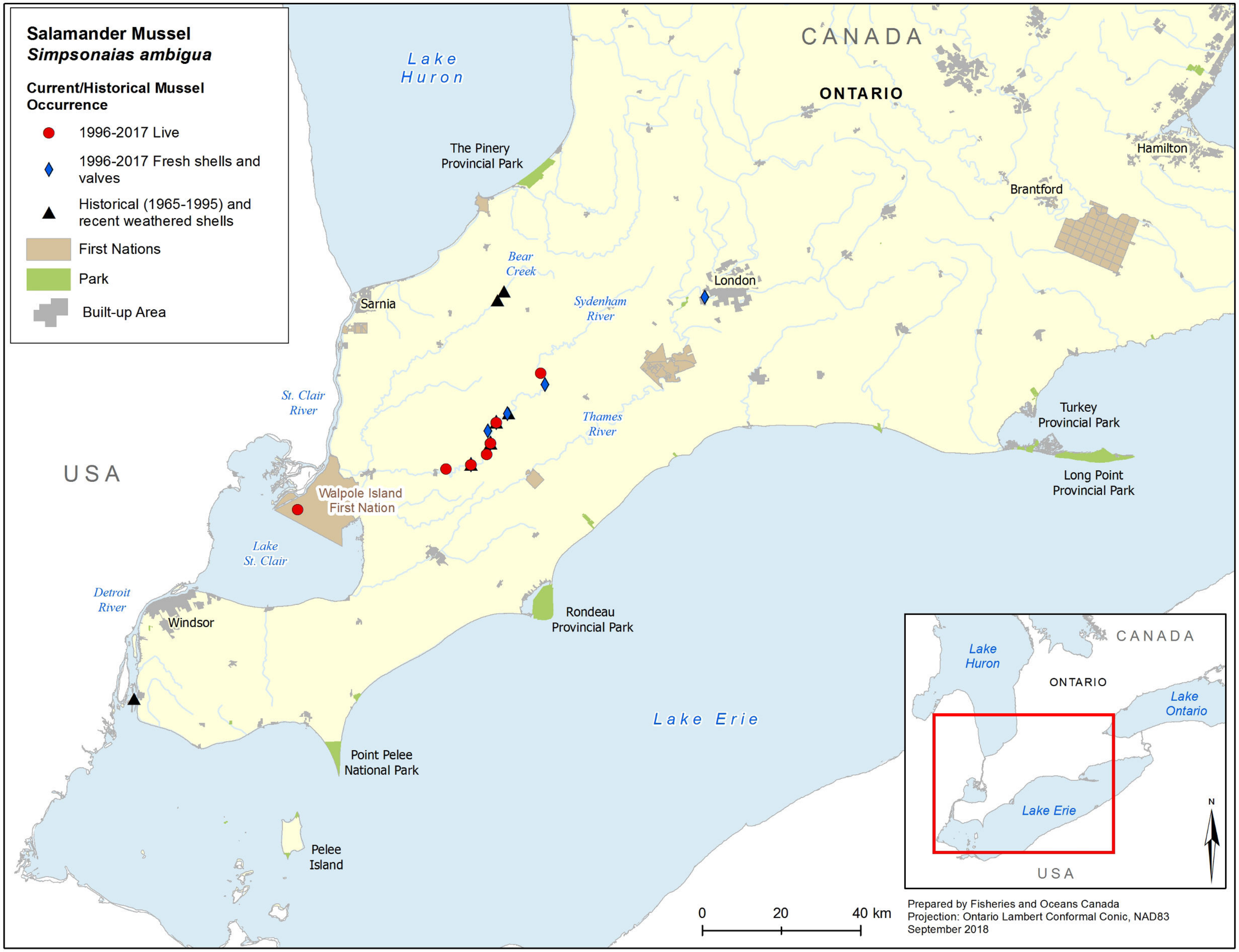

Figure 12. Distribution of Salamander Mussel in Canada.

1.4.4 Needs of the Salamander Mussel

Habitat and Biological Needs

Spawning: Refer to Section 1.1.4. (Needs of the Northern Riffleshell) for the general reproductive biology of freshwater mussels. Although the reproductive biology of the Salamander Mussel follows the general reproductive biology of most mussels, this species is unique in the fact that it is the only species to use a host other than a fish. Gravid females have not been observed in Canada; however, Barnhart et al. (1998) observed a single gravid female in April in the Meramec River in Missouri. Water temperatures required for successful gamete development (and perhaps gamete release) have not been recorded for the Salamander Mussel.

Encysted Glochidial Stage: Refer to Section 1.1.4. (Needs of the Northern Riffleshell) for general biology and habitat information on freshwater mussel glochidia. The glochidia of the Salamander Mussel have hooks that likely ensure a firm attachment to the external gills of their host. The Mudpuppy Salamander (*Necturus maculosus*) is the only known host for the Salamander Mussel. After they have attached to a host, the glochidia become completely encysted within 36 hours. Once encystment on a suitable host occurs, it may take from six days to over six months to complete the transformation from glochidium to juvenile mussel (Kat 1984). Barnhart et al. (1998) found that at 20°C, metamorphosis and drop off occurred between 19 and 28 days post infestation. Howard (1915), as stated in Watters et al. (2009), suggested that the glochidia overwinter on their host, as glochidia were observed on Mudpuppy Salamander in October. Barnhart et al. (1998) found infested Mudpuppy Salamander in April. Once metamorphosis is complete, the juvenile mussel ruptures the cyst by extending its foot (Lefevre and Curtis 1910). The Mudpuppy Salamander itself is broadly distributed in lakes and rivers throughout Quebec, Ontario, and Manitoba. The Mudpuppy Salamander inhabits areas with flat rocks, submerged logs, wooden slabs, and other debris. The habitat requirements of the Mudpuppy Salamander correspond with the habitat characteristics typically assigned to the Salamander Mussel. Howard (1951) speculated that the Mudpuppy Salamander feeds on adult Salamander Mussel as it moves from one hiding place to another. During the process, it becomes heavily infested with glochidia. When the glochidia have matured, they are most likely released in the salamander’s retreat (i.e., under large, flat, stones). There is no information on the thermal tolerance of the Salamander Mussel.

Juvenile: Refer to Section 1.1.4. (Needs of the Northern Riffleshell) for general biology and habitat information on juvenile freshwater mussels. Because populations of Salamander Mussel in the East Sydenham River show evidence of recruitment, it appears that the quality of the habitat in at least some reaches is suitable. Until the habitat requirements of Salamander Mussel juveniles are defined, optimal habitat requirements will be described in the adult section below.

Adult: TNC (1999) states that the Salamander Mussel is most commonly found in sand or silt under flat stones in areas of swift current, where it may be locally abundant. Such habitat is consistent with the habitat of its host, the Mudpuppy Salamander. Gordon and Layzer (1989) report that records are available from shallow sections of creeks to large rivers with calm to swift mid-depth current velocities, where it may be found in mud to cobble and boulder but primarily under large, flat rocks. Cummings and Mayer (1992) describe the habitat of this mussel as medium to large rivers on mud or gravel bars and under flat slabs or stones. During surveys in the Meramec River Basin in Missouri, Buchanan (1980) found Salamander Mussel “…under large flat rocks in a gravel, cobble and boulder substrate in three inches of water in swift current". In 1999, live specimens were located on the East Sydenham River near Florence in similar habitat. Salamander Mussel is often found in great numbers, with up to several hundred individuals packed tightly together under a single flat rock. This is due to the close association between the mussel and its host (Parmalee and Bogan 1998).

The lifespan and age to maturity for this species is unknown. Although the exact food preferences and optimum particle sizes siphoned by adult Salamander Mussel are unknown, they are probably similar to those of other freshwater mussels (i.e., suspended organic particles such as detritus, bacteria, and algae; Strayer et al. 2004). Adults may also engage in some pedal feeding (Nichols et al. 2005).

Limiting Factors

The Salamander Mussel may be limited by its complex life cycle and by its dispersal mechanism. The dependency on a host for development (as described above) may limit reproduction because any change that affects the host species can also affect the mussel. In addition, this species also appears to be specific in its host selection with the only known host being the Mudpuppy Salamander (Barnhart et al. 1998). The availability and health of the host species may also pose a limitation to the species.

Refer to the Limiting Factors for the Northern Riffleshell for information on freshwater mussel dispersal.

1.5 Rayed Bean

1.5.1 Species Information

Common Name: Rayed Bean
Scientific Name: *Villosa fabalis*
Status: Endangered
Reason for Designation: This freshwater mussel is one of the smallest in Canada. It is found in two rivers in southern Ontario; more than 99% of the estimated total population is found in the Sydenham River. The original COSEWIC assessment (2000) concluded that it had been extirpated from most of its Canadian range and was confined to one river but a new, albeit small, population was discovered in 2004 in the North Thames River. Thirteen live individuals were found between 2004 and 2008 in this river. The main limiting factor is the availability of shallow, silt-free riffle habitat. Both riverine populations are in areas of intense agriculture and urban development, subject to siltation and pollution. Invasive Zebra Mussels have rendered much of the historic habitat unsuitable and pose a continuing threat to one of the last remaining populations.
Occurrence: Ontario
Status History: Designated Endangered in April 1999. Status re-examined and confirmed in May 2000 and April 2010.

The Rayed Bean (*Villosa fabalis* I. Lea, 1831) (Figure 13) is a very small freshwater mussel with a semi-elliptical shape. Females are more broadly rounded and inflated than males. The periostracum is light or dark green and covered with wide or narrow, wavy, darker green rays that are clearly apparent except in old specimens. The beaks are narrow, slightly elevated above the hinge line and not excavated. The hinge teeth are relatively heavy with erect, pyramidal, serrated pseudocardinals, short laterals with diagonal serrations, and a thick interdentum.

The genus *Villosa* is represented by 18 species in North America, only two of which occur in Canada.

Figure 13. Rayed Bean (*Villosa fabalis*).
(Photo Credit: S. Staton, DFO)

1.5.2 Distribution

Global Range – The Rayed Bean was once widely but discontinuously distributed throughout the Ohio and Tennessee River systems, western Lake Erie and its tributaries, and in tributaries to the St. Clair River and Lake St. Clair. In the U.S., Rayed Bean currently occurs in Indiana, Michigan, New York, Ohio, Pennsylvania, Tennessee, and West Virginia (NatureServe 2015). In Canada, it occurs only in southern Ontario (Figure 14).

Canadian Range – Historically, this species was known from western Lake Erie and the Detroit, East Sydenham, and Thames rivers. The current Canadian distribution of Rayed Bean is limited to a 92 km continuous stretch of the East Sydenham River and an 8 km reach of the North Thames River (COSEWIC 2010b; Figure 15).

Percent of Global Range in Canada – Less than 10% of the species' global distribution is currently found in Canada.

Distribution Trend – Rayed Bean has been extirpated from Alabama, Illinois, Kentucky, and Virginia (NatureServe 2015). In Canada, the current range of Rayed Bean has changed little over time. It is found throughout a 92 km reach of the East Sydenham River and a 8 km reach of the North Thames River, where it is successfully reproducing (Woolnough and Mackie 2001; Woolnough 2002; COSEWIC 2010b).

1.5.3 Population Status and Abundance

Global Status and Abundance – The Rayed Bean is considered globally imperilled (G2) and has a national status of imperilled (N2) in the U.S. It is presumed extirpated (SX) in four states, critically imperilled (S1) in six states, and critically imperilled to imperilled (S1S2) in one state (NatureServe 2015). In the U.S., Rayed Bean is now most frequently found in the Ohio drainage. The Rayed Bean was listed as Endangered under the U.S. federal *Endangered Species Act* on February 13, 2012 (USFWS 2012b).

Canadian Status and Abundance – Rayed Bean is considered critically imperilled nationally (N1) and provincially (S1) (NatureServe 2015). The largest remaining population of Rayed Bean in Ontario is restricted to the middle reach of the East Sydenham River. Quantitative surveys in the East Sydenham River have shown densities of > 3 mussels/m^2 and the population appears to be much larger than historically thought (COSEWIC 2010b). The population in the North Thames River is several orders of magnitude less dense than that in the East Sydenham River (COSEWIC 2010b). The species has not been seen in the Detroit River or Lake Erie for more than 40 years.

Percent of Global Abundance in Canada – Less than 20% of the species' global distribution is currently found in Canada.

Population Trend – Although population trends are difficult to quantify due to a lack of numerical data, the species is generally recognized to have significantly declined throughout its range in recent years. The Rayed Bean is considered to be a rare species; however, abundant populations have recently been seen in parts of Ohio and Pennsylvania. In Canada, populations of Rayed Bean have been reported from the Detroit River and Lake Erie near Pelee Island. These locations have not reported Rayed Bean sightings since 1986 and the populations are assumed to be extirpated. It is impossible to estimate trends in the East Sydenham or Thames river populations as historical abundance estimates are not available.

Figure 14. Global distribution of the Rayed Bean (modified from Parmalee and Bogan 1998).

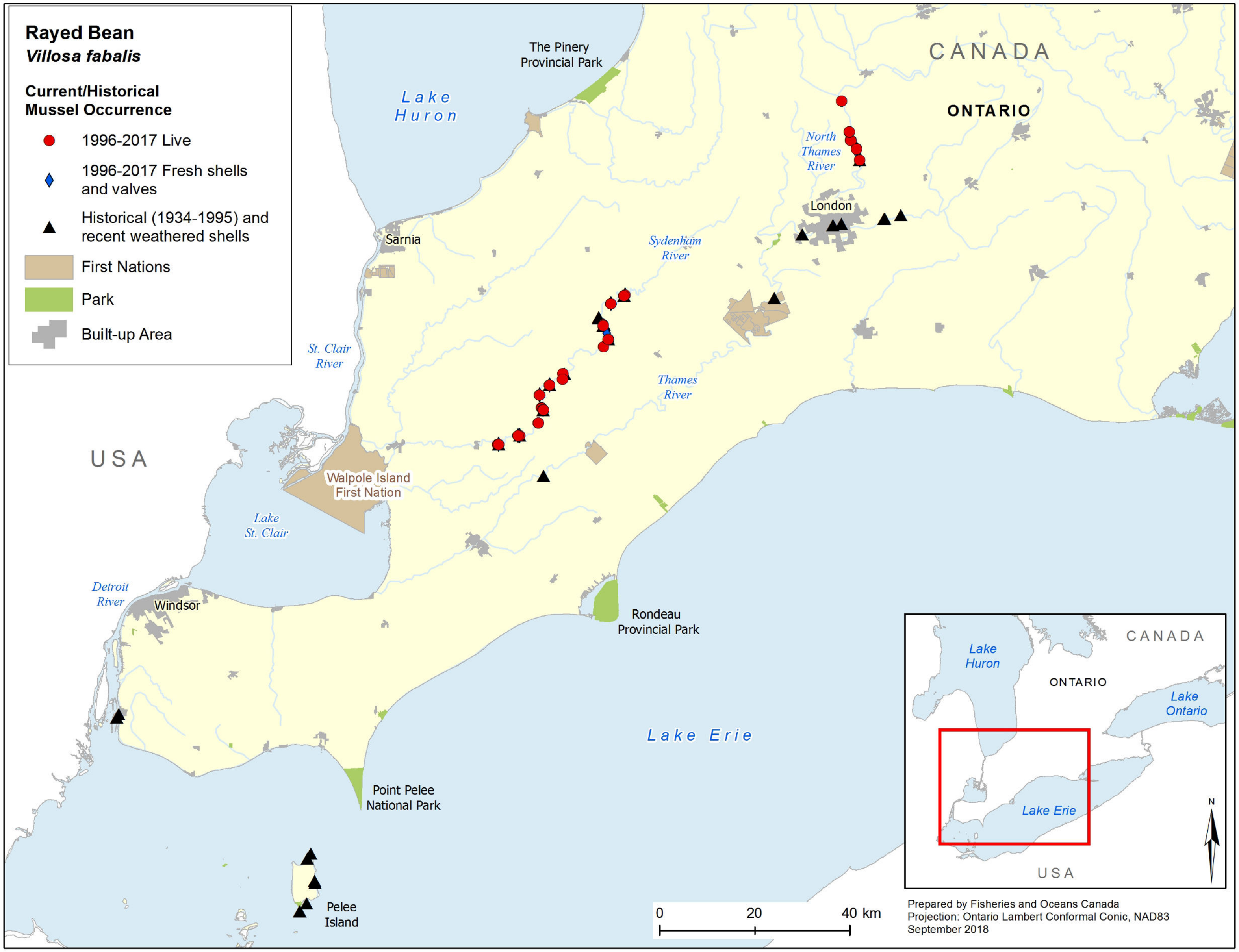

Figure 15. Distribution of Rayed Bean in Canada.

1.5.4 Needs of the Rayed Bean

Habitat and Biological Needs

Spawning: Refer to Section 1.1.4. (Needs of the Northern Riffleshell) for the general reproductive biology of freshwater mussels. The Rayed Bean is a long-term brooder (bradytictic) that holds its glochidia over winter for spring release. The specific time frame for fertilization requires further research. Females in the East Sydenham River are gravid from late May until early August in water temperatures of 14 – 28°C (Woolnough 2002; McNichols 2007). Water temperatures required for successful gamete development (and perhaps gamete release) have not been recorded for the Rayed Bean.

Encysted Glochidial Stage: Refer to Section 1.1.4. (Needs of the Northern Riffleshell) for general biology and habitat information on freshwater mussel glochidia. Little is known about Rayed Bean reproduction; however, an active mantle flap has been recorded during recent surveys and the gravid female gapes, exposing its bright, white marsupia, which contain glochidia (Woolnough 2002; Zanatta 2009). The timing of encystment is unknown, but suspected to begin in May as this is when gravid females have been observed. Laboratory experiments have shown that glochidia can stay encysted on the host between seven and 28 days (Woolnough 2002; McNichols 2007). In nature, this length of time could be longer or shorter depending on environmental conditions such as water temperature. During encystment, immature juveniles will feed on the body fluids of the host and development will occur, but with very little growth (COSEWIC 2010b). Woolnough (2002) identified four host species for the Rayed Bean: Greenside Darter (*E. blennioides*), Largemouth Bass, Mottled Sculpin, and Rainbow Darter. Further host fish experiments have been completed and a small number of juveniles have developed on Brook Stickleback, Johnny Darter, and Logperch; however, these data must be interpreted with caution as low numbers (< 10) developed (McNichols and Mackie 2004; McNichols 2007). Further research is required to determine the functional host(s); however, the Greenside Darter appears to be the most likely candidate as there are large numbers present in the East Sydenham River (D. Woolnough, UG, unpubl. data). The upper and lower temperature thresholds required for metamorphosis and excystment have not been studied for the Rayed Bean but laboratory experiments have been successful at 19.5°C (McNichols 2007).

Juvenile: Refer to Section 1.1.4. (Needs of the Northern Riffleshell) for general biology and habitat information on juvenile freshwater mussels. After excysting from the host, juvenile Rayed Bean will settle in the river bottom as free-living juveniles where they will remain buried for three to five years until they sexually mature, after which they will move to the surface for reproduction (Balfour and Smock 2005; Schwalb and Pusch 2007). Because populations of Rayed Bean in the East Sydenham River show evidence of recruitment, it appears that the quality of the habitat in at least some reaches is suitable. Until the habitat requirements of Rayed Bean juveniles are defined, optimal habitat requirements will be described in the adult section below.

Adult: Cummings and Mayer (1992) describe Rayed Bean habitat as “lakes and small to large streams in sand or gravel”. It is occasionally reported from shallow water areas of lakes and large rivers (TNC 1996). For example, historical records show that it has been found along the edges of islands in Lake Erie and the Detroit River. The Rayed Bean is usually found deeply buried (~ 5 – 15 cm) in the substrate, among the roots of aquatic vegetation. Live specimens encountered in the East Sydenham River (Metcalfe-Smith et al. 1998, 1999) were found buried in stable substrates of sand or fine gravel, generally in low flow areas along the margins of the river or the edges of small islands. A monitoring program for the East Sydenham River was developed between 1999 and 2003 (Metcalfe Smith et al. 2007). During this study, Rayed Bean was observed at ten of 12 sites and these sites had a water depth between 12 – 26 cm (summer depth) and velocity of 0.16 – 0.31 m/s. Woolnough (2002) found that Rayed Bean was most abundant in areas characterized by higher flow (> 0.5 m/s); therefore, this species may not be as sensitive to flow rate fluctuations in its habitat as some other mussel species (TNC 1987). Substrate type in the East Sydenham River where Rayed Bean was found was made up of an average of 15% boulder, 21% rubble, 27% gravel, 21% sand, 11% silt, 0.29% clay, and 0.60% muck (Metcalfe-Smith et al. 2007). In the East Sydenham River, Rayed Bean abundance has been positively associated with sites that are dominated by gravel and sand substrate, and it is never present at sites that are dominated by silt (Staton et al. 2003). It appears as though the Rayed Bean relies on the presence of gravel substrate for stability in flowing rivers where adults use byssal threads to anchor themselves, which has been suggested to be an adaptation to their small size relative to other freshwater mussels (Woolnough 2002; COSEWIC 2010b). Further studies are required to determine optimal habitat characteristics in the Thames River.

There is no direct information on the thermal tolerance of the Rayed Bean; however, water temperatures at sites where live specimens were found in the East Sydenham River between 2002 and 2010 (summer and fall temperatures) were between 14.5 – 26°C (J. Ackerman, UG, unpubl. data).

Age at maturity is unknown for the Rayed Bean. However, the average age of maturity for unionids is 6 – 12 years (McMahon 1991), which is the estimated generation time for this species (COSEWIC 2010b).

Although the exact food preferences and optimum particle sizes siphoned by adult Rayed Bean are unknown, they are probably similar to those of other freshwater mussels (i.e., suspended organic particles such as detritus, bacteria and algae; Strayer et al. 2004). Adults may also engage in some pedal feeding (Nichols et al. 2005).

Limiting Factors

The Rayed Bean may be limited by its complex life cycle and by its dispersal mechanism. The dependency on a host for development (as described above) may limit the reproduction of the Rayed Bean because any change that affects the host species can also affect the mussel. The availability and health of the host species may also pose a limitation to the species. To date, seven hosts have been identified; however, it is likely that only a few of these are functional hosts in nature. Therefore, further research is required to identify primary versus marginal hosts in the lab, as well as specific functional hosts.

