Species at Risk Act
Recovery Strategy Series

Recovery Strategy for Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean in Canada.

December 2006

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 Canada, Parks Canada Agency and Fisheries and Oceans Canada — under the Accord for the Protection of Species at Risk. Sections 37–46 of SARA (http://www.sararegistry.gc.ca/the_act/default_e.cfm) spell out 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 SARA Public Registry (http://www.sararegistry.gc.ca/) and the web site of the Recovery Secretariat (http://www.speciesatrisk.gc.ca/recovery/default_e.cfm).

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

December 2006

Recommended citation:

Morris, T. J. and M. Burridge. 2006. Recovery Strategy for Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean in Canada. *Species at Risk Act* Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa, x + 76 pp.

Additional copies:

You can download additional copies from the SARA Public Registry (http://www.sararegistry.gc.ca/)

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

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

© Her Majesty the Queen in Right of Canada, represented by the Minister of Fisheries and Oceans, 2006. All rights reserved.
ISBN: 978-0-662-44850-1
Cat. no.: En3-4/16-2007E-PDF

Content (excluding the cover illustration) may be used without permission, with appropriate credit to the source.

DECLARATION

This recovery strategy for the Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean has been prepared in cooperation with the jurisdictions described in the Preface. Fisheries and Oceans Canada has reviewed and accepts this document as its recovery strategy for the Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean as required by the *Species at Risk Act*. This recovery strategy also constitutes advice to other jurisdictions and organizations on the recovery goals, approaches and objectives that are recommended to protect and recover the species.

Success in the recovery of this 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. In the spirit of the National Accord for the Protection of Species at Risk, the Minister of Fisheries and Oceans invites all Canadians to join Fisheries and Oceans Canada in supporting and implementing this strategy for the benefit of the Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel, Rayed