Refer to the Limiting Factors for the Northern Riffleshell for information on freshwater mussel dispersal.

1.6 Ecological Role

Freshwater mussels play an integral role in the functioning of aquatic ecosystems (Vaughn et al. 2004). Vaughn and Hakenkamp (2001) have summarized much of the literature relating to the role of unionids and identified numerous water column and sediment processes mediated by the presence of mussel beds (e.g., nutrient cycling, control of phosphorus abundance). Vaughn et al. (2008) demonstrated the importance of mussel communities to aquatic ecosystem food webs. Welker and Walz (1998) have shown that freshwater mussels are capable of limiting plankton in European rivers while Neves and Odom (1989) reported that mussels also play a role in the transfer of energy to the terrestrial environment through predation by muskrats and raccoons.

1.7 Threats

All five mussel species are exposed to a wide range of stresses throughout their range. In the Sydenham River watershed, Jacques Whitford Environment Ltd. (2001) determined the principal anthropogenic stresses affecting populations of species at risk to be loadings of suspended solids causing turbidity and siltation, nutrient loads, contaminants, thermal effects, and invasive species. These likely represent the most significant threats to these species across their entire Canadian range. The following discussion emphasizes threats in the Ausable, Sydenham, and Thames rivers, and St. Clair River delta; areas where extant reproducing populations can still be found.

1.7.1 Threat Classification

Threats believed to be affecting Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are listed in Table 1. Seven potential threats were ranked based on their expected relative impacts, spatial and temporal nature, and expected severity.

Table 1. Threat classification to extant populations of Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean.

Threat	Relative Impact	Spatial Nature	Temporal Nature	Certainty of Effect
Invasive Species (e.g., dreissenid mussels*, Round Goby**)	Predominant	Widespread	Chronic	Probable
Siltation and Turbidity	Predominant	Widespread	Chronic, episodic	Probable
Nutrient Loads	Contributing	Widespread	Chronic, episodic	Speculative
Toxic Compounds	Contributing	Widespread	Chronic, episodic	Speculative
Thermal Effects	Contributing	Widespread	Chronic	Speculative
Habitat Removal and Alteration	Contributing	Localized	Chronic	Speculative
Decline in Host Fish	Contributing	Widespread	Chronic	Speculative

*Zebra Mussel and Quagga Mussel (*D. bugensis*); ***Neogobius melanostomus*

1.7.2 Description of Threats

The following brief description emphasizes the principal threats currently acting on these mussel populations.

Invasive Species

The introduction and spread of dreissenid mussels throughout the Great Lakes in the late 1980s has decimated native mussel populations in the lower Great Lakes region of Ontario (Gillis and Mackie 1994; Schloesser et al. 1996; Schloesser et al. 2006). Zebra Mussel and Quagga Mussel attach to a native mussel's shell and interfere with feeding, respiration, excretion, and locomotion (Haag et al. 1993; Baker and Hornback 1997). The refuge for native mussels in the St. Clair River delta raises hope for their continued coexistence with dreissenid mussels; however, it is not known if this native mussel community is stable or simply in a slower decline than other Great Lakes communities (Zanatta et al. 2002). Recent data from 2011 do not support a stable mussel community but one that continues to decline (T. Morris, DFO, pers. comm. 2012). It is clear that dreissenid mussels pose the most significant threat to all native mussels within the St. Clair River delta.

In the East Sydenham River, dreissenid mussels are currently found only in the lower reaches of the river. It is unlikely to threaten existing populations of these five mussel species as the river is not navigable by boats and has no impoundments that could support a permanent colony (Dextrase et al. 2003). However, the reservoirs at Coldstream and Strathroy in the East Sydenham River headwaters are of some concern. Dreissenid mussels are not currently found within the Ausable River or its reservoirs (e.g., Morrison Dam Reservoir); however, should they become established, they will represent a significant threat to these species. Dreissenid mussels were first found in the Thames River in Fanshawe Reservoir in 2002 and have since successfully colonized it, and can now be found downstream in the Thames River all the way to Thamesville (Upper Thames River Conservation Authority [UTRCA] 2011). In the lower Thames River, near Big Bend, Zebra Mussel have been found attached to adult unionids (Morris and Edwards 2007).

Any threats that affect the host species' abundance, movements, or behaviour during the period of glochidial release or attachment must be considered as threats to these mussels as well. For example, the invasive Round Goby has been implicated in the following declines of native benthic fish species, most of which appear to be hosts for these mussel species, in the lower Great Lakes: 1) Logperch and Mottled Sculpin populations in the St. Clair River (French and Jude 2001); 2) Johnny Darter, Logperch, and Trout-perch (*Percopsis omiscomaycus*) in Lake St. Clair (Thomas and Haas 2004); and, 3) Channel Darter (*P. copelandi*), Fantail Darter (*E. flabellare*), Greenside Darter, Johnny Darter, and Logperch in the Bass Islands, western Lake Erie (Baker 2005). Index trawling data from 1987 to 2004 (Lake Erie Fisheries Assessment Unit, MNRF, unpubl. data) indicate that similar declines of fish species have occurred in Inner Long Point Bay and the western basin of Lake Erie. Potential causes include Round Goby predation on eggs and juveniles, competition for food and habitat, and interference competition for nests (French and Jude 2001; Janssen and Jude 2001). A study has estimated that 89% of benthic fishes and 17% of mussels that occur in rivers where the secondary invasion of the Round Goby has occurred have been or will be negatively impacted (Poos et al. 2010). In particular, Poos et al. (2010) reported Round Goby in the lower portions of several rivers including the Sydenham, Ausable, and Thames rivers between 2003 and 2008, suggesting that an upstream invasion was in progress. This study also predicted a high degree of potential impact to benthic host fishes of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean as well as other endangered mussels. The continued spread of Round Goby thus poses a real threat to host fish populations and could devastate remaining mussel populations by disrupting their reproductive cycle. Round Goby has been detected in the lower Thames River as far upstream as Thamesville (UTRCA 2011) and in the Sydenham River (Poos et al. 2010).

Another invasive species that may currently be exerting negative effects in the Sydenham River is the Common Carp (*Cyprinus carpio*). This species is abundant throughout the watershed and is likely to be adversely affecting sensitive species. Although it can potentially consume juvenile mussels and dislodge adult mussels, its uprooting of plants and feeding on sediment-associated fauna can significantly increase turbidity, which is likely of far greater impact (Dextrase et al. 2003).

Additional introductions of invasive species into these waters are most likely to occur through the movement of boats from infested areas, the use of live baitfishes, or the natural invasion of species introduced into the Great Lakes basin.

Siltation and Turbidity

Loading of suspended solids causing turbidity and siltation is presumed to be the primary limiting factor for most species at risk in the Ausable, Sydenham, and Thames rivers. The majority of rare mussel species depend on clean gravel and sand riffles and are particularly vulnerable to siltation. Siltation can bury and smother mussels as well as interfere with feeding and successful reproduction. Species that burrow completely in the substrate may be more sensitive to sedimentation than most other mussel species because an accumulation of silt on the streambed would reduce flow rates and dissolved oxygen (DO) concentrations below the surface (Watson et al. 2000b). The Salamander Mussel may be directly impacted by siltation due to silt settling around the flat rocks, logs and other debris under which it is found. In addition, the Salamander Mussel may be indirectly affected as there is some evidence that siltation has resulted in the extirpation of the Mudpuppy Salamander from some areas through reduced access to nesting sites and hiding places (Gendron 1999).

Farming practices that may result in increased siltation rates include allowing livestock access to streams, which can result in stream bank instability; installation of tile drainage systems; and, clearing of riparian vegetation. Erosion due to poor agricultural practices can result in siltation and shifting substrates that can smother mussels. Additionally, forestry operations often lead to increased sediment loading to streams and rivers.

Southern Ontario is Canada's most populated area; therefore, there are concerns that relate to residential and urban development, including increased rates of siltation resulting from sewage system outflows and the removal of riparian buffers.

Nutrient Loads

Phosphorus and nitrogen compounds, primarily from agriculture, are at high levels within these watersheds and represent potential risks to aquatic fauna. Mean levels of total phosphorus at sites on the East Sydenham River ranged from approximately 0.075 to 0.13 mg/L, and the levels in the North Sydenham basin were about two times higher (St. Clair Region Conservation Authority 2008). Not surprisingly, nitrogen has replaced phosphorus as the limiting nutrient in the system. Although there has been no evidence of blooms of blue-green algae, which can occur when nitrogen is limiting, there is still potential for significant reductions in DO at night.

Nutrient concentrations within the Ausable River typically exceed provincial water quality objectives with mean nitrate concentrations at eight stations within the watershed ranging between 3.5 and 5.6 mg/L between 1965 and 2002 (Ausable River Recovery Team [ARRT]

2005). Phosphorus concentrations are also high within the Ausable River watershed with large proportions (30 – 58%) occurring in the dissolved fraction (Veliz 2003).

Phosphorus and nitrogen loadings have increased steadily and some of the highest livestock loadings for the entire Great Lakes basin have been reported for the Thames River watershed (UTRCA 2004). Mean ammonia concentrations in all sub-basins of the Thames River exceed the federal freshwater aquatic life guidelines (Metcalfe-Smith et al. 2000). Newton and Bartsch (2007) and Wang et al. (2007) demonstrated that juvenile mussels are chronically sensitive to ammonia, which can cause poor growth.

The potential for run-off of fertilizer must be considered where agriculture is present. Accidental spills that have the potential to reduce DO can negatively influence unionid populations (Tetzloff 2001). Manure spills also occur and can have significant nutrient-enriching effects, as well as being acutely toxic to fishes and invertebrates. Similarly, nutrient loadings can result from municipal wastewater discharges, domestic septic systems and run-off associated with lawn maintenance in areas of urban and residential development.

DO levels in the East Sydenham River typically average about 10 mg/L; however, levels at all four Provincial Water Quality Monitoring Stations in this basin have dropped as low as 5 mg/L during the last 35 years (Jacques Whitford Environment Ltd. 2001). Over the same time period, DO levels in the Ausable River have on occasion fallen to comparable levels (2 – 3 mg/L) (Nelson et al. 2003).

Toxic Compounds

Herbicides and insecticides, associated with agricultural practices and urban areas, run off into watersheds and could have a significant impact on species at risk. Roads and urban areas can also contribute significant contaminants to waterways, including oil and grease, heavy metals, and chlorides. A recent study (Gillis 2011) has shown that glochidia of the Wavyrayed Lampmussel (*Lampsilis fasciola*) were acutely sensitive to sodium chloride. Assuming that the salt sensitivities of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are comparable to that of the Wavyrayed Lampmussel, and because their range is limited to southern Ontario, Canada's most road-dense and thus heavily salted region, chloride (from road salt) is a substantial threat to the early life stages. Although water does buffer the toxic effects of chloride to the glochidia, chloride levels in mussel habitat have been reported at levels (> 1300mg/L) that are toxic to these species (Gillis 2011). Until about 1990, chloride levels in particular were high enough in the North Sydenham River to cause significant biological impairment. Chloride concentrations at all three monitoring sites in the north branch were as high as 1000 mg/L between 1967 and 1990, often exceeding 200 mg/L, which is the concentration estimated to cause long-term toxicity to some freshwater organisms (Evans and Frick 2002). Prior to 1990, saline formation waters produced from local oil wells were released to surface waters in the North Sydenham watershed. Since then, these waters have been injected back into the ground, and chloride concentrations have declined to levels similar to those in the East Sydenham River (10 – 50 mg/L).

Pesticide run-off (e.g., herbicides and insecticides) associated with agricultural practices and urban areas enter the Ausable River basin and could have a significant impact on species at risk. For example, tributary monitoring at the mouth of the Ausable River for currently used pesticides in 2002 indicated that both atrazine and des-ethyl atrazine were found to exceed federal guidelines for the protection of aquatic life (ARRT 2005). The extent and impact of these and other toxic contaminants (e.g., chloride) are just beginning to receive attention, and studies have shown that glochidia and juvenile mussels are among the most sensitive to environmental contaminants (Bringolf et al. 2007; Gillis et al. 2008; Gillis 2011). It is likely that this threat is widespread as the primary source of pesticides is from agricultural land.

Many forms of pollution resulting from human activity may be present in Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean habitat (e.g., run-off of lawn fertilizers and pesticides, road salts, and heavy metals from industrial sources) (e.g., Pip 1995). Exposure to municipal wastewater effluent can also negatively affect unionid health (e.g., Gagné et al. 2004; Gagnon et al. 2006; Gagné et al. 2011, Gillis 2012, Gillis et al. 2017). Pharmaceuticals can enter streams, rivers and lakes, largely via effluent from sewage treatment plants. There is increasing concern about possible endocrine and reproductive effects from these chemicals on aquatic biota; related work with unionids is in its infancy (see Cope et al. 2008), but there is reason for concern as significant effects on freshwater fish communities have been demonstrated (Kidd et al. 2007), including reports of feminization of fishes in the Grand River, a significant mussel habitat in Ontario (Tetreault et al. 2011). Gagné et al. (2011) determined that Eastern Elliptio (*Elliptio complanata*) in Quebec showed a dramatic increase in the number of females, and that males showed a female-specific protein downstream of a municipal effluent outfall, demonstrating that pollution is disrupting gonad physiology and reproduction of this species.

The severity of impacts of toxic compounds is likely linked to duration and intensity of exposure. Contaminants can directly kill the individual, its food or can slowly degrade the watercourse affecting all life history parameters. Contaminants can be chronic or episodic and may also be cumulative (Thames River Recovery Team [TRRT] 2004). Since mussels live in the substrate, the consequences of toxic substances may be greater for mussels than other aquatic animals.

Johnson et al. (2001) have found mussel survival rates are closely related to DO levels, while Tetzloff (2001) reported massive mussel die-offs in Big Darby Creek, Ohio, following a low oxygen event resulting from a chemical spill.

Thermal Effects

The loss of riparian zones in agricultural lands increases solar radiation reaching the stream surface. Although there are riparian corridors along the Sydenham River and its tributaries, these vary in width and quality, and there are extensive reaches lacking riparian zones. Reservoirs also increase temperatures by increasing surface area and by water holding. There are six reservoirs in the Sydenham River watershed at conservation areas in Strathroy, Coldstream, Petrolia, Alvinston, Henderson, and Warwick that have potential thermal impacts. Finally, global climate change is expected (among other disruptions) to cause an increase in surface water temperatures in southern Ontario. Although the Sydenham River supports a warmwater environment, and many species are tolerant of warm water, higher water temperatures may be an added stress for some. Increased water temperatures may also increase algal growth, which could result in reductions in DO levels at night.

Habitat Removal and Alteration

Destruction of habitat through grading, excavation and other forms of channelization, including measures that result in flow reduction and practices that result in changes in water temperatures, can have negative effects on these mussel species. River channel modifications such as dredging can result in the direct destruction of mussel habitat and lead to siltation and sand accumulation of local and downstream mussel beds.

The construction of impoundments can lead to the fragmentation of habitat (which can limit the reproductive capabilities of mussels by eliminating or decreasing the number of hosts available), altered water levels, habitat conversion, and the clearing of riparian zones, resulting in the loss of cover, increased rates of siltation, and thermal shifts. Altered water levels (whether it be from impoundments or climate change) may have large impacts on mussels and their hosts. Spooner et al. (2011) used a model to determine how a decrease in water quantity would affect species-discharge relationships using mussels and their host fish species. This study showed that there will be severe reductions in mussel and fish richness due to changes in climate change and water use. This will not only directly affect fishes and mussels, it will have a huge negative effect on food webs and nutrient recycling (Spooner et al. 2011).

Driving motor vehicles (e.g., all-terrain vehicles [ATVs]) through streams may negatively impact mussel beds. ATVs are noted as a potential threat to mussel beds in the Ausable, Sydenham, and Thames rivers, where ATVs travel up and down waterways, crushing mussel beds (Bouvier and Morris 2011) and disrupting substrates and water clarity.

Decline in Host Fish Species

Due to the parasitic stages in their life cycle, the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are sensitive not only to environmental factors that limit them directly, but also to factors that affect their hosts (Burky 1983; Bogan 1993). Therefore, any factor that changes the abundance or species composition of host fauna may have detrimental effects on mussel populations.

Seven glochidial hosts have been identified for Northern Riffleshell in Canada: Blackside Darter, Brook Stickleback, Iowa Darter, Johnny Darter, Logperch, Mottled Sculpin, and Rainbow Darter (McNichols 2007). The Iowa Darter and Mottled Sculpin appear to be the primary host in the laboratory (McNichols et al. 2011).

Snuffbox was thought to have had two host species in Ontario, namely Blackside Darter and Logperch. Historical data on the distribution of these two species indicate that Logperch was likely the primary host as its distribution is more similar to that of Snuffbox (Watson et al. 2000a). Recent records of Blackside Darter show that it presently occupies the same reach of the East Sydenham River as Snuffbox. However, it is a less likely host as it was never found in the reaches of the Grand and Thames rivers where Snuffbox historically occurred. Infestation experiments at the University of Guelph have shown that the primary and most likely functional host (distributional overlap with Snuffbox) of the Snuffbox is the Logperch (McNichols 2007; Schwalb et al. 2011).

In the U.S., the glochidial hosts of Round Pigtoe are known to be Bluegill, Bluntnose Minnow, Northern Redbelly Dace, Southern Redbelly Dace, and Spotfin Shiner. All but Southern

Redbelly Dace are known to occur in the East Sydenham River and are likely hosts for Round Pigtoe in Canada.

Host fish identification studies at the University of Guelph (Woolnough 2002; McNichols 2007) have found that seven species served as successful hosts for Rayed Bean including Brook Stickleback, Greenside Darter, Johnny Darter, Largemouth Bass, Logperch, Mottled Sculpin, and Rainbow Darter. Greenside Darter, Logperch, and Rainbow Darter have been confirmed as hosts during repetitive studies (McNichols 2007). These species have been found in the East Sydenham River, although Brook Stickleback and Mottled Sculpin are not abundant and distributions do not overlap with that of Rayed Bean (M. Poos, DFO, unpubl. data).

Most of the host fish species for Northern Riffleshell, Snuffbox, Round Pigtoe, and Rayed Bean are considered to be relatively common species, and none are believed to be at risk. Recent surveys of the Ausable (Nelson et al. 2003), Grand (Mandrak et al. 2006a; Mandrak et al. 2006b), Sydenham (M. Poos, DFO, unpubl. data; N. Mandrak, DFO, pers. comm. 2004), and Thames (Edwards and Mandrak 2006; Mandrak et al. 2006b) rivers have found many of these species to be present in variable numbers.

The only known host for the Salamander Mussel is the Mudpuppy Salamander. The status of the Mudpuppy Salamander in Canada is Not at Risk (Gendron 1999). Significant limiting factors for the Mudpuppy Salamander include habitat loss as a result of severe siltation and environmental contamination, particularly the use of the lampricide TFM. Indications of extirpations from formerly occupied habitats are relatively few, although Gendron (1999) did report the loss of the species from the highly impacted Hamilton Harbour, and low capture rates at several localities in lakes Erie, Ontario, and St. Clair in 1995. McDaniel and Martin (2003) conducted surveys of Mudpuppy Salamander in the Sydenham River in 2002-2003 and found a total of 61 animals with densities estimated at between 13 – 22 animals per 100/m^2. The highest densities were observed between Dawn Mills and Shetland with no records above Alvinston.

Any activity that disrupts the connectivity between mussel populations and their host species must be taken into consideration. Activities that may disrupt the mussel-host relationship include, but are not limited to: damming, dewatering, and sport or commercial harvest. Note that activities occurring outside the currently occupied habitat zone may affect the host population within the zone (e.g., downstream damming activities may prevent the movement of fishes into the zone during the period of mussel reproduction). Any activity that impacts a host population within an area of currently occupied habitat should be evaluated to ensure that the reproductive cycle is not disrupted.

1.8 Actions Already Completed or Underway

Reporting: The original recovery strategy was posted in 2006 and a five year progress report on the original strategy was completed in 2012 (DFO 2013). This report summarizes what has been accomplished and/or learned over the past five years.

Status Reports: Updated COSEWIC status reports have been completed for the Northern Riffleshell (COSEWIC 2010a), Snuffbox (COSEWIC 2011a), and Rayed Bean (COSEWIC 2010b). Status Appraisal Summaries have been completed for the Salamander Mussel (COSEWIC 2011b) and Round Pigtoe (COSEWIC 2014).

Recovery Potential Assessments (RPA): This process began in 2007 on fish species, and were then completed for mussel species beginning in 2011 (DFO 2010, 2011b). These assessments were developed by the Ecosystems and Oceans Science sector in DFO to provide scientific advice and information required to fulfill the requirements of SARA. Although there is no specific RPA (to date) for Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean, mitigations and alternatives listed in other mussel RPAs will benefit these species.

Ecosystem-Based Recovery Strategies: Each recovery team is co-chaired by DFO and a conservation authority and receives support from a diverse partnership of agencies and individuals. Recovery activities implemented by these teams include active stewardship and outreach/awareness programs to reduce identified threats. Funding for these actions is supported by Ontario's Species at Risk Stewardship Fund and the Government of Canada's Habitat Stewardship Program (HSP) for species at risk. Additionally, research requirements for species at risk identified in recovery strategies are funded, in part, by the federal Interdepartmental Recovery Fund (IRF). Note: Although these recovery strategies are supported by DFO, they are not formally endorsed as recovery strategies under SARA.

Sydenham River Action Plan: This action plan is a multi-species, ecosystem-based plan that addresses the needs of seven freshwater mussels as well as two species of fishes: the Eastern Sand Darter (*Ammocrypta pellucida*) and Northern Madtom (*Noturus stigmosus*) (DFO 2018a). The plan builds on the recovery program established ten years earlier by the Sydenham River Recovery Team (Dextrase et al. 2003); it targets stewardship actions for maximum effectiveness in threat mitigation at the landscape level to recover multiple aquatic species at risk that share similar threats and habitat. A network of monitoring sites (15 stations) for mussel species at risk was established in 2003 (see Metcalfe-Smith et al. 2007).

Ausable River Ecosystem Recovery Strategy: This plan covers four Endangered mussel species including the Northern Riffleshell and Snuffbox. The overall goal of the strategy is to "sustain a healthy native aquatic community in the Ausable River through an ecosystem approach that focuses on species at risk" (ARRT 2005). Stewardship efforts are ongoing and a monitoring program (seven stations) to track the recovery of endangered freshwater mussels in the Ausable River has been established (Baitz et al. 2008).

Ausable River Action Plan: The Action Plan for the Ausable River in Canada: An Ecosystem Approach (DFO 2018b) includes recovery activities for both Northern Riffleshell and Snuffbox. The Action Plan includes implementation schedules with 34 prioritized measures to support the recovery of the target fish and mussel species at risk. To maximize the effectiveness of threat mitigation, priority sub-watersheds of the Ausable River watershed have been identified for stewardship activities to benefit critical habitat.

Thames River Recovery Ecosystem Strategy: The stated goal is to develop "a recovery plan that improves the status of all aquatic species at risk in the Thames River through an ecosystem approach that sustains and enhances all native aquatic communities" (TRRT 2004). This recovery strategy addresses 25 COSEWIC-assessed species including seven mussels, 12 fishes, and six reptiles. Four of the five mussel species are being considered in the development of this strategy: Northern Riffleshell, Round Pigtoe, Salamander Mussel, and Rayed Bean. Recovery actions proposed by the TRRT will increase the likelihood that recovery habitat for these species in the Thames River will prove suitable for possible future reintroductions. As with the Ausable and Sydenham rivers, a monitoring program has been established to track the health of mussel populations in the Thames River (12 stations).

Grand River Fish Species at Risk Recovery Strategy: The goal of this strategy is "to conserve and enhance the native fish community using sound science, community involvement and habitat improvement measures" (Portt et al. 2003). Although the strategy does not directly address any mussel species, their "habitat preferences and requirements will be taken into account when assessing management actions targeting fish species at risk. In most cases, it is anticipated that recovery actions benefiting fishes at risk will also benefit these other rare species" (Portt et al. 2003). Seven mussel monitoring stations have been established in the Grand River (in 2007/2010).

Walpole Island Ecosystem Recovery Strategy: The Walpole Island Ecosystem Recovery Strategy Team was established in 2001 to develop an ecosystem-based recovery strategy for the area containing the St. Clair River delta, with the goal of outlining steps to maintain or rehabilitate the ecosystem and species at risk (Walpole Island Heritage Centre 2002). Although the strategy is initially focusing on terrestrial ecosystems, there are future plans to include aquatic components of the ecosystem.

Host Fish Identification: A research group led by Dr. J. Ackerman and Dr. G. Mackie has been established at the University of Guelph to investigate aspects of the reproductive cycle of freshwater mussels (host fish determination, glochidial development, juvenile growth and survival). The group conducts its research at the Hagen Aqualab on the grounds of the University in Guelph, Ontario, Canada. This facility has been used to investigate potential hosts for six species of endangered mussels including Northern Riffleshell, Rayed Bean, and Snuffbox (McNichols 2007). See Sections 1.1.4, 1.2.4, 1.3.4, 1.4.4 and 1.5.4. (Habitat and biological needs) for results of host species identification experiments.

Stewardship Activities: Stewardship activities occurring throughout the ranges of these five mussel species are able to occur, in large part, because of funding obtained through the federal HSP.

Stewardship programs are available at all conservation authorities for projects involving tree planting; stream stabilization; wetland creation; buffer strips; grassed waterways; sediment traps; repair or replacement of faulty septic systems; manure storage facilities; clean water diversions; run-off collection systems; fencing livestock from watercourses; plugging and repairing wells; nutrient management plans; and, the Ontario Drinking Water Stewardship Program. Implementation of these projects improves and protects rural water quality, and the habitat for aquatic species at risk.

Mussel Monitoring Network: Fifteen permanent monitoring stations for mussels have been established within the Sydenham River. An additional six stations were established during 2004/2005 in the Thames River and seven sites were established on the Ausable River in 2006. These sites will be part of an ongoing monitoring system as part of the Ausable, Sydenham, and Thames ecosystem recovery strategies, and will provide quantitative trend through time data to evaluate recovery actions as well as the overall status of mussel communities. Additionally, nine monitoring stations were established in the St. Clair River delta in 2003-2004.

***Nutrient Management Act*:** Implementation of this provincial legislation, which came into force September 30, 2003, will regulate the storage and use of nutrients including manure, farmyard run-off, and farm washwater. This should reduce nutrient inputs to the watercourses, which will benefit the aquatic habitats of freshwater mussels.

***Ontario Clean Water Act*:** This Act, which came into effect in 2006, protects Ontario's source water via local committees that list existing and potential threats, and implement actions that will reduce or eliminate these threats (OMOE 2011). This allows communities to take a "hands on" approach to conserve and protect their own watersheds and it is based on sound science. This will benefit all aquatic species; however, it is particularly important for freshwater mussels as they have been found to be sensitive to copper, ammonia, and nitrogen (see Section 1.7 Threats).

***Ontario Water Resource Act*:** This Act came into effect in 1990. It is directed towards both ground and surface water throughout the province of Ontario, with the goal of conserving, protecting, and managing Ontario's water resources (OMOE 2011). This should aid in preventing further degradation of aquatic habitats in which these mussel species occur.

***Ontario Environmental Protection Act*:** This is the main legislation for environmental protection, which came into effect in 1990. It prohibits the discharge of any contaminants (causing negative effects) into the environment, and requires that any spills of pollutants be reported and cleaned up in a timely fashion (OMOE 2011). This will reduce the amount of pollution entering aquatic ecosystems, which will benefit all mussel species.

1.9 Biological and Technical Feasibility of Recovery

Recovery of the Northern Riffleshell, Snuffbox , Round Pigtoe, Salamander Mussel, and Rayed Bean is believed to be both biologically and technically feasible as reproducing populations still exist as potential sources to support recovery, suitable habitat can be made available through recovery actions, threats can be mitigated, and proposed recovery techniques are anticipated to be effective.

- Mussels are slow-growing and sessile animals that depend on their host fishes for the survival and dispersal of their young. The slow rate of population growth of freshwater mussels makes the natural recovery of decimated populations extremely difficult.
- The habitat in the Ausable, Grand, Sydenham, and Thames rivers could be improved significantly with proper stewardship of both agricultural and urban lands in the watershed.
- Reductions in soil erosion and turbidity in all the watersheds can be achieved but would be challenging due to the number and intensity of the impacts.
- Removing the impacts of dreissenid mussels to the St. Clair River delta population is not possible; however, it may be possible to establish managed refuge sites to reduce the impacts of Zebra Mussel on Round Pigtoe.

A high level of effort will be required to recover Northern Riffleshell in the Ausable River, Rayed Bean in the North Thames River, and Round Pigtoe populations. There is little evidence of natural reproduction within these populations and recovery may require captive breeding and/or relocations from U.S. populations.

A low to moderate level of effort will be required to recover the Sydenham River populations of Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean, and the

Ausable River Snuffbox populations. These populations are believed to be threatened by general habitat loss resulting from characteristic land-use practices within the basin. A general suite of ecosystem recovery actions such as those proposed by Dextrase et al. (2003) will assist with the recovery of these populations.

Recovery of the St. Clair River delta populations of Round Pigtoe and Northern Riffleshell will require a higher degree of effort. Active management of selected refuge sites including the regular cleaning of dreissenid mussel-infested individuals will be required to maintain and recover these populations. Long-term population augmentation and/or translocations may also be required to return the Round Pigtoe to healthy self-sustaining levels in Canada.

2 RECOVERY

2.1 Recovery Goal

The long-term goals of this recovery strategy are to:

i. Prevent the extirpation of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean in Canada;
ii. To maintain/return healthy self-sustaining Northern Riffleshell populations to the Ausable and East Sydenham rivers, and to reintroduce healthy self-sustaining populations to the Thames River and the St. Clair River delta;
iii. To maintain/return healthy self-sustaining populations of Snuffbox to the Ausable and East Sydenham rivers, and to reintroduce healthy self-sustaining populations to the Grand and Thames rivers;
iv. To maintain/return healthy self-sustaining populations of Round Pigtoe to Bear Creek, East Sydenham River, and St. Clair River delta, and to reintroduce healthy self-sustaining populations to the Thames and Grand rivers;
v. To maintain/return healthy self-sustaining populations of Salamander Mussel to the East Sydenham River; and,
vi. To maintain/return healthy self-sustaining populations of Rayed Bean to the East Sydenham and Thames rivers.

These populations can only be considered recovered when they have returned to historically estimated ranges and/or population densities and are showing signs of reproduction and recruitment. Because much of the Great Lakes and its connecting channels have been devastated by the introduction of dreissenid mussels, these areas no longer provide suitable habitat for freshwater mussels (DFO 2011a). For this reason, the Detroit River, Lake Erie, Lake St. Clair proper, and the Niagara River are currently excluded from the recovery goal. If, in the future, it is determined that the restoration of suitable habitats in these locations is possible, the recovery goal will be revisited.

2.2 Population and Distribution Objectives

Specifically, the population and distribution objectives are to return/maintain self-sustaining populations of the:

(1) Northern Riffleshell to the Ausable and East Sydenham rivers;
(2) Snuffbox to the Ausable and East Sydenham rivers;
(3) Round Pigtoe to East Sydenham, Grand, and Thames rivers, Bear Creek, and St. Clair River delta;
(4) Salamander Mussel to East Sydenham River; and,
(5) Rayed Bean to the East Sydenham and North Thames rivers.

The populations at these locations could be considered recovered when they have returned to historically estimated ranges and/or population densities and demonstrate active signs of reproduction and recruitment throughout their distribution. More quantifiable objectives (that may include consideration of extirpated populations where suitable habitats may be present) will be developed once necessary surveys and studies have been completed (refer to Section 2.6.5 Schedule of studies to identify critical habitat).

2.3 Recovery Objectives

The five-year recovery objectives are to:

i. Determine extent, abundance and population demographics of existing populations;
ii. Determine host fishes and their distributions and abundances;
iii. Define key habitat requirements to identify critical habitat;
iv. Establish a long-term monitoring program for all species, their hosts and the habitats;
v. Confirm/identify threats, evaluate their relative importance and implement remedial actions to minimize their impacts;
vi. Examine the feasibility of relocations, reintroductions and the establishment of managed refuge sites; and,
vii. Increase awareness about the distribution, threats and recovery of these species.

2.4 Approaches to Meeting Recovery Objectives

The approaches to recovery have been organized into four distinct categories – Research and Monitoring (Table 2), Management (Table 3), Stewardship (Table 4), and Awareness (Table 5). Successful recovery will require consideration of approaches from all categories. A narrative has been included after each table where appropriate.

Recovery of these five species cannot be achieved through the actions of any one party. Implementation of the recovery approaches outlined below will require a concerted effort of many groups including, but not limited to, federal, provincial and municipal governments, conservation authorities, academic institutions, First Nations communities, non-governmental organizations, and local citizens.

Table 2. Recovery planning table - research and monitoring approaches for Northern Riffleshell (NRS), Snuffbox (SB), Round Pigtoe (RP), Salamander Mussel (SM), and Rayed Bean (RB).

Priority	Number	Recovery Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
Urgent	1-1	i, iii	Research – Reproduction	Identify spawning periods of NRS, SB, RP, SM, and RB. Determine length of encystment period on host in nature.	Determine reproductive timing windows for entire life cycle, which will ensure that these stages can be protected. Determine if any of these populations are functionally extirpated.	Component of host fish declines
Urgent	1-2	ii, v	Research – Host Fishes	Continue testing to identify fish species that serve as hosts for the NRS, SB, RP, and RB.	Will help determine if host abundance is limiting factor for the four mussel species. Will assist with refining the identification of critical habitat.	Host fish declines

Priority	Number	Recovery Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
Urgent	1-3	ii, v	Surveys – Host Fishes	Determine the distribution abundance, and health of the host species at sites where NRS, SB, RP, SM, and RB currently occur.	Will help determine if host abundance is limiting the five mussel species.	Host fish declines
Urgent	1-4	iii	Research – Critical Habitat	Determine the habitat requirements for all life stages, particularly for juveniles as very little information can be found on this topic.	Will assist with defining critical habitat for the different life stages of NRS, SB, RP, SM, and RB.	All threats
Urgent	1-5	iii, vi	Research and Surveys – Critical Habitat	Prepare a distribution map of areas of suitable habitat (currently occupied and unoccupied).	Will assist with refining the identification of critical habitat and potential areas of reintroduction. Will assist with explanations of why mussel species are not in habitats/sites that seem suitable.	All threats
Urgent	1-6	vi	Research – Managed Refuge Sites	Investigate the feasibility of establishing actively managed refuge sites in the St. Clair River delta. Results of investigation may lead to future management recommendations.	Will determine if RP in the St. Clair River delta can be insulated from the effects of Zebra Mussel.	Invasive species
Urgent	1-7	iii, iv, v	Research – Water Quality Parameters	Determine water quality requirements for all life stages.	Will determine the physical tolerance thresholds with respect to various water quality parameters (e.g., DO, toxic compounds) and check against existing standards.	Toxic compounds

Priority	Number	Recovery Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
Urgent	1-8	vi	Population Augmentation	Examine the feasibility of translocations and reintroductions.	Will determine if small populations can be augmented or if the species can be reintroduced in historical range.	All threats
Necessary	1-9	i, iv	Monitoring – Mussel and Host Fish Populations	Continue to monitor the current stations and establish new permanent monitoring stations throughout historical and present ranges (if not already established).	Will permit tracking of populations, analysis of trend patterns, and permit the evaluation of recovery actions.	Host fish declines
Necessary	1-10	iv, v	Monitoring – Habitat	Establish permanent monitoring sites for tracking changes in habitat.	Provides trend data for key habitat and will help evaluate the relative threat of habitat loss.	All threats
Necessary	1-11	v	Research – Threats	Identify and evaluate threats to all life stages.	Will assist with determining reasons for declines and developing remedial actions.	All threats
Necessary	1-12	vi	Research – Conservation Genetics	Compare the within and among population genetic variability of Canadian populations and determine if populations show genetic structure by comparing variability between populations in Canadian and U.S. waterways.	Will assist with determining if population translocation or augmentation is appropriate and determining appropriate locations. Identify designatable units and population structure and viability.	All threats

1-1 and 1-3: Very little is known regarding the spawning stages of these species, especially in Canada. It is important that specific spawning periods (sperm release, fertilization, length of encystment on host) are known to inform the protection and recovery of these species. Without this knowledge, it will be difficult to determine the time of year during which these species (mussels and fishes) are susceptible to many of the threats listed above.

The necessity for a period of encystment represents a potential bottleneck in the life cycle of the mussel. Research and recovery actions focusing on the pre- or post-encystment period may prove unproductive if the presence of a host fish is the limiting step. To determine if these species are host limited, it is necessary to first identify the host species and then to confirm that the distributions of the mussel and its host overlap in time and space in a manner that will permit successful encystment. The identification of high host specificity in some mussel species requires that hosts be identified for local populations whenever possible. It is already well documented that the Salamander Mussel is host specific with the Mudpuppy Salamander. Host species for Canadian populations of Northern Riffleshell, Rayed Bean, and Snuffbox have been identified in the laboratory; however, further testing should continue as there are some mixed results (Woolnough 2002; McNichols and Mackie 2004; McNichols 2007). Host species for Canadian populations of Round Pigtoe are based on results from the U.S. Once the Canadian hosts have been confirmed for these species, it is necessary to verify that host species distributions overlap with their respective mussel distributions. Because adult mussels are essentially sessile, this can be accomplished by confirming that members of the host species occur in reaches with mature female mussels at times when the female mussels possess mature glochidia.

1-4 and 1-5: Determination and refinement of critical habitat is an essential component in the recovery of these species. Although adult mussels are relatively passively distributed, distinct habitat types can be associated with adult distributions suggesting that survival is linked to local habitat conditions. Habitat conditions may be equally important during the juvenile stage (optimal substrate, temperature, water chemistry) and attention must also be paid to the habitat preferences of the hosts. The identification and refinement of critical habitat will be a multi-stage process. For more information on the required steps, refer to Section 2.6 (Critical Habitat).

1-6: Remnant populations of Round Pigtoe can be found in the St. Clair River delta despite the presence of Zebra Mussel. Metcalfe-Smith et al. (2004) reported Zebra Mussel infestation rates ranging from < 1 to 36 Zebra Mussel/unionid in this area during 2003. While this rate of infestation is below the lethal limits reported elsewhere (Ricciardi et al. 1995), it may be resulting in long-term chronic effects that are causing prolonged declines. Comparisons of collections made in 2001 with those in 2003 showed that abundance of all unionids had declined by about 14%, while declines were much higher for some species (i.e., 80% decline of Round Hickorynut [*Obovaria subrotunda*]) (Metcalfe-Smith et al. 2004). Although the overall trend was toward declining unionid densities, some sites showed stable overall abundances. These sites were associated with low Zebra Mussel infestation rates and high unionid diversity and may represent potential refuge sites. Because these sites are still affected by Zebra Mussel, it is likely that unionids will need to be actively managed with regular Zebra Mussel removal and the active relocation of Round Pigtoe and other mussel species at risk to these locations from the more heavily infested sites.

1-9 and 1-10: A network of detailed, permanent monitoring stations should be established throughout the present and historical ranges of the five mussel species if they do not already exist. Monitoring sites should be established in a manner so as to permit:

- Quantitative tracking of changes in mussel abundance or demographics (size distribution, age structure etc.) and/or that of their hosts.
- Detailed analyses of habitat use and the ability to track changes in use or availability.
- The ability to detect the presence of invasive species (i.e., Zebra Mussel). Reservoirs represent the likely seed locations for Zebra Mussel in the Ausable, Grand, Sydenham,

and Thames rivers. Monitoring sites should be established within or close to these reservoirs to permit the early detection of Zebra Mussel in the event that it invades these systems. Monitoring of invasive species in the St. Clair River delta will likely be conducted in close association with the managed refuge sites.

Table 3. Recovery planning table - management approaches for Northern Riffleshell (NRS), Snuffbox (SB), Round Pigtoe (RP), Salamander Mussel (SM), and Rayed Bean (RB).

Priority	Number	Recovery Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
Urgent	2-1	i-vi	Capacity Building	Continue to promote and enhance expertise in freshwater mussel identification/biology and provide for the transfer of knowledge.	Will ensure correct identification and understanding of mussel species at risk.	All threats
Urgent	2-2	v, vi	Cooperation – Ecosystem Recovery Strategies	Work with existing ecosystem recovery teams to implement recovery actions.	Ensure a seamless implementation of all recovery actions.	All threats
Necessary	2-3	v	Municipal Planning	Encourage municipal planning authorities to consider critical habitat in official plans.	Will provide further protection for the NRS, SB, RP, SM, and RB to ensure that future development does not degrade important habitat.	Siltation and turbidity, nutrient loads, toxic compounds, thermal effects
Necessary	2-4	v	Reduction of Chloride Loading	Encourage municipalities to adapt Best Management Practices (BMPs) to reduce the use of road salt.	Will reduce the loading of road salt and decrease the potential impact of chloride levels on freshwater mussels.	Water quality
Necessary	2-5	v	Drainage	Work with drainage supervisors, engineers and contractors to limit the effects of drainage activities on mussel habitat.	Will reduce the harmful effects of drainage activities.	Siltation and turbidity, nutrient loads, toxic compounds, thermal effects

Priority	Number	Recovery Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
Necessary	2-6	v	Baitfish	Work with the baitfish industry to reduce the impacts of commercial baitfishing on host species. Update baitfish guide to include information on the mussel life cycle and note potential host fishes and time frames when encystment is likely to occur.	Will provide protection for potential host species. Will increase public knowledge of mussels and the importance of baitfish for natural ecological processes.	Host fishes, invasive species
Necessary	2-7	v	Wastewater Treatment Plants and Stormwater Management Facilities	Evaluate whether wastewater treatment plants are functioning up to specifications and encourage upgrading where appropriate. Review stormwater management facilities for quantity and quality control in new developments, and retro-fit existing development where possible.	Will improve water quality by reducing nutrient and suspended solid inputs from urban centres.	Siltation and turbidity, nutrient loads, toxic compounds
Necessary	2-8	v	Enforcement	Assist federal and provincial enforcement officers in obtaining the necessary information and/or resources required to protect these species and their habitats.	Will ensure that these five species and their habitats receive the necessary protection.	All threats

2-1: The current capacity within southwestern Ontario to perform the necessary survey and monitoring work is insufficient. Knowledge of freshwater mussel identification, distribution, life history and genetics is limited to a small number of individuals from a limited number of government and academic institutions. Furthermore, the retirement and relocation out of province of several key researchers has occurred. A concerted effort must be made to increase this capacity by:

- Training personnel in the identification of all mussel species with emphasis on the rare species (e.g., DFO freshwater mussel identification course, freshwater mussel application for IPhone).
- Promote the use of the freshwater mussel field guide (Metcalfe-Smith et al. 2005).
- Encourage graduate and post-graduate research aimed at fulfilling the needs identified under Research and Monitoring.
- Encouraging the public to learn more about freshwater mussels and their importance.

2-2: Many of the threats to the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean can be classified as widespread and chronic (Table 1) and represent general ecosystem threats affecting numerous other aquatic species. Efforts to remediate these threats will benefit many species in addition to these five mussel species and should be attempted in close connection with the aquatic ecosystem recovery teams for the Ausable, Sydenham, and Thames rivers (see Section 1.8 Activities Already Completed or Underway) to eliminate duplication of efforts and ensure that undertaken activities are not detrimental to other species.

2-5: The host fishes for these five mussel species must be afforded some degree of protection if the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are to recover. The known host species for the five mussel species include: Mudpuppy Salamander, Bluegill, Bluntnose Minnow, Brook Stickleback, Central Stoneroller, Greenside Darter, Iowa Darter, Johnny Darter, Largemouth Bass, Logperch, Mottled Sculpin, Northern Redbelly Dace, Rainbow Darter, and Spotfin Shiner. None of these species are assessed by COSEWIC and therefore are not explicitly considered in any recovery plans. It may be necessary to develop formal management plans for these species to ensure that their populations remain healthy and do not hinder the recovery of the mussel species.

2-6: While the host species of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are not typically targeted as baitfishes, they are potentially collected as bycatch during legal bait harvesting activities. Effort should be made to minimize potential bycatch of these species and to ensure that gear selection and operation do not contribute to habitat degradation, which may adversely affect host populations.

Table 4. Recovery planning table- stewardship approaches for Northern Riffleshell (NRS), Snuffbox (SB), Round Pigtoe (RP), Salamander Mussel (SM), and Rayed Bean (RB).

Priority	Number	Recovery Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
Urgent	3-1	v	Riparian Buffers	Establish riparian buffer zones in areas of high erosion potential by encouraging naturalization or planting of native species.	Will improve water quality by reducing bank erosion, sedimentation and overland run-off.	Siltation and turbidity, nutrient loads, toxic compounds, thermal effects
Urgent	3-2	v	Tile Drainage	Work with landowners to mitigate the effects of tile drainage.	Will reduce nutrient and sediment inputs.	Siltation and turbidity, nutrient loads, toxic compounds
Urgent	3-3	v	Herd Managem-ent	Encourage the active exclusion of livestock from the watercourse.	Will reduce bank erosion, sediment and nutrient inputs.	Siltation and turbidity, nutrient loads, toxic compounds, thermal effects
Urgent	3-4	v	Livestock Waste Managem-ent	Assist with establishing adequate manure collection and storage systems to avoid accidental spills and winter-spreading of manure.	Will improve water quality by reducing nutrients.	Siltation and turbidity, nutrient loads
Urgent	3-5	v	Farm Planning	Encourage the development and implementation of Environmental Farm Plans and Nutrient Management Plans.	Will assist with minimizing inputs of nutrients and sediments.	Siltation and turbidity, nutrient loads, thermal effects
Urgent	3-6	v	Sewage Treatment	Work with landowners to improve faulty septic systems.	Will improve water quality by reducing nutrient inputs.	Siltation and turbidity, nutrient loads, toxic compounds
Necessary	3-7	v	Managed Refuge Site	As required, implement recommendation(s) from investigations into the feasibility of managing a refuge site in the St. Clair River delta.	Will insulate RP population from the effects of Zebra Mussel.	Invasive species
Necessary	3-8	v	Agency Interaction	Coordinate efforts and collaborate with stewardship councils and conservation authorities.	Will improve the implementation of stewardship activities.	Siltation and turbidity, nutrient loads, thermal effects

Priority	Number	Recovery Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
Beneficial	3-9	v	Soil Testing	Encourage soil testing to determine fertilizer application rates.	Will reduce nutrient inputs to the river.	Nutrient loads

The stewardship activities outlined here can be described as "Best Management Practices (BMPs)" and represent a selection of activities that can be encouraged within these predominantly agricultural watersheds to help reduce the impacts of terrestrial practices on aquatic ecosystems. Encouragement can be achieved through increasing awareness of these activities as well as through the provision of financial assistance to local landowners.

Table 5. Recovery planning table - awareness approaches for Northern Riffleshell (NRS), Snuffbox (SB), Round Pigtoe (RP), Salamander Mussel (SM), and Rayed Bean (RB).

Priority	Number	Recovery Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
Urgent	4-1	vii	Awareness – Stewardship Actions	Increase public knowledge of stewardship options and financial assistance available to participate in activities.	Increased public participation in recovery actions and a reduction in threats to the NRS, SB, RP, SM, and RB.	All threats
Urgent	4-2	vii	Invasive Species	Increase public awareness of the potential impacts of transporting/ releasing invasive species.	Will reduce the risk of Zebra Mussel becoming established in reservoirs, and the upstream spread of Round Goby.	Invasive species
Beneficial	4-3	vii	Outreach	Encourage public support and participation by developing awareness materials and programs.	Will increase public awareness of the importance of freshwater mussel species at risk.	All threats

Public participation in the recovery process for these species is essential as the primary threats to populations in the Ausable, Grand, Sydenham, and Thames rivers result from diffuse non-point source inputs relating to the general agricultural activities within these watersheds. Recovery cannot occur without the full participation of local citizens and landowners. The need for an effective public awareness program is crucial to the recovery of these species.

2.5 Evaluation

The routine monitoring programs will provide the primary means of evaluating the success of the listed recovery approaches. The monitoring programs will provide trend data through time, which aid in tracking populations and habitats of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean. This will form the basis of an adaptive management program. Recovery Implementation Groups will develop specific targets in the action plan(s) for the recovery strategy to provide a further basis for evaluating success. The entire recovery strategy will be reported on every five years at which time all goals, objectives and related approaches may be re-evaluated.

2.6 Critical Habitat

2.6.1 General Identification of Critical Habitat for the Five Mussel Species

The identification of critical habitat for Threatened and Endangered species (on Schedule 1) is a requirement of the SARA. Once identified, SARA includes provisions to prevent the destruction of critical habitat. Critical habitat is defined under section 2(1) of SARA as:

> "…*the habitat necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species*". [s. 2(1)]

SARA defines habitat for aquatic species at risk as:

> *"… spawning grounds and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where aquatic species formerly occurred and have the potential to be reintroduced."* [s. 2(1)]

Critical habitat for Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean, has been identified to the extent possible, using the best information currently available. The critical habitat identified in this recovery strategy describes the geospatial areas that contain the habitat necessary for the survival or recovery of the species. The current areas identified may be insufficient to achieve the population and distribution objectives for the species. As such, a schedule of studies has been included to further refine the description of critical habitat (in terms of its biophysical functions/features/attributes as well as its spatial extent) to support its protection.

2.6.2 Information and Methods Used to Identify Critical Habitat

Using the best available information, critical habitat has been identified using a 'bounding box' approach for riverine populations of the five mussel species within the following watersheds:

- East Sydenham River (all five species)

- Ausable River (Northern Riffleshell and Snuffbox)
- Bear Creek (Round Pigtoe)
- Thames River (Round Pigtoe and Rayed Bean)
- Grand River (Round Pigtoe)

Additional areas of potential critical habitat within the St. Clair River delta region will be considered in collaboration with Walpole Island First Nation.

This approach requires the use of essential functions, features and attributes for each life stage of these species to identify patches of critical habitat within the ‘bounding box’, which is defined by occupancy data for the species. Life stage habitat information was summarized in chart form using available data and studies referred to in Sections 1.1.4, 1.2.4, 1.3.4, 1.4.4, and 1.5.4 (Habitat and Biological Needs) for the five species. The ‘bounding box’ approach was the most appropriate, given the limited information available for the species and the lack of detailed habitat mapping for these areas. This approach and the methods used to identify reaches of critical habitat are consistent with the approaches recommended by DFO (2011a) for freshwater mussels.

Within the rivers currently occupied by the five mussel species, an ecological classification system was used in the identification of critical habitat. The OMNRF Aquatic Landscape Inventory System (ALIS, version 1) (Stanfield and Kuyvenhoven 2005) was used as the base unit for defining reaches within riverine systems. The ALIS system employs a valley classification approach to define river segments with similar habitat and continuity on the basis of hydrography, surficial geology, slope, position, upstream drainage area, climate, landcover, and the presence of instream barriers, all of which are believed to have a controlling effect on the biotic and physical processes within the catchment. Therefore, if a species has been found in one part of the ecological classification, it would be reasonable to expect that it would be present in other spatially contiguous areas of the same valley segment. Within all identified river segments (i.e., valley segments) the width of the habitat zone is defined as the area from the mid-channel point to bankfull width on both the left and right banks. Critical habitat for populations of Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean were therefore identified as the reach of river that includes all contiguous ALIS segments from the uppermost stream segment with the species present to the lowermost stream segment with the species present; segments or reaches were excluded only when supported by robust data indicating species absence and/or unsuitable habitat conditions. Current occupancy for these species was defined by recent records of live individuals (and/or fresh shells) from 1996 onward; this is the point in time when systematic surveys of freshwater mussel communities in southern Ontario began. Unoccupied ALIS segments with suitable habitats were also included when limited sampling had occurred (i.e., species was assumed to be present).

While individual ALIS segments generally represent relatively homogenous habitat conditions, an exception was noted in the Sydenham River. In this case, the very long ALIS segment was broken at the point where stream gradient flattens out by using river gradient profiles to exclude the lower stretches of the river below Dresden; below this point, the riverine habitat of riffles and runs would not be present due to insufficient stream gradient.

2.6.3 Identification of Critical Habitat: Biophysical Functions, Features and Their Attributes

Tables 6-10 summarize the limited available knowledge of the functions, features, and attributes for each life stage of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean (refer to Sections 1.1.4, 1.2.4, 1.3.4, 1.4.4, and 1.5.4 Habitat and Biological Needs for full references). Areas within which critical habitat is found must be capable of supporting one or more of these habitat functions. Note that not all attributes in Tables 6-10 must be present in order for a feature to be identified as critical habitat. If the features, as described in Tables 6-10, are present and capable of supporting the associated functions, the feature is considered critical habitat for the species, even though some of the associated attributes might be outside of the range indicated in the table. All attributes may be used to help inform management decisions for the recovery and/or protection of critical habitat.

Table 6. General summary of the functions, features and attributes of critical habitat for each life stage of the Northern Riffleshell (riverine populations)*.

Life Stage	Function	Feature(s)	Attribute(s)
Spawning and fertilization (time period unknown) Glochidia present in females (mid-August – following June)	Reproduction	Reaches of rivers and streams with riffle and/or run habitats with sand and gravel substrates present (includes 'bankfull channel').	• Attributes assumed to be same as for adults (see Adult/Juvenile row below). • Flow present (distribution of sperm). • Low contaminants levels – including the following: – Long-term chloride levels < 120 mg/L (CCME 2011). – Mean concentrations of < 0.3 mg/L total ammonia as N at pH 8; for protection of all life stages of freshwater mussels (Augspurger et al. 2003). – Copper levels < 3 µg/L (CCME 2005) should protect sensitive glochidia (Gillis et al. 2008).
Encysted glochidial stage (spring – unknown)** on host fish until drop off	Feeding Cover Nursery	Same as above with host fish(es) present.	• Attributes assumed to be same as Adult/Juvenile (as these conditions support both host fishes and adults). • Host fishes (e.g., Blackside Darter, Brook Stickleback, Iowa Darter***, Johnny Darter, Logperch, Mottled Sculpin***, and Rainbow Darter). • Summertime water temperatures reach ~18°C (18.5 – 26°C) for successful development. • DO levels sufficient to support host (> 4 mg/L; OMOE [1994] for protection of warmwater species).
Adult/Juvenile	Feeding Cover Nursery	Reaches of rivers and streams with riffle and/or run habitats with sand and gravel substrates present (includes 'bankfull channel').	• Steady to moderate flows (~0.16 – 0.27 m/s in summer) (in sufficient volume to prevent stranding and increased predation). • Adequate supply of food (plankton: bacteria, algae, organic detritus, protozoans). • Substrates having higher percentage of packed sand (< 2 mm) and/or fine to coarse gravel (2 – 60 mm). • Well oxygenated riffle areas. • Adequate depth (~12 – 26 cm in summer). • Dreissenids absent or in low abundance. • Warm water temperatures (gamete production and development).

*Where known or supported by existing data; **If they overwinter on their host it would be year round; ***Primary host in laboratory.

Table 7. General summary of the functions, features and attributes of critical habitat for each life stage of the Snuffbox (riverine populations)*.

Life Stage	Function	Feature(s)	Attribute(s)
Spawning and fertilization (time period unknown) Glochidia present in females (mid-August to the following June)	Reproduction	Reaches of rivers and streams with riffle and/or run habitats with sand and gravel substrates present (includes 'bankfull channel').	• Attributes assumed to be same as for adults (see Adult/Juvenile row below). • Flow present (distribution of sperm). • Low contaminants levels – including the following: – Long-term chloride levels < 120 mg/L (CCME 2011). – Mean concentrations of < 0.3 mg/L total ammonia as N at pH 8; for protection of all life stages of freshwater mussels (Augspurger et al. 2003). – Copper levels < 3 µg/L (CCME 2005) should protect sensitive glochidia (Gillis et al. 2008).
Encysted glochidial stage (spring - August)** on host fish until drop off	Feeding Cover Nursery	Same as above with host fish(es) present.	• Attributes assumed to be same as Adult/Juvenile (as these conditions support both host fishes and adults). • Host fishes (e.g., Brook Stickleback, Iowa Darter, Largemouth Bass, Logperch***, Mottled Sculpin, and Rainbow Darter). • Warm water temperatures (~14 – 26°C between August and October). • DO levels sufficient to support host (> 4 mg/L; OMOE [1994] for protection of warmwater species).
Adult/Juvenile	Feeding Cover Nursery	Reaches of rivers and streams with riffle and/or run habitats with sand and gravel substrates present (includes 'bankfull channel').	• Steady to moderate flows (mean ~0.23 m/s in summer) (in sufficient volume to prevent stranding and increased predation). • Adequate supply of food (plankton: bacterial, algae, organic detritus, protozoans). • Substrates having higher percentage of packed sand (< 2 mm) and/or fine to coarse gravel (2 – 60 mm). • Well oxygenated riffles. • Adequate depth (up to 2.5 m in summer). • Dreissenids absent or in low abundance. • Warm water temperatures (gamete production and development).

*Where known or supported by existing data; **If they overwinter on their host it would be year round; ***Primary host in laboratory.

Table 8. General summary of the functions, features and attributes of critical habitat for each life stage of the Round Pigtoe (riverine populations)* .

Life Stage	Function	Feature(s)	Attribute(s)
Spawning and fertilization (time period unknown) Glochidia present in females (May-July)	Reproduction	Reaches of rivers and streams with riffle and/or run habitats with sand and gravel substrates present (includes ‘bankfull channel’).	• Attributes assumed to be same as for adults (see Adult/Juvenile row below). • Flow present (distribution of sperm). • Low contaminants levels – including the following: – Long-term chloride levels < 120 mg/L (CCME 2011). – Mean concentrations of < 0.3 mg/L total ammonia as N at pH 8; for protection of all life stages of freshwater mussels (Augspurger et al. 2003). – Copper levels < 3 µg/L (CCME 2005) should protect sensitive glochidia (Gillis et al. 2008).
Encysted glochidial stage (May – August) on host fish until drop off	Feeding Cover Nursery	Same as above with host fish(es) present.	• Attributes assumed to be same as Adult/Juvenile (because both support host fishes and adults). • Host fishes (e.g., Bluegill, Bluntnose Minnow, Central Stoneroller, Northern Redbelly Dace, and Spotfin Shiner). • Warm water temperatures (~14 – 26°C between May and October). • DO levels sufficient to support host (> 4 mg/L; OMOE [1994] for protection of warmwater species).
Adult/Juvenile	Feeding Cover Nursery	Reaches of rivers and streams with riffle and/or run habitats with sand and gravel substrates present (includes ‘bankfull channel’).	• Steady to moderate flows (~0.16 – 0.31 m/s in summer) (in sufficient volume to prevent stranding and increased predation). • Adequate supply of food (plankton: bacterial, algae, organic detritus, protozoans). • Substrates having higher percentage of packed sand (< 2 mm) and/or fine to coarse gravel (2 – 60 mm). • Adequate depth (~0.12 – 3 m in summer). • Dreissenids absent or in low abundance. • Warm water temperatures (gamete production and development).

*Where known or supported by existing data.

Table 9. General summary of the functions, features and attributes of critical habitat for each life stage of the Salamander Mussel (riverine populations)* .

Life Stage	Function	Feature(s)	Attribute(s)
Spawning and fertilization (time period unknown) Glochidia present in females (time period unknown)	Reproduction	Reaches of rivers and streams with moderate to swift flows with silt and sand deposits under large rocks (includes 'bankfull channel').	• Attributes assumed to be same as for adults (see Adult/Juvenile row below). • Flow present (distribution of sperm). • Low contaminants levels – including the following: – Long-term chloride levels < 120 mg/L (CCME 2011). – Mean concentrations of < 0.3 mg/L total ammonia as N at pH 8; for protection of all life stages of freshwater mussels (Augspurger et al. 2003). – Copper levels < 3 µg/L (CCME 2005) should protect sensitive glochidia (Gillis et al. 2008).
Encysted glochidial stage (October – May) on host until drop off	Feeding Cover Nursery	Same as above with host present.	• Attributes assumed to be same as Adult/Juvenile (because both support salamander host and adults). • Host (Mudpuppy Salamander). • Warm water temperatures (must reach 20°C). • DO levels sufficient to support host (> 4 mg/L; OMOE [1994] for protection of warmwater species.
Adult/Juvenile	Feeding Cover Nursery	Reaches of rivers and streams with moderate to swift flows with silt and sand deposits under large rocks (includes 'bankfull channel').	• Steady to moderate flows (in sufficient volume to prevent stranding and increased predation). • Adequate supply of food (plankton: bacterial, algae, organic detritus, protozoans). • Silt and sand (< 2 mm) deposits under large rocks. • Adequate depth. • Dreissenids absent or in low abundance. • Warm water temperatures (gamete production and development).

*Where known or supported by existing data.

Table 10. General summary of the functions, features and attributes of critical habitat for each life stage of the Rayed Bean (riverine populations)* .

Life Stage	Function	Feature(s)	Attribute(s)
Spawning and fertilization (time period unknown) Glochidia present in females (May – late August)	Reproduction	Reaches of rivers and streams with riffle and/or run habitats with sand and gravel substrates present (includes 'bankfull channel').	• Attributes assumed to be same as for adults (see Adult/Juvenile row below). • Flow present (distribution of sperm). • Low contaminants levels – including the following: – Long-term chloride levels < 120 mg/L (CCME 2011). – Mean concentrations of < 0.3 mg/L total ammonia as N at pH 8; for protection of all life stages of freshwater mussels (Augspurger et al. 2003). – Copper levels < 3 µg/L (CCME 2005) should protect sensitive glochidia (Gillis et al. 2008).
Encysted glochidial stage (May – unknown) on host fish until drop off	Feeding Cover Nursery	Same as above with host fish(es) present.	• Attributes assumed to be same as Adult/Juvenile (because both support host fishes and adults). • Host fishes (e.g., Brook Stickleback***, Greenside Darter**, Johnny Darter***, Largemouth Bass, Logperch***, Mottled Sculpin, and Rainbow Darter). • Warm water temperatures (~14 – 28°C between May and October). • DO levels sufficient to support host (> 4 mg/L; OMOE [1994] for protection of warmwater species).
Adult/Juvenile	Feeding Cover Nursery	Reaches of rivers and streams with riffle and/or run habitats with sand and gravel substrates present (includes 'bankfull channel').	• Steady to moderate flows (~0.16 – 0.5 m/s in summer) (in sufficient volume to prevent stranding and increased predation). • Adequate supply of food (plankton: bacterial, algae, organic detritus, protozoans). • High percentage of sand (< 2 mm) and/or gravel (2 – 30 mm). • Adequate depth (~12 – 26 cm in summer). • Dreissenids absent or in low abundance. • Warm water temperatures (gamete production and development).

*Where known or supported by existing data; ** Primary host in laboratory; ***Low number of juveniles developed on host; therefore, consider as a "potential" host (further testing required).

Studies to further refine knowledge on the essential functions, features and attributes for various life stages of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are described in Section 2.6.5 (Schedule of Studies to Identify Critical Habitat).

2.6.4 Identification of Critical Habitat: Geospatial

Using the best available information, critical habitat has been identified in the following watercourses:

- East Sydenham River (all five species)
- Ausable River (Northern Riffleshell and Snuffbox)
- Bear Creek (Round Pigtoe)
- Thames River (Round Pigtoe and Rayed Bean)
- Grand River (Round Pigtoe)

Areas of critical habitat identified at these locations may overlap with critical habitat identified for other co-occurring species at risk (e.g., Kidneyshell [*Ptychobranchus fasciolaris*], Round Hickorynut, Eastern Sand Darter [*Ammocrypta pellucida*], and Northern Madtom [*Noturus stigmosus*]); however, the specific habitat requirements within these areas may vary by species.

The areas delineated on the following maps (Figures 16-25) represent the areas within which critical habitat is found for the above mentioned populations. Note that the areas delineated include the entire 'bankfull' channel; this supports long-term channel forming discharges important in maintaining in-stream habitat conditions required by freshwater mussels. Using the 'bounding box' approach, critical habitat is not comprised of all areas within the identified boundaries, but only those areas where biophysical features/attributes are present and are capable of supporting one or more habitat functions (refer to Tables 6-10).

Table 11 below provides the geographic coordinates that situate the boundaries within which critical habitat is found for the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean; these points are indicated on Figures 16-25.

Table 11. Coordinates locating the boundaries within which critical habitat is found for Northern Riffleshell (NRS), Snuffbox (SB), Round Pigtoe (RP), Salamander Mussel (SM), and Rayed Bean (RB)**.

	Coordinates† Locating Areas of Critical Habitat				
Location (Species)	Point 1	Point 2	Point 3	Point 4	Point 5
East Sydenham River (all species)	42° 54' 14.98"N 81° 42' 12.31"W	42° 51' 35.43"N 81° 44' 0.29"W	42° 51' 35.54"N 81° 52' 1.57"W	42° 39' 12.60"N 81° 59' 56.18"W	42° 32' 33.71"N 82° 25' 1.58"W
Ausable River (NRS)[2]	43° 16' 8.51"N 81° 31' 42.15"W	43° 6' 23.08"N 81° 35' 26.71"W	43° 4' 43.97"N 81° 46' 23.66"W	43° 11' 13.92"N 81° 49' 5.60"W	
Ausable River (SB)	43° 16' 8.51"N 81° 31' 42.15"W	43° 11' 13.92"N 81° 49' 5.60"W			
Bear Creek (RP)	42° 59' 48.81"N 81° 56' 42.30"W	42° 52' 47.07"N 82° 8' 22.39"W			
South Thames River (RP)	42° 59' 8.19"N 81° 5' 18.01"W	42° 58' 53.51"N 81° 15' 26.50"W			
Middle Thames River (RP)	43° 8' 20.04"N 80° 53' 33.23"W	43° 4' 11.64"N 80° 58' 45.38"W	43° 1' 58.29"N 81° 0' 4.59"W		
North Thames River (RB)	43° 12' 32.54"N 81° 12' 28.27"W	43° 4' 20.90"N 81° 11' 4.84"W			
Grand River (RP)	43° 6' 37.83"N 80° 15' 15.89"W	42° 56' 13.20"N 79° 51' 12.41"W			

** All coordinates obtained using map datum NAD 83
** Riverine habitats are delineated to the midpoint of channel of the uppermost stream segment and lowermost stream segment (i.e., two points only)

A brief explanation for the areas identified as critical habitat is provided for each of the areas below.

East Sydenham River: The area within which critical habitat is found in the East Sydenham River is currently identified for Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean as the reach of river that includes all contiguous ALIS segments from the uppermost stream segment with the species present to the lowermost stream segment with the species present. This area is the same for all five species. It represents a stretch of river approximately 160 km long for Northern Riffleshell (Figure 16), Snuffbox (Figure 18), Round Pigtoe (Figure 20), Salamander Mussel (Figure 23), and Rayed Bean (Figure 24). Also connected with this segment are the lower reaches (< 3 km) of the following tributaries: Fansher, Brown, and Spring creeks. This critical habitat description includes the entire 'bankfull' channel. The downstream boundary within which critical habitat can be found ends at the County Road 21 bridge in the town of Dresden; by this point the gradient of the river has flattened out causing low current velocities that no longer support the required habitat. The

[2] In the case of Northern Riffleshell, there are two separate river segments identified as critical habitat in the Ausable River. Point 1 to Point 2 represents one segment and Point 3 to Point 4 represents one segment. Points 2 and 3 are not connected (see Figure 17).

upstream boundary within which critical habitat can be found for all species in the East Sydenham River is the bridge at Murphy Drive (approximately 15 km northeast of Alvinston).

Ausable River: The area within which critical habitat is found in the Ausable River is currently identified for Northern Riffleshell and Snuffbox as the reach of river that includes all contiguous ALIS segments from the uppermost stream segment with the species present to the lowermost stream segment with the species present. This area represents a stretch of river approximately 81 km long for Northern Riffleshell (Figure 17), and 134 km long for Snuffbox (Figure 19). This critical habitat description includes the entire ‘bankfull’ channel.

In the case of Northern Riffleshell, there are two separate river segments. For the first segment, the downstream boundary within which critical habitat can be found ends approximately 1 km upstream of Parkhill Drive (County Road 18). The upstream boundary ends approximately 5 km downstream of Kerwood Road (County Road 6). For the second segment, the downstream boundary within which critical habitat can be found ends approximately 4 km downstream of Nairn. The upstream boundary ends approximately 1 km upstream of Mount Carmel Drive (County Road 5). The two segments were not connected because extensive targeted sampling between the two segments did not yield any Northern Riffleshell.

In the case of Snuffbox, there is only one river segment, which encompasses both river segments for Northern Riffleshell. The downstream boundary within which critical habitat can be found ends approximately 1 km upstream of Parkhill Drive (County Road 18). The upstream boundary ends approximately 1 km upstream of Mount Carmel Drive (County Road 5).

Bear Creek: The area within which critical habitat is found in Bear Creek is currently identified for Round Pigtoe as the reach of river that includes all contiguous ALIS segments from the uppermost stream segment with the species present to the lowermost stream segment with the species present. This area represents a stretch of river approximately 53 km long (Figure 20). This critical habitat description includes the entire ‘bankfull’ channel. The downstream boundary within which critical habitat can be found ends at the dam in Petrolia. The upstream boundary within which critical habitat can be found ends approximately 1 km upstream of Highway 402.

Thames River: The area within which critical habitat is found in the Thames River is currently identified for Round Pigtoe as the reaches of river that include all contiguous ALIS segments from the uppermost stream segment with the species present to the lowermost stream segment with the species present. This area represents a total stretch of river approximately 57 km long (Figure 21). There are two separate river segments. This critical habitat description includes the entire ‘bankfull’ channel. The first segment is found on the South Thames River. The downstream boundary within which critical habitat is found is the confluence of the North and South branches of the Thames River. The upstream boundary within which critical habitat can be found is approximately 1 km upstream of Ferrar Road. The second segment is found on the Middle Thames River near Thamesford. The downstream boundary within which critical habitat is found is approximately 3 km downstream of Thamesford. The upstream boundary ends at 37 Line Road near Embro. This includes approximately 2 km of the Woods Drain.

The area within which critical habitat is found in the North Thames River is currently identified for Rayed Bean as the reach of river that includes all contiguous ALIS segments from the uppermost stream segment with the species present to the lowermost stream segment with the species present. This area represents a stretch of river approximately 25 km long (Figure 25). This critical habitat description includes the entire ‘bankfull’ channel. The downstream boundary within which critical habitat is found starts at the upstream end of Fanshawe Reservoir and continues upstream to Elginfield Road.

Grand River: The area within which critical habitat is found in the Grand River is currently identified for Round Pigtoe as the reach of river that includes all contiguous ALIS segments from the uppermost stream segment with the species present to the lowermost stream segment with the species present. This area represents a stretch of river approximately 88 km long (Figure 22). This critical habitat description includes the entire ‘bankfull’ channel. The downstream boundary within which critical habitat can be found ends approximately 1 km downstream of the bridge over the Grand River in Cayuga. The upstream boundary within which critical habitat can be found is approximately 1.5 km upstream of Erie Avenue.

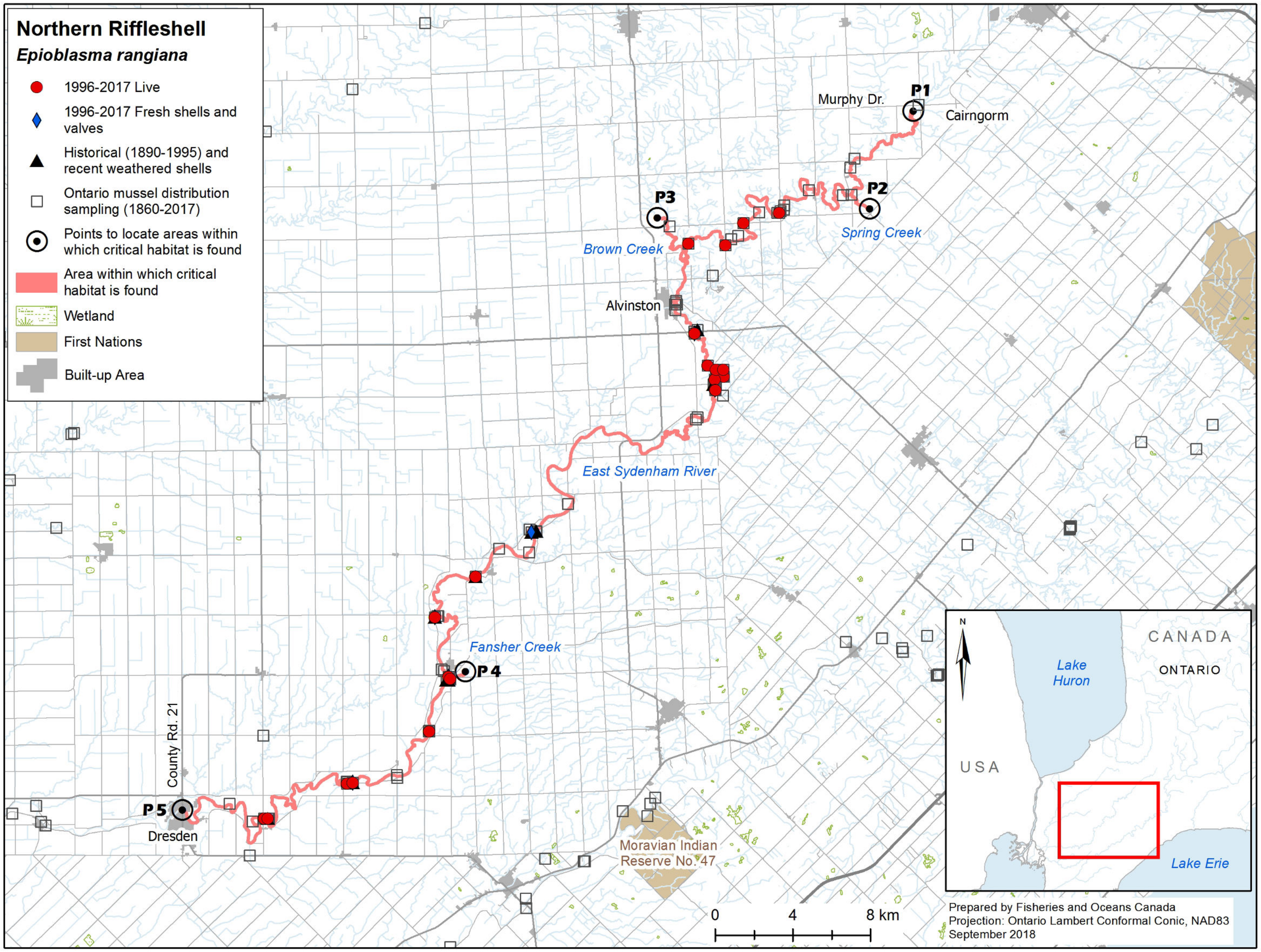

Figure 16. Area within which critical habitat is found for Northern Riffleshell in the East Sydenham River.

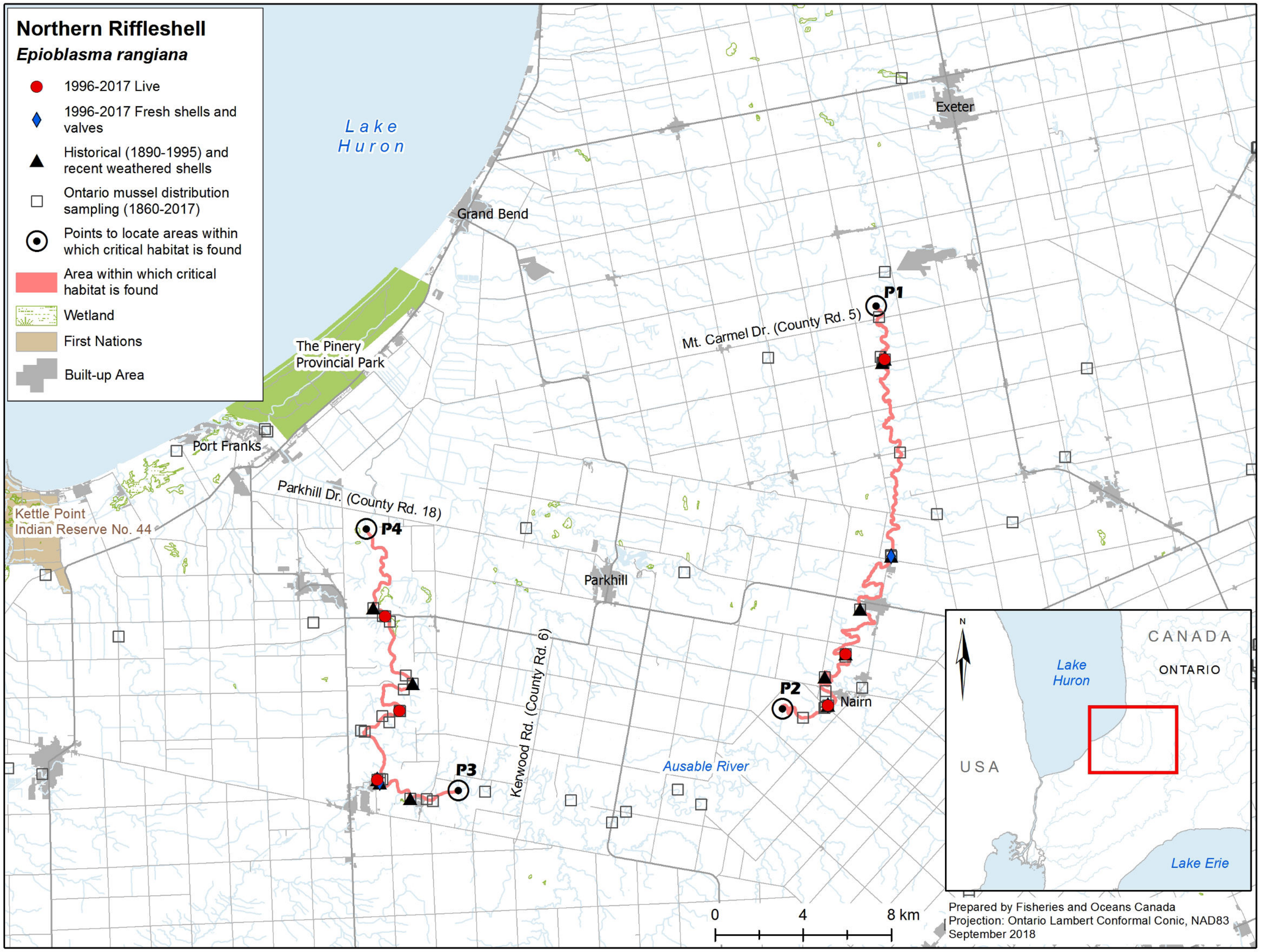

Figure 17. Area within which critical habitat is found for Northern Riffleshell in the Ausable River.

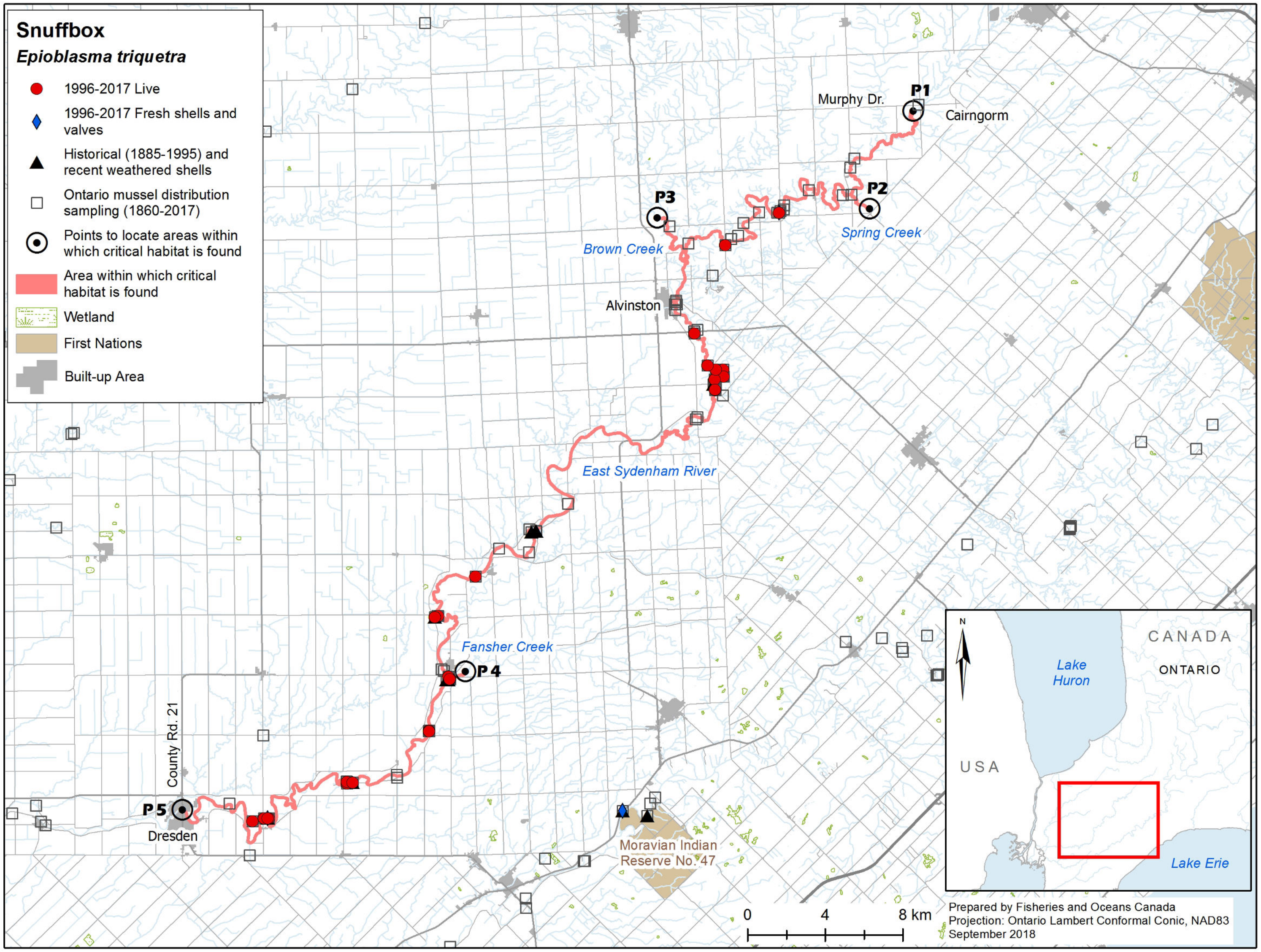

Figure 18. Area within which critical habitat is found for Snuffbox in the East Sydenham River.

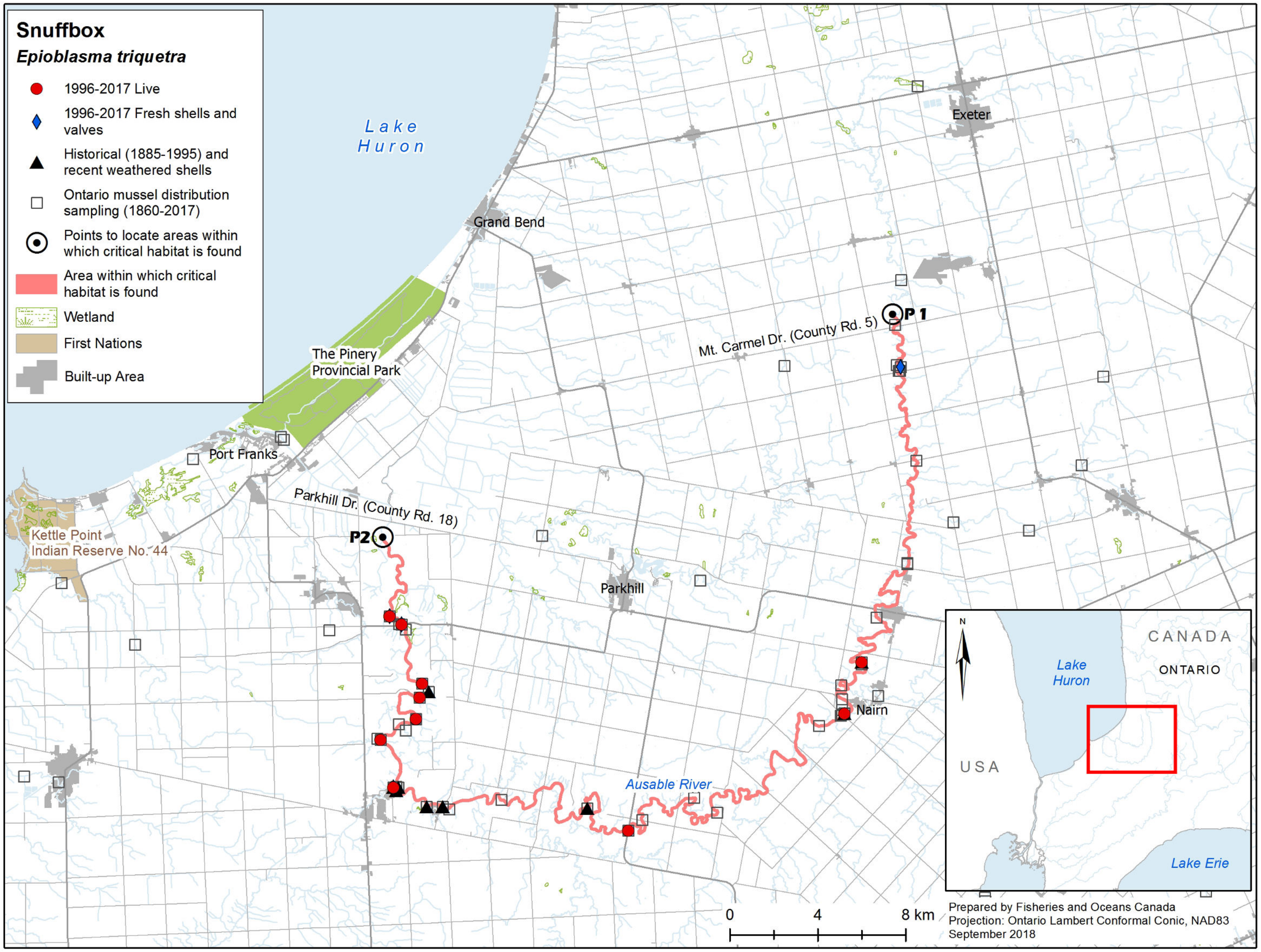

Figure 19. Area within which critical habitat is found for Snuffbox in the Ausable River.

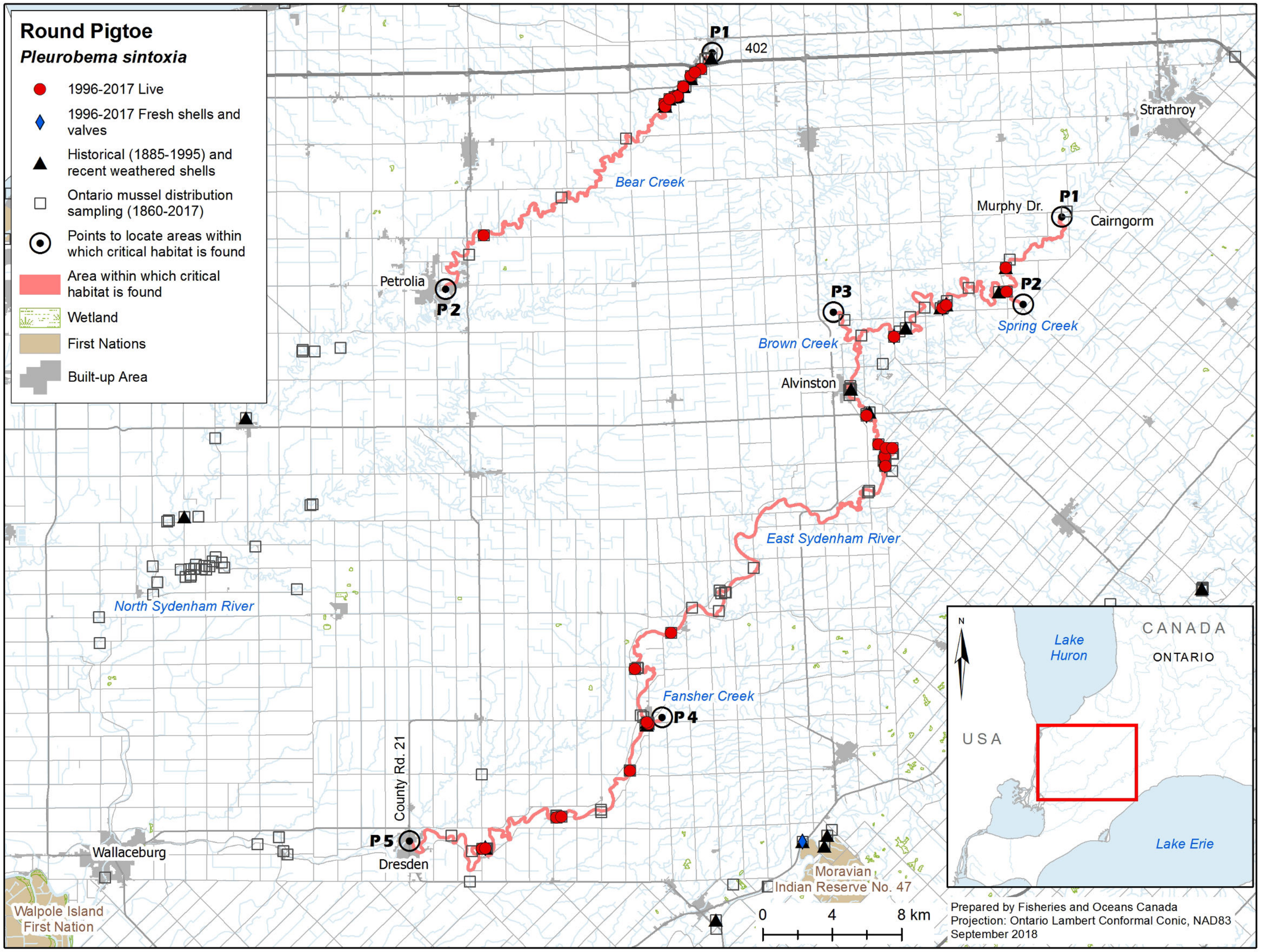

Figure 20. Area within which critical habitat is found for Round Pigtoe in the East Sydenham River and Bear Creek.

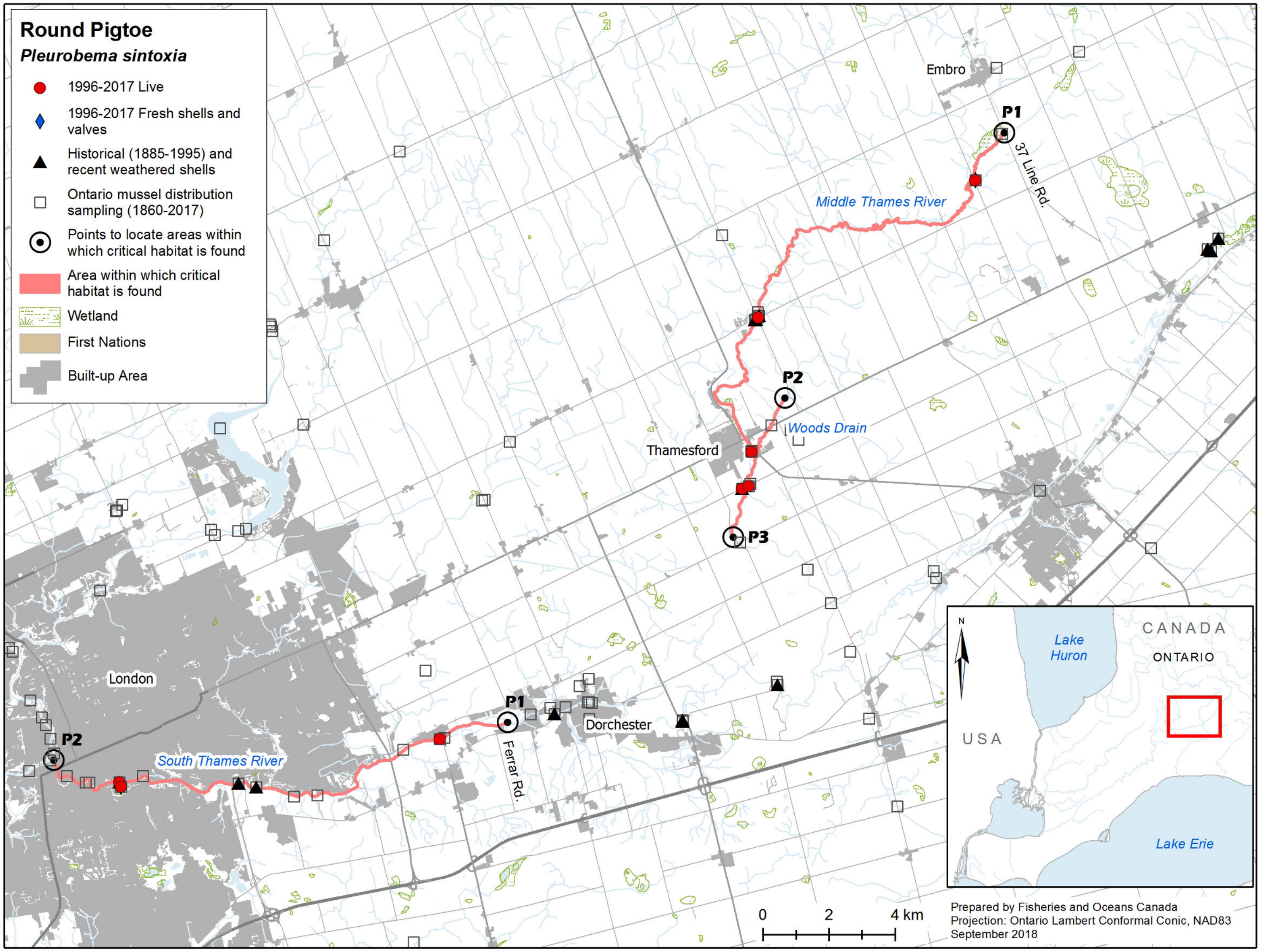

Figure 21. Area within which critical habitat is found for Round Pigtoe in the Middle and South Thames rivers.

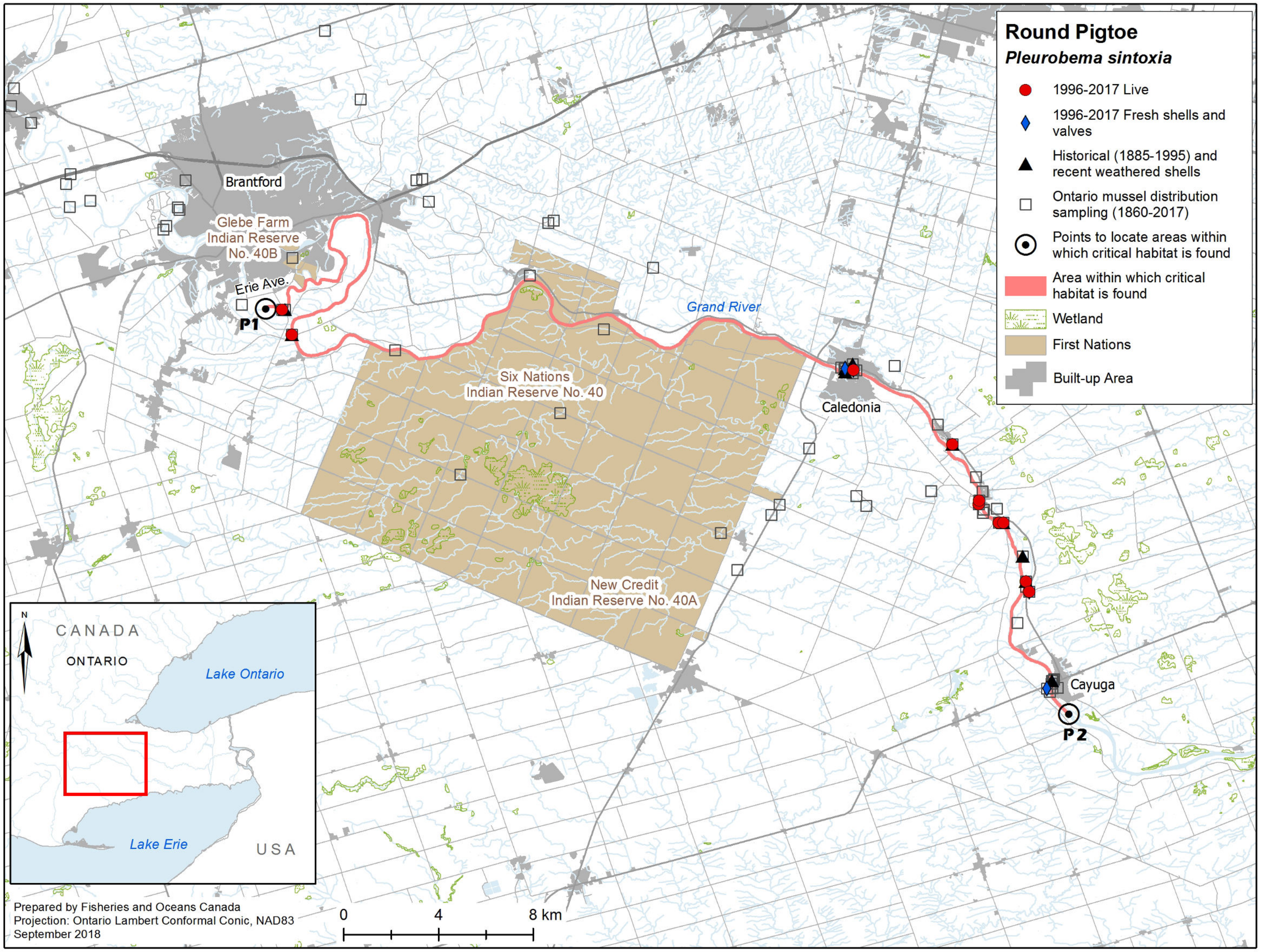

Figure 22. Area within which critical habitat is found for Round Pigtoe in the Grand River.

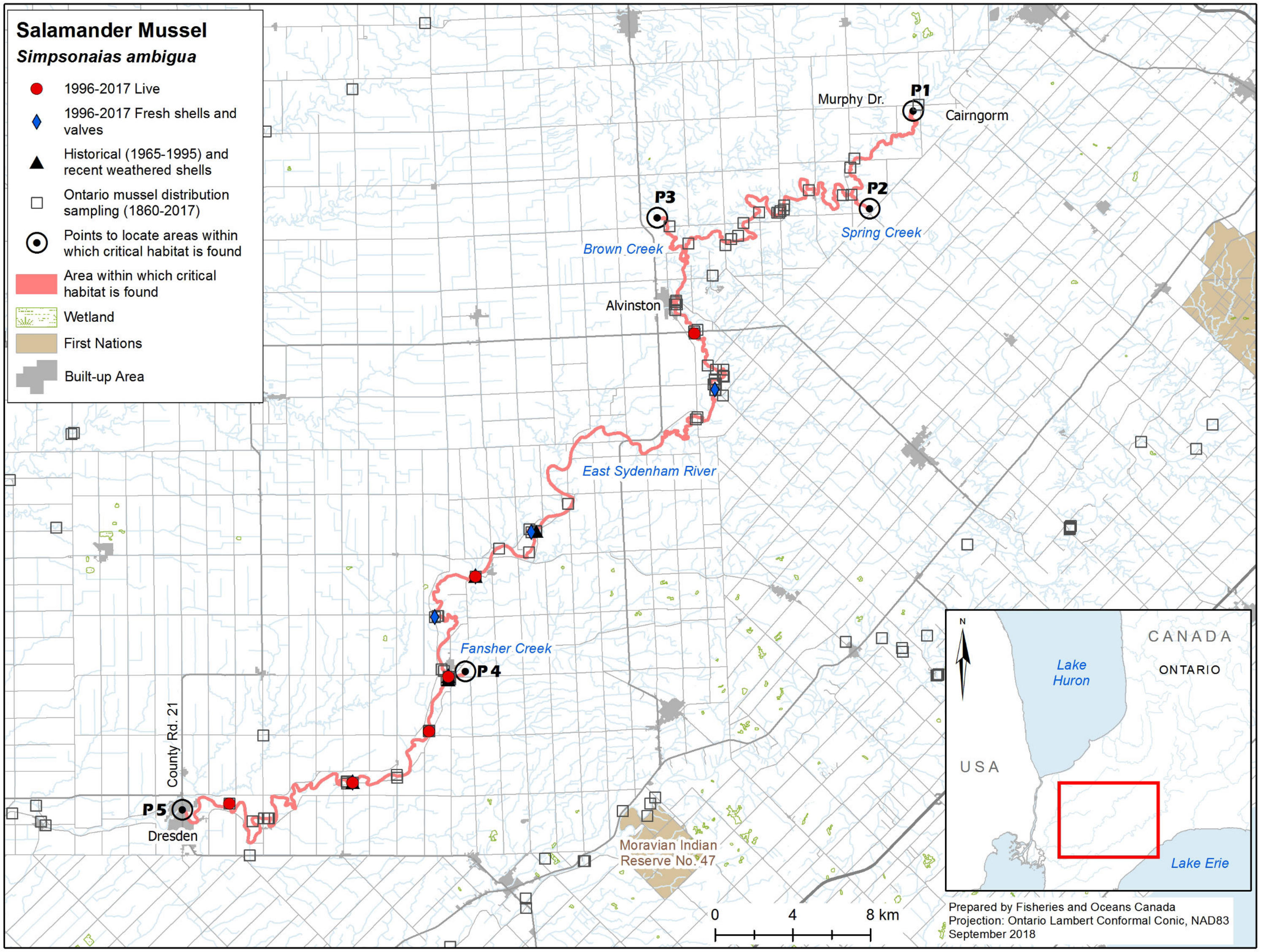

Figure 23. Area within which critical habitat is found for Salamander Mussel in the East Sydenham River.

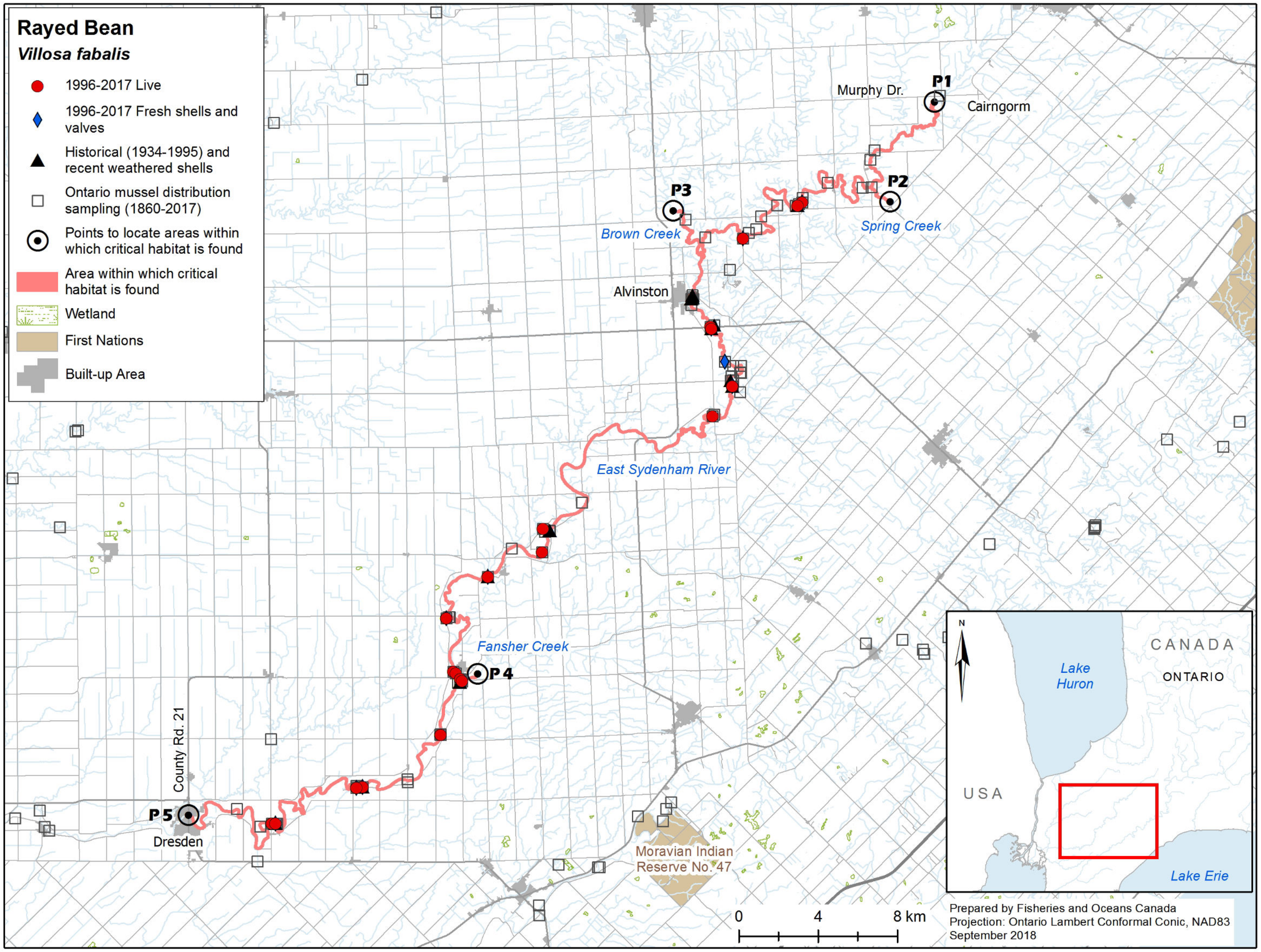

Figure 24. Area within which critical habitat is found for Rayed Bean in the East Sydenham River.

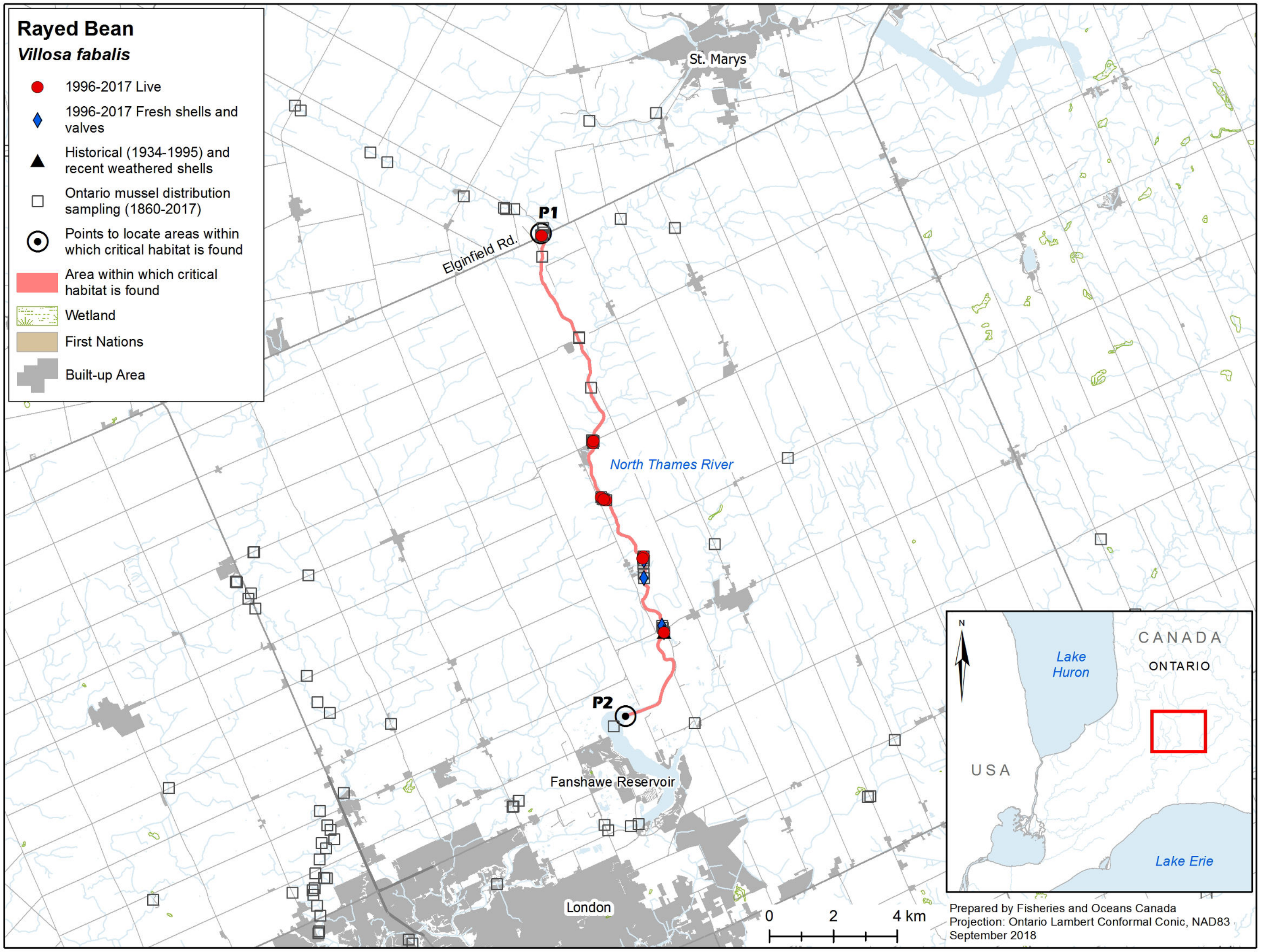

Figure 25. Area within which critical habitat is found for Rayed Bean in the North Thames River.

The identification of critical habitat within the Ausable, East Sydenham, Grand, and Thames rivers, and Bear Creek, will ensure that currently occupied habitat is protected until such time as critical habitat is further refined according to the schedule of studies laid out in Section 2.6.5 (Schedule of Studies to Identify Critical Habitat). The schedule of studies outlines activities necessary to refine the current critical habitat descriptions at confirmed extant locations as well as address locations with limited information (e.g., North Thames River). Critical habitat descriptions will be refined as additional information becomes available to support the population and distribution objectives.

2.6.5 Schedule of Studies to Identify Critical Habitat

The identification of critical habitat requires a thorough knowledge of the species' needs during all life stages as well as an understanding of the distribution, quantity, and quality of habitat across the range of the species. This recovery strategy includes an identification of critical habitat to the extent possible, based on the best available information. Further studies are required to refine critical habitat identified for Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean, and to support the population and distribution objectives for the species. The activities listed in Table 12 are not exhaustive and it is likely that the process of investigating these actions will lead to the discovery of further knowledge gaps that need to be addressed.

Table 12. Schedule of activities to identify critical habitat for Northern Riffleshell (NRS), Snuffbox (SB), Round Pigtoe (RP), Salamander Mussel (SM), and Rayed Bean (RB).

Description of Activity	Rationale	Approximate Time Frame*
Assess time frames and habitat required for spawning (release of sperm into the water column).	Very little is known regarding spawning of these Canadian populations. The presence of glochidia has been briefly noted; however, there is a need to determine when sperm are released and what the optimal conditions are for successful fertilization.	2019-2021
Conduct mussel population surveys.	Will define current NRS, SB, RP, SM, and RB distribution and aid in defining population trajectories.	2019-2021
Assess and map habitat conditions in occupied areas (e.g., flow, substrate, water clarity and quality).	Will aid in identifying NRS, SB, RP, SM, and RB habitat requirements.	2020-2021
Determine any life stage differences in habitat use.	There is almost no published information on the optimal habitat requirements for spawning or for juvenile NRS, SB, RP, SM, and RB. Determining habitat requirements for each life stage will ensure that all types of critical habitat for these species will be identified.	2019-2024
Survey and map unoccupied historical habitat within systems of occupancy.	Will aid in identifying factors responsible for NRS, SB, RP, SM, and RB extirpation and reinforce the importance of the suite of habitat features critical to the species.	2019-2022
Assess genetic structure of populations.	If distinct genetic stocks are discovered, protection of habitat for each stock will be desirable.	2020-2022
Determine/confirm host	Will allow a determination or confirmation of the	2019-2021

Description of Activity	Rationale	Approximate Time Frame*
fish (laboratory and functional) species and their distributions.	extent to which the NRS, SB, RP, and RB ranges are constrained by host fish(es) distribution.	
Assess habitat use by host species.	Determining habitat requirements for each life stage of the host species will ensure that this feature of critical habitat is available for hosting mussel glochidia. Will determine potential range of host fish(es).	2021-2023
Determine areas of overlap between mussel and host habitat.	Will determine potential range of the NRS, SB, RP, SM, and RB based on host distribution.	2022-2025
Based on collected information, review population and distribution goals. Determine amount and configuration of critical habitat required to achieve goal if adequate information exists.	Will aid in reviewing population and distribution goals.	Ongoing

*Timeframes are subject to change as new priorities arise or as a result of changing demands on resources or personnel

2.6.6 Examples of Activities Likely to Result in the Destruction of Critical Habitat

Under SARA, critical habitat must be legally protected from destruction within 180 days of being identified in a final recovery strategy or action plan and included in the Species at Risk Public Registry. For Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean critical habitat, it is anticipated that this will be accomplished through a SARA Critical Habitat Order made under subsections 58(4) and (5), which will invoke the prohibition in subsection 58(1) against the destruction of the identified critical habitat.

The Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean, like most mussel species, are sensitive to a wide variety of stressors. Therefore, the activities described in Table 13 are neither exhaustive nor exclusive and have been guided by the general threats described in Section 1.7 (Threats) of this recovery strategy. The absence of a specific human activity does not preclude, or fetter DFO's ability to regulate it pursuant to SARA. Furthermore, the inclusion of an activity does not result in its automatic prohibition because it is destruction of critical habitat that is prohibited. Because habitat use is often temporal in nature, every activity is assessed on a case-by-case basis and site-specific mitigation is applied where it is available and reliable. In every case, where information is available, thresholds and limits are associated with attributes to better inform management and regulatory decision-making. However, in many cases the knowledge of a species and its critical habitat may be lacking and, in particular, information associated with a species' or habitat's thresholds of tolerance to disturbance from human activities is lacking and must be acquired.

Table 13. Examples of human activities likely to result in the destruction of critical habitat for Northern Riffleshell (NRS), Snuffbox (SB), Round Pigtoe (RP), Salamander Mussel (SM), and Rayed Bean (RB).

The pathway of effect for each activity is provided as well as the potential links to the biophysical functions, features and attributes of critical habitat (if attributes are not specified NRS, SB, RP, SM, and RB then they apply to all species).

Activity	Effect-Pathway	Function Affected	Feature Affected	Attribute Affected
Siltation and Turbidity: Work in or around water with improper sediment and erosion control (e.g., installation of bridges, pipelines, culverts, overland run-off from ploughed fields, run-off from urban and residential development use of industrial equipment, cleaning or maintenance of bridges, drains or other structures) Unfettered livestock access to waterbodies Removal or cultivation of riparian zones	Improper sediment and erosion control or mitigation can cause increased turbidity and sediment deposition, changing preferred substrates, and impairing feeding and reproductive functions. When livestock have unfettered access to waterbodies, damage to shorelines, banks and watercourse bottoms can cause increased erosion and sedimentation, affecting turbidity and water temperatures. Agricultural lands, particularly those with little riparian vegetation and without tile drainage, allow large inputs of sediments to the watercourse. Also see: Habitat Modifications	Reproduction Feeding Cover Nursery	Reaches of rivers and streams with riffle and/or run habitats with sand and gravel substrates present (NRS, SB, RP, RB) Reaches of rivers and streams with moderate to swift flows with silt and sand deposits under large rocks (SM) (includes 'bankfull channel') Presence of host(s)	• All species: low levels of contaminants • All species: dissolved oxygen levels sufficient for host survival (more than 4 mg/L) • Water temperatures: NRS – about 18 °C (18.5 à 26 °C); SB – from 14 to 26 °C between August and October; RP - from 14 to 26 °C between May and October; SM – must reach 20 °C; RB – from 14 to 28 °C between May and October. • Substrate composition: NRS, SB, RP - packed sand (less than 2 mm) or fine to coarse gravel (2 to 60 mm); SM - silt and sand deposits (less than 2 mm) under large rocks; RB - higher percentage of sand

Activity	Effect-Pathway	Function Affected	Feature Affected	Attribute Affected
				(less than 2 mm) or gravel (2 to 30 mm) • All species: availability of hosts • All species: adequate food supply
Nutrient Loadings (Water Quality): Over-application of fertilizer and improper nutrient management (e.g., organic debris management, wastewater management, animal waste, septic systems and municipal sewage) Introduction of high levels of chloride through activities such as excessive salting of roads in winter	Improper nutrient management can cause nutrient loading of nearby waterbodies. Elevated nutrient levels (phosphorous and nitrogen) can cause increased turbidity causing harmful algal blooms, changing water temperatures, and reduced DO levels. Recent evidence has shown that juvenile mussels are among the most sensitive aquatic organisms to ammonia toxicity. Chloride levels have shown recent increases due to an increased use of road salt. Sensitive glochidia require habitat with low chloride levels. Mussel survival rates are closely related to DO levels. Low DO may also cause mortality of warmwater host fishes thereby disrupting mussel reproductive cycles.	Reproduction Feeding Cover Nursery	Reaches of rivers and streams with riffle and/or run habitats with sand and gravel substrates present (NRS, SB, RP, RB) Reaches of rivers and streams with moderate to swift flows with silt and sand deposits under large rocks (SM) (includes 'bankfull channel') Presence of host(s)	• All species: low levels of contaminants • All species: dissolved oxygen levels sufficient for host survival (more than 4 mg/L) • Water temperatures: NRS – about 18 °C (18.5 à 26 °C); SB – from 14 to 26 °C between August and October; RP - from 14 to 26 °C between May and October; SM – must reach 20 °C; RB – from 14 to 28 °C between May and October • Substrate composition: NRS, SB, RP - packed sand (less than 2 mm) or fine to coarse gravel (2 to 60 mm); SM - silt and sand deposits (less than 2 mm) under large rocks;

Activity	Effect-Pathway	Function Affected	Feature Affected	Attribute Affected
				RB - higher percentage of sand (less than 2 mm) or gravel (2 to 30 mm) • All species: availability of hosts • All species: adequate food supply All species: constant to moderate flow (in sufficient volume to prevent stranding and increased predation) (NRS - between 0.16 and 0.27 m / s in summer, SB - mean of 0.23 m / s in summer, RP - between 0.16 and 0.31 m / s in summer, RB - between 0.16 and 0.5 m / s in summer)
Toxic Compounds: Release of urban and industrial pollution into habitat (including the impact of stormwater run-off from existing and new developments)	Introduction of toxic compounds (e.g., high chloride levels from stormwater run-off) into habitat used by these species can change water chemistry, affecting habitat and host availability or use; this can be particularly detrimental during sensitive life stages (glochidia, juvenile).	Reproduction Feeding Nursery	Same as above	• All species: low levels of contaminants • All species: availability of hosts All species: dissolved oxygen levels sufficient for host survival (more than 4 mg/L)
Habitat Removal and Alteration:	Changes in bathymetry, shoreline and channel morphology caused by dredging and nearshore grading and excavation can move mussels, alter	Reproduction Feeding Cover	Same as above	• All species: low levels of

Activity	Effect-Pathway	Function Affected	Feature Affected	Attribute Affected
Dredging, grading, excavation	preferred substrates, change water depths, and change flow patterns, potentially affecting turbidity, nutrient levels, and water temperatures.	Nursery		contaminants • Water temperatures: NRS – about 18 °C (18.5 à 26 °C); SB – from 14 to 26 °C between August and October; RP - from 14 to 26 °C between May and October; SM – must reach 20 °C; RB – from 14 to 28 °C between May and October • Substrate composition: NRS, SB, RP - packed sand (less than 2 mm) or fine to coarse gravel (2 to 60 mm); SM - silt and sand deposits (less than 2 mm) under large rocks; RB - higher percentage of sand (less than 2 mm) or gravel (2 to 30 mm) • All species: suitable depth of water (NRS, RB - between 12 and 26 cm in summer, SB - up to 2.5 m in summer, RP between 0.12 and 3 m in summer)All species - present flow - sperm

Activity	Effect-Pathway	Function Affected	Feature Affected	Attribute Affected
				distributionAll species: availability of hosts • All species: adequate food supply
Habitat Removal and Alteration: Placement of material or structures in water (e.g., groynes, piers, infilling, partial infills, jetties) Shoreline hardening	Placing material or structures in water reduces habitat availability (i.e., the footprint of the infill or structure is lost). Placing of fill can cover organisms and preferred substrates for mussels and their host(s). Hardening of shorelines can reduce organic inputs into the water and alter water temperatures, potentially affecting the availability of food for these species. Changing shoreline morphology can result in altered flow patterns, change sediment depositional areas, reduce oxygenation of substrates, cause erosion and alter turbidity levels. These changes can promote aquatic plant growth and cause changes to nutrient levels.	Same as above	Same as above	• Same as above
Habitat Removal and Alteration: Construction of dams and/or barriers	Dams/barriers can result in direct loss of habitat or fragmentation, which can limit the reproductive capabilities of mussels by eliminating or decreasing the number of hosts available.	Same as above	Same as above	• Same as above
Habitat Removal and Alteration (Water Quantity): Change in timing, duration and frequency of flow Water-level management	High flow conditions (and “flashier” flows) can cause dislodgement and passive transport of mussels from areas of suitable habitat into areas of lesser or marginal habitat. Low flows can result in depressed DO levels, desiccation, elevated temperatures, and strandings. Host species may also be impacted,	Same as above	Same as above	• Same as above

Activity	Effect-Pathway	Function Affected	Feature Affected	Attribute Affected
(e.g., through dam operation or water extraction activities [e.g., for irrigation], that causes dewatering of habitat or excessive flow rates); large increases in impervious surfaces from urban and residential development	thereby disrupting reproduction. Altered flow patterns can affect habitat availability (e.g., by 'dewatering' habitats) in creeks and rivers, sediment deposition (e.g., changing preferred substrates), and water temperatures.			
Recreational Activities: Use of motor vehicles in the river	Disrupt substrate, dislodge mussels.	Same as above	Same as above	• All species: low levels of contaminants • Substrate composition: NRS, SB, RP - packed sand (less than 2 mm) or fine to coarse gravel (2 to 60 mm); SM - silt and sand deposits (less than 2 mm) under large rocks; RB - higher percentage of sand (less than 2 mm) or gravel (2 to 30 mm) • All species: suitable depth of water (NRS, RB - between 12 and 26 cm in summer, SB - up to 2.5 m in summer, RP between 0.12 and 3 m in summer)All species: availability of hosts

Activity	Effect-Pathway	Function Affected	Feature Affected	Attribute Affected
Decline of Host Fish Direct removal of host fish(es) through harvest or indirect means (e.g., damming activities may prevent fish movement) Excessive baitfish collection; baitfish releases	Any activities that affect the host species' abundance, movements, or behaviour during the period of encystment or release may disrupt the reproductive cycle of these mussels. Can affect number and health of available host fishes. Spread aquatic invasive species (boats, bait buckets).	Reproduction	Same as above	• All species: availability Presence of host fishAll species: absence or limited amount of dredenid mussels

In future, threshold values for some stressors may be informed through further research. For some of the above activities, BMPs may be enough to mitigate threats to the species and their habitats; however, in some cases, it is not known if BMPs are adequate to protect critical habitat and further research is required.

2.7 Habitat Protection

SARA was proclaimed in June of 2003. Under SARA, there are general prohibitions against killing, harming, taking, possessing, capturing, and collecting the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel or Rayed Bean. Once identified, SARA includes provisions to prevent the destruction of critical habitat.

Provincially, protection is also afforded under the *Planning Act*. Planning authorities are required to be “consistent with” the provincial Policy Statement under Section 3 of Ontario’s *Planning Act*, which prohibits development and site alteration in the habitat of Endangered or Threatened species. In addition, the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are listed as Endangered under Ontario’s *Endangered Species Act*, *2007*. Under the Act, individuals of each species are currently protected and their habitat is protected under the general habitat protection provisions of the Act as of June 30, 2013. Stream-side development in Ontario is managed through flood plain regulations enforced by local conservation authorities. The majority of land in the Ausable and Sydenham rivers where these mussels are found is privately owned, while the land in the St. Clair River delta is controlled by the Walpole Island First Nation.

2.8 Effects on Other Species

The Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are sensitive species, particularly to issues of water quantity and quality. Additionally, there is considerable overlap in distribution of these mussels with currently listed fishes such as the Eastern Sand Darter and Northern Madtom. Many of the threats impacting these species are similar. For this reason, it is expected that efforts made to improve conditions for these mussels will benefit most other aquatic species. A few opportunistic species that can readily adapt to degraded conditions (e.g., Giant Floater [*Pyganodon grandis*] or Fathead Minnow [*P. promelas*]) may see a decline in numbers/range as a result of rehabilitative efforts. These changes should not be viewed in a negative light but rather as a restoration of the aquatic community to pre-disturbance conditions.

2.9 Statement on Action Plans

One or more action plans relating to this recovery strategy will be produced within five years of the final strategy being posted on the public registry. Wherever possible, action plans should be developed based on input received from those involved with existing watershed recovery teams. Recovery resources in southwestern Ontario (both fiscal and personnel) are limited. Partnership with other recovery teams will ensure that efforts are not duplicated and will help to prevent the implementation of recovery efforts that may conflict between species. As such, DFO, in partnership with the Sydenham River Recovery Team, has developed a multi-species, ecosystem-based action plan for the Sydenham River, which was completed in 2018; the action plan included recovery measures for Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel and Rayed Bean.

3 REFERENCES

Allan, J.D. and A.S. Flecker. 1993. Biodiversity conservation in running waters. BioScience 43: 32-43.

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. Environmental Toxicology and Chemistry 22: 2569-2575.

Ausable River Recovery Team (ARRT). 2005. Recovery strategy for species at risk in the Ausable River: an ecosystem approach 2004-2009. Draft 5 – June 2005. xi + 128 p.

Baitz, A., M. Veliz, H. Brock, and S. Staton. 2008. Monitoring program to track the recovery of endangered freshwater mussels in the Ausable River, Ontario [DRAFT]. Prepared for the Ausable River Recovery Team, the Interdepartmental Recovery Fund and Fisheries and Oceans Canada. 26 p.

Baker, F.C. 1928. The Fresh Water Mollusca of Wisconsin. Part II: Pelecypoda. Bulletin 70, Wisconsin Geological and Natural History Survey: 495 p.

Baker, K. 2005. Nine year study of the invasion of western Lake Erie by the Round Goby (*Neogobius melanostomus*): changes in goby and darter abundance. Ohio Journal of Science 105: A-31.

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*. Canadian Journal of Fisheries and Aquatic Sciences 54: 512-519.

Balfour, D.L. and L.A. Smock. 1995. Distribution, age structure, and movements of the freshwater mussel *Elliptio complanata* (Mollusca: Unionidae) in a headwater stream. Journal of Freshwater Ecology 10: 255-268.

Barnhart, M.C., W.R. Haag, and W.N. Roston. 2008. Adaptations to host infection and larval parasitism in Unionida. Journal of North American Benthological Society 27: 370-394.

Barnhart, M.C., F.A. Riusech, and A.D. Roberts. 1998. Host of Salamander Mussel (*Simpsonaias ambigua*) and Snuffbox (*Epioblasma triquetra*) from the Meramec River system, Missouri. Triannual Unionid Report 16: 34.

Bauer, G. 2001. Factors affecting naiad occurrence and abundance. Pages 155-162 *in* Ecology and evolution of the freshwater mussels Unionida. Edited by G. Bauer and K. Wächtler. Springer-Verlag, Berlin, Heidelberg.

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

Bringolf, R.B., W.C. Cope, C.B. Eads, P.R. Lazaro, M.C. Barnhart, and D. Shea. 2007. Acute and chronic toxicity of freshwater mussels (uniondae). Environmental Toxicology and Chemistry 26(10): 2086-2093.

Buchanan, A.C. 1980. Mussels (naiades) of the Meramec River basin, Missouri. Aquatic Series No. 17, Missouri Department of Conservation, Jefferson City, MO: 68 p.

Burky, A.J. 1983. Physiological ecology of freshwater bivalves. Pages 281-327 *in* The Mollusca, Vol. 6. Ecology. Edited by W.D. Russell-Hunter. Academic Press, Orlando, FL.

Canadian Council of Ministers of the Environment (CCME). 2005. Canadian water quality guidelines (copper). Canadian Council of Ministers of the Environment, Environment and Climate Change Canada. Ottawa, ON.

Canadian Council of Ministers of the Environment (CCME). 2011. Canadian water quality guidelines for the protection of aquatic life: Chloride. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

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

Clarke, A.H. 1985. The tribe Alasmidontini (Unionidae: Anodontinae), Par II: *Lasmigona* and *Simpsonaias*. Smithsonian Contributions to Zoology, Number 399: 75 p.

Clarke, A.H. 1992. Ontario's Sydenham River, an important refugium for freshwater mussels against competition from the Zebra Mussel *Dreissena polymorpha*. Malacology Data Net 3: 43-55.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2004. COSEWIC assessment and status report on the Round Pigtoe *Pleurobema sintoxia* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 33 p.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2010a. COSEWIC assessment and status report on the Northern Riffleshell *Epioblasma torulosa rangiana* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 47 p.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2010b. COSEWIC assessment and status report on the Rayed Bean *Villosa fabalis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 40 p.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2011a. COSEWIC assessment and status report on the Snuffbox *Epioblasma triquetra* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 63 p.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2011b. COSEWIC status appraisal summary on the Salamander Mussel *Simpsonaias ambigua* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xv p.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2014. COSEWIC status appraisal summary on the Round Pigtoe *Pleurobema sintoxia* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xxii p.

Cope, W.G., R.B. Bringolf, D.B. Buchwalter, T.J. Newton, C.G. Ingersoll, N. Wang, T. Augspurger, F.J. Dwyer, M.C. Barnhart, R.J. Neves, and E. Hammer. 2008. Differential exposure, duration, and sensitivity of unionoidean bivalve life stages to environmental contaminants. Journal of the North American Benthological Society 27: 451-462.

Cummings, K.S. and C.A. Mayer. 1992. Field Guide to the Freshwater Mussels of the Midwest. Illinois Natural History Survey Manual 5. 194 p.

Dennis, S.D. 1984. Distributional analysis of the freshwater mussel fauna of the Tennessee River system, with special reference to possible limiting effects of siltation. Ph.D. thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 245 p.

Dennis, S.D. 1987. An unexpected decline in populations of the freshwater mussel, *Dysnomia* (= *Epioblasma*) *capsaeformis*, in the Clinch River of Virginia and Tennessee. Virginia Journal of Science 38: 281-288.

Department of Energy and Resources Management. 1965. Sydenham valley conservation report, Toronto, Ontario.

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. 73 p.

Dudgeon, D. and B. Morton. 1984. Site selection and attachment duration of *Anodonta woodiana* (Bivalvia: Unionacea) glochidia on fish hosts. Journal of Zoology (London) 204: 355-362.

Edwards, A. and N.E. Mandrak. 2006. Fish assemblage surveys of the lower Thames River, Ontario, using multiple gear types: 2003-2004. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2772: vii + 94 p.

Epp, J.M., T.J. Morris, and K.A. McNichols-O'Rourke. 2013. A preliminary search for *Epioblasma torulosa rangiana* (Northern Riffleshell) in the Maitland River watershed. Canadian Manuscript Report of Fisheries and Aquatic Sciences 3025: v + 19 p.

Evans, M. and C. Frick. 2002. The effects of road salts on aquatic ecosystems. Environment and Climate Change Canada, National Water Research Institute, Burlington/Saskatoon, NWRI Contribution No. 02-308.

Fisheries and Oceans Canada (DFO). 2010. Recovery potential assessment of Wavyrayed Lampmussel (*Lampsilis fasciola*), in Canada. DFO Canadian Science Advisory Secretariat Science Advisory Report 2010/045.

Fisheries and Oceans Canada (DFO). 2011a. Assessment of methods for the identification of critical habitat for freshwater mussels. DFO Canadian Science Advisory Secretariat Science Advisory Report 2011/047.

Fisheries and Oceans Canada (DFO). 2011b. Recovery potential assessment of Eastern Pondmussel (*Ligumia nasuta*), Fawnsfoot (*Truncilla donaciformis*), Mapleleaf (*Quadrula quadrula*) and Rainbow (*Villosa iris*) in Canada. DFO Canadian Science Advisory Secretariat Science Advisory Report 2010/073.

Fisheries and Oceans Canada (DFO). 2013. Report on the progress of recovery strategy implementation for the Wavyrayed Lampmussel, Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel, and Rayed Bean in Canada for the period 2006-2011. *Species at Risk Act* Recovery Strategy Report Series. Fisheries and Oceans Canada, Ottawa. iv + 34 p.

Fisheries and Oceans Canada (DFO). 2018a. Action plan for the Sydenham River in Canada: an ecosystem approach. *Species at Risk Act* Action Plan Series. Fisheries and Oceans Canada, Ottawa. iv + 37 p.

Fisheries and Oceans Canada (DFO). 2018b. Action plan for the Ausable River in Canada: an ecosystem approach. *Species at Risk Act* Action Plan Series. Fisheries and Oceans Canada, Ottawa. v + 47 p.

French, J.R.P. and D.J. Jude. 2001. Diets and diet overlap of nonindigenous gobies and small benthic native fishes co-habiting the St. Clair River, Michigan. Journal of Great Lakes Research 27(3): 300–311.

Gagné, F., C. Blaise, and J. Hellou. 2004. Endocrine disruption and health effects of caged mussels, *Elliptio complanata*, placed downstream from a primary-treated municipal effluent plume for 1 year. Comparative Biochemistry and Physiology C 138: 33-44.

Gagné, F., B. Bouchard, C. André, E. Farcy, and M. Fournier. 2011. Evidence of feminization in wild *Elliptio complanata* mussels in the receiving water downstream of a municipal effluent outfall. Comparative Biochemistry and Physiology, Part C 153: 99-106.

Gagnon, C., F. Gagné, P. Turcotte, I. Saulnier, C. Blaise, M. Salazar, and S. Salazar. 2006. Metal exposure to caged mussels in a primary-treated municipal wastewater plume. Chemosphere 62: 998-1010.

Galbraith, H.S. and C.C. Vaughn. 2009. Temperature and food interact to influence gamete development in freshwater mussels. Hydrobiologia 636: 35-47.

Gendron, A.D. 1999. Status report on the Mudpuppy, *Necturus maculosus*, in Canada. Prepared for the Committee on the Status of Endangered Wildlife in Canada: 86 p.

Gillis, P.L. 2011. Assessing the toxicity of sodium chloride to the glochidia of freshwater mussels: implications for salinization of surface waters. Environmental Pollution 159 (6): 1702-1708.

Gillis, P.L. 2012. Cumulative impacts of urban runoff and municipal wastewater effluents on wild freshwater mussels (*Lasmigona costata*). Science of the Total Environment 431(2012): 348-356.

Gillis, P.L. and G.L. Mackie. 1994. Impact of the Zebra Mussel, *Dreissena polymorpha*, on populations of Unionidae in Lake St. Clair. Canadian Journal of Zoology 72: 1260-1271.

Gillis, P.L., R. McInnis, J. Salerno, S.R. de Solla, M.R. Servos, and E.M. Leonard. 2017. Freshwater mussels in an urban watershed: impacts of anthropogenic inputs and habitat alterations on populations. Science of the Total Environment 574(2017): 671-679.

Gillis, P.L., R.J. Mitchell, A.N. Schwalb, K.A. McNichols, G.L. Mackie, C.M. Wood, and J.D. Ackerman. 2008. Sensitivity of glochidia (larvae) of freshwater mussel to copper: assessing the effect of water hardness and dissolved organic carbon on the sensitivity of endangered species. Aquatic Toxicology 88: 137-145.

Gordon, M.E. and J.B. Layzer. 1989. Mussels (Bivalvia: Unionoidea) of the Cumberland River: review of life histories and ecological relationships. Biological Report 89(15). U.S. Department of the Interior, Fish and Wildlife Service, Washington D.C. vii + 99 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. Canadian Journal of Fisheries and Aquatic Sciences 50: 13-19.

Hove, M.C. 1995. Host research on Round Pigtoe glochidia. Triannual Unionid Report (8): 8.

Howard, A.D. 1951. A river mussel parasitic on a salamander. Natural History Miscellanea 77: 2-6.

Jacques Whitford Environment Ltd. 2001. Sydenham River recovery project: synthesis and analysis of background data. Report to the Sydenham River Recovery Team.

Janssen, J. and D.J. Jude. 2001. Recruitment failure of Mottled Sculpin *Cottus bairdii* in Calumet Harbour, southern Lake Michigan, induced by the newly introduced Round Goby *Neogobius melanostomus*. Journal of Great Lakes Research 27: 319-328.

Kat, P.W. 1984. Parasitism and the Unionacea (Bivalvia). Biological Reviews 59: 189-207.

Kidd, K.A., P.J. Blanchfield, K.H. Mills, V.P. Palace, R.E. Evans, J.M. Lazorchak, and R.W. Flick. 2007. Collapse of a fish population after exposure to a synthetic estrogen. Proceedings of the National Academy of Science 104: 8897-8901.

Lefevre, G. and W.C. Curtis. 1910. Reproduction and parasitism in the Unionidae. Journal of Experimental Zoology 9: 79-115.

Lydeard, C., R.H. Cowie, W.F. Ponder, A.E. Bogan, P. Bouchet, S.A. Clark, K.S. Cummings, T.J. Frest, O. Gargominy, D.G. Herbert, R. Hershler, K.E. Perez, B. Roth, M. Seddon, E.E. Strong, and F.G. Thompson. 2004. The global decline of nonmarine mollusks. BioScience 54: 321-330.

Mackie, G.L. and J.M. Topping. 1988. Historical changes in the unionid fauna of the Sydenham River watershed and downstream changes in shell morphometrics of three common species. Canadian Field-Naturalist 102: 617-626.

Mandrak, N.E., J. Barnucz, and D. Marson. 2006a. Targeted sampling of fish species at risk in the Grand River watershed, 2003. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2778: v + 27 p.

Mandrak, N.E., J. Barnucz, G.J. Velema, and D. Marson. 2006b. Survey of the status of Black Redhorse (*Moxostoma duquesnei*) and Spotted Gar (*Lepisosteus oculatus*) in Canada, 2002. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2776: v + 39 p.

McDaniel, T. and P. Martin. 2003. Status of the Mudpuppy (*Necturus maculosus*) populations in the Sydenham River. Interdepartmental Recovery Fund Final Report. 17 p.

McMahon, R.F. 1991. Mollsca: Bivalvia. Pages 315-399 *in* Ecology and Classification of North American Freshwater Invertebrates. Edited by J.H. Thorp and A.P. Covich. Academic Press, San Diego, California.

McNichols, K.A. 2007. Implementing recovery strategies for mussel species at risk in Ontario. M.Sc. Thesis, University of Guelph. 171 p.

McNichols, K.A. and G.L. Mackie. 2002. Fish host determination of endangered freshwater mussels in the Sydenham River Ontario, Canada. ESRF 2002/2003 Final Report. 22 p.

McNichols, K. and G.L. Mackie. 2004. Fish host determination of endangered freshwater mussels in the Sydenham River, Ontario, Canada. ESRF 2003/2004 Final Report. 26 p.

McNichols, K.A., G.L. Mackie, and J.D. Ackerman. 2011. Host fish quality may explain the status of endangered *Epioblasma torulosa rangiana* and *Lampsilis fasciola* (Bivalvia: Unionidae) in Canada. Journal of North American Benthological Society 30: 60-70.

McNichols-O'Rourke, K.A., A. Robinson, and T.J. Morris. 2012. Summary of freshwater mussel timed search surveys in southwestern Ontario in 2010 and 2011. Canadian Manuscript Report of Fisheries and Aquatic Sciences 3009: vi + 42 p.

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. American Midland Naturalist 150: 37-50.

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

Metcalfe-Smith, J.L., G.L. Mackie, J. Di Maio, and S. Staton. 2000. Changes over time in the diversity and distribution of freshwater mussels (Unionidae) in the Grand River, southwestern Ontario. Journal of Great Lakes Research 26(4): 445-459.

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. Environment and Climate Change Canada, National Water Research Institute, Burlington, Ontario. Technical Note No. AEI-TN-04-001.

Metcalfe-Smith, J.L, D.J. McGoldrick, D.T. Zanatta, and L.C. Grapentine. 2007. Development of a monitoring program for tracking the recovery of endangered freshwater mussels in the Sydenham River, Ontario. Prepared for the Sydenham River Recovery Team, the Interdepartmental Recovery Fund and Fisheries and Oceans Canada. 61 p.

Metcalfe-Smith, J.L., S.K. Staton, G.L. Mackie, and I.M. Scott. 1999. Range, population stability and environmental requirements of rare species of freshwater mussels in southern Ontario. Environment and Climate Change Canada, National Water Research Institute, Burlington, Ontario, NWRI Contribution No. 99-058.

Metcalfe-Smith, J.L., S.K. Staton, G.L. Mackie, and E.L. West. 1998. Assessment of the current status of rare species of freshwater mussels in southern Ontario. Environment and Climate Change Canada, National Water Research Institute, Burlington, Ontario, NWRI Contribution No. 98-019.

Morris, T.J. and A. Edwards. 2007. Freshwater mussel communities of the Thames River, Ontario: 2004-2005. Canadian Manuscript of Report of Fisheries and Aquatic Sciences 2810: v + 30 p.

Nalepa, T.F. 1994. Decline of native unionid bivalves in Lake St. Clair after infestation by the Zebra Mussel, *Dreissena polymorpha*. Canadian Journal of Zoology 61: 832-838.

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. Journal of Great Lakes Research 22: 354-369.

Natural Heritage Information Centre (NHIC). 1997. Draft report on the conservation status of Ontario unionids. Natural Heritage Information Centre, Ontario Ministry of Natural Resources and Forestry. Peterborough, Ontario.

NatureServe. 2015. NatureServe explorer: an online encyclopedia of life. Version 7.1. NatureServe, Arlington, Virginia. (Accessed: October, 2016)

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. September 2003. 92 p.

Neves, R.J. and M.C. Odom. 1989. Muskrat predation on endangered freshwater mussels in Virginia. Journal of Wildlife Management 53(4): 934-941.

Newton, T.J. and M.R. Bartsch. 2007. Lethal and sublethal effects of ammonia to juvenile *Lampsilis* mussels (Unionidae) in sediment and water-only exposures. Environmental Toxicology and Chemistry 26: 2057-2065.

Nichols, S.J., H. Silverman, T.H. Dietz, J.W. Lynn, and D.L. Garling. 2005. Pathways of food uptake in native (Unionidae) and introduced (Corbiculidae and Dreissenidae) freshwater bivalves. Journal of Great Lakes Research 31: 87-96.

Ontario Ministry of the Environment (OMOE). 1994. Provincial water quality objectives (Ontario). (Accessed: April 2012).

Ontario Ministry of the Environment (OMOE). 2011. Great Lakes protection legislation. (Accessed: September 2011).

Ortmann, A.E. 1919. A monograph of the naiads of Pennsylvania, Part III. Systematic account of the genera and species. Memoirs of the Carnegie Museum 8(1), Carnegie Institute, Pittsburgh, Pennsylvania. 384 p.

Parmalee, P.W. and A.E. Bogan. 1998. The Freshwater Mussels of Tennessee. The University of Tennessee Press, Knoxville. 328 p.

Pip, E. 1995. Cadmium, lead and copper in freshwater mussels from the Assiniboine River, Manitoba, Canada. Journal of Molluscan Studies 61: 295-302.

Poos, M.A., A.J. Dextrase, A.N. Schwalb, and J.D. Ackerman. 2010. Secondary invasion of the Round Goby into high diversity Great Lakes tributaries and species at risk hotspots: potential new concerns for endangered freshwater species. Biological Invasions 12: 1269–1284.

Portt, C., G. Coker, and K. Barrett. 2003. Recovery strategy for fish species at risk in the Grand River, Ontario. Draft report prepared for the Grand River Recovery Team, March 31, 2003.

Ricciardi, A., F.G. Whoriskey, and J.B. Rasmussen. 1995. Predicting the intensity and impact of *Dreissena* infestation on native unionid bivalves from *Dreissena* field density. Canadian Journal of Fisheries and Aquatic Sciences 52: 1449-1461.

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. American Midland Naturalist 155: 307-320.

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*. Canadian Journal of Fisheries and Aquatic Sciences 51: 2234-2242.

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

Schwalb, A.N., M.S. Poos, and J.D. Ackerman. 2011. Movement of Logperch - the obligate host fish for endangered Snuffbox mussels: implications for mussel dispersal. Aquatic Sciences 73: 223-231.

Schwalb, A.N. and M. Pusch. 2007. Horizontal and vertical movement of unionid mussels in a low land river. Journal of North American Benthological Society 26: 261-272.

Spooner, D., M. Xenopoulos, C. Schneider, and D. Woolnough. 2011. Coextirpation of host-affiliate relationships in rivers: the role of climate change, water withdrawal, and host-specificity. Global Change Biology 17(4): 1720.

St. Clair Region Conservation Authority. 2008. Watershed report card 2008. (Accessed: August 2011).

Stanfield, L. and R. Kuyvenhoven. 2005. Protocol for applications used in the Aquatic Landscape Inventory Software application for delineating, characterizing and classifying valley segments within the Great Lakes basin. Ontario Ministry of Natural Resources and Forestry Report, July 27, 2005.

Stansbery, D.H. 1967. Growth and longevity of Naiads from Fishery Bay in western Lake Erie. American Malacological Union Annual Reports 1967: 10-11.

Staton, S.K., A. Dextrase, J.L. Metcalfe-Smith, J. Di Miao, M. Nelson, J. Parish, B. Kilgour, and E. Holm. 2003. Status and trends of Ontario’s Sydenham River in relation to aquatic species at risk. Environmental Monitoring and Assessment 88: 283-310.

Strayer, D.L., J.A. Downing, W.R. Haag, T.L. King, J.B. Layzer, T.J. Newton, and S.J. Nichols. 2004. Changing perspectives on pearly mussels, North America's most imperilled animals. BioScience 54(5): 429-439.

Strayer, D.L. and K.J. Jirka. 1997. The Pearly Mussels of New York State. Memoirs of the New York State Museum 26: 113 p. + 27 plates.

Tetreault, G.R., C.J. Bennett, K. Shires, B. Knight, M.R. Servos, and M.E. McMaster. 2011. Intersex and reproductive impairment of wild fish exposed to multiple municipal wastewater discharges. Aquatic Toxicology 104: 278–290.

Tetzloff, J. 2001. Survival rates of unionid species following a low oxygen event in Big Darby Creek, Ohio. Ellipsaria 3: 18-19.

Thames River Recovery Team (TRRT). 2004. Recovery strategy for the Thames River Aquatic Ecosystem: 2005-2010. December 2004 Draft. 146 p.

The Nature Conservancy (TNC). 1987. Element stewardship abstract for Rayed Bean (*Villosa fabalis*). Arlington, Virginia. 5 p.

The Nature Conservancy (TNC). 1996. Invertebrate characterization abstract (global): *Villosa fabalis*. The Nature Conservancy. Unpublished. Arlington, Virginia. 3 p.

The Nature Conservancy (TNC). 1999. Element global ranking form as of November 18, 1999 for *Simpsonaias ambigua*. The Nature Conservancy. Unpublished.

The Nature Conservancy (TNC). 2000. Element global ranking form for *Epioblasma triquetra*, January 24, 2000. The Nature Conservancy. Unpublished. Arlington, Virginia.

Thomas, M.V. and R.C. Haas. 2004. Status of Lake St. Clair fish community and sport fish,1996-2004. Michigan Department of Natural Resources, Fisheries Division. Fisheries Research Report 2067. 26 p.

United States Fish and Wildlife Service (USFWS). 1994. Clubshell (*Pleurobema clava*) and Northern Riffleshell (*Epioblasma torulosa rangiana*) recovery plan. Hadley Massachusetts. 68 p.

United States Fish and Wildlife Service (USFWS). 2012a. Snuffbox (*Epioblasma triquetra*). (Accessed: April 2012).

United States Fish and Wildlife Service (USFWS). 2012b. Rayed Bean (*Villosa fabalis*). (Accessed: April 2012).

Upper Thames River Conservation Authority (UTRCA). 2004. UTRCA water report. (Accessed: August 2011).

Upper Thames River Conservation Authority (UTRCA). 2011. Invasive non-native species. (Accessed: September 2011).

van der Schalie, H. 1938. The Naiad Fauna of the Huron River, in Southeastern Michigan. Miscellaneous Publication No. 40, Museum of Zoology, University of Michigan. University of Michigan Press, Ann Arbor, Michigan. 83 p. + plates I-XII.

Vaughn, C.C., K.B. Gido, and D.E. Spooner. 2004. Ecosystem processes performed by unionid mussels in stream mesocosms: species roles and effects of abundance. Hydrobiologia 527: 35-47.

Vaughn, C.C. and C.C. Hakenkamp. 2001. The functional role of burrowing bivalves in freshwater ecosystems. Freshwater Biology 46: 1431-1446.

Vaughn, C.C., S.J. Nichols, and D.E. Spooner. 2008. Community and food web ecology of freshwater mussels. Journal of the North American Benthological Society 27: 409–423.

Veliz, M. 2003. Ausable River water quality report: a background report to the Ausable River recovery plan. Ausable Bayfield Conservation Authority: Exeter, ON.

Villella, R.F., D.R. Smith, and D.P. Lemarie. 2004. Estimating survival and recruitment in a freshwater mussel population using mark-recapture techniques. American Midland Naturalist 151: 114-133.

Wächtler, K., M.C. Dreher-Mansur, and T. Richter. 2001. Larval types and early post larval biology in Naiads (Unionoida). Pages 93-125 *in* Ecology and Evolution of the Freshwater Mussels Unionida. Edited by G. Bauer and K. Wächtler. Springer-Verlag, Berlin, Heidelberg.

Walpole Island Heritage Centre. 2002. Walpole Island First Nation heritage centre newsletter. Special Edition. Summer/Fall 2002. Published by the Walpole Island Heritage Centre, R.R. 3 (Walpole Island), Wallaceburg, Ontario, Canada, N8A 4K9. 16 p.

Wang, N., C.G. Ingersoll, I.E. Greer, D.K. Hardesty, C.D. Ivey, J.L. Kunz, W.G. Brumbaugh, F.J. Dwyer, A.D. Roberts, T. Augspurger, C.M. Kane, R.J. Neves, and M.C. Barnhart. 2007. Chronic toxicity of copper and ammonia to juvenile freshwater mussels (Unionidae). Environmental Toxicology and Chemistry 26(10): 2048-2056.

Watson, E.T., J.L. Metcalfe-Smith, and J. Di Maio. 2000a. Status of the Snuffbox, *Epioblasma triquetra*, in Canada. COSEWIC Status Report, Ottawa, Ontario. 51 p.

Watson, E.T., J.L. Metcalfe-Smith, and J. Di Maio. 2000b. Status of the Mudpuppy Mussel, *Simpsonaias ambigua*, in Canada. COSEWIC Status Report, Ottawa, Ontario. 46 p.

Watters, G.T., M.A. Hoggarth, and D.H. Stansbury. 2009. The Freshwater Mussels of Ohio. Ohio State University Press, Columbus. 421 p.

Watters, G.T., T. Menker, S. Thomas, and K. Kuehnl. 2005. Host identification or confirmations. Ellipsaria 7: 11-12.

Watters, G.T. and S.H. O'Dee. 1999. Glochidia of the freshwater mussel *Lampsilis* overwintering on fish hosts. Journal of Molluscan Studies 65: 453-459.

Welker, M. and N. Walz. 1998. Can mussels control the plankton in rivers? A Plantological approach applying Lagrangian sampling strategy. Limnology and Oceanography 43: 753-762.

Williams, J.D., M.L. Warren Jr., 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. 2002. Life history of endangered freshwater mussels of the Sydenham River, southwestern Ontario, Canada. M.Sc. Thesis. University of Guelph, Guelph, Ontario, Canada. 128 p.

Woolnough, D.A. and G.L. Mackie. 2001. Endangered freshwater mussels in the Sydenham River, Ontario, Canada. Final report to the Endangered Species Recovery Fund. University of Guelph, Guelph, Ontario.

Yeager, B.L. and C.F. Saylor. 1995. Fish hosts for four species of freshwater mussels (Pelecypoda: Unionidae) in the Upper Tennessee River Drainage. American Midland Naturalist 133: 1-6.

Zanatta, D.T. 2009. Rayed Bean freshwater mussel display. (Accessed: August 2011).

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. Journal of Great Lakes Research 28(3): 479-489.

APPENDIX 1: EFFECTS ON THE ENVIRONMENT AND OTHER SPECIES

A strategic environmental assessment (SEA) is conducted on all SARA recovery planning documents, in accordance with the *Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals*. The purpose of a SEA is to incorporate environmental considerations into the development of public policies, plans, and program proposals to support environmentally sound decision-making.

Recovery planning is intended to benefit species at risk and biodiversity in general. However, it is recognized that strategies may also inadvertently lead to environmental effects beyond the intended benefits. The planning process based on national guidelines directly incorporates consideration of all environmental effects, with a particular focus on possible impacts upon non-target species or habitats. The results of the SEA are incorporated directly into the strategy itself, but are also summarized below in this statement.

This recovery strategy will clearly benefit the environment by promoting the recovery of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean. The potential for the strategy to inadvertently lead to adverse effects on other species was considered. The SEA concluded that this strategy will clearly benefit the environment and will not entail any significant adverse effects. Refer to the following sections of the document in particular: Description of the Species' Needs – Biological Needs, Ecological Role and Limiting Factors; Effects on Other Species; and, Recommended Approach for Recovery, as applicable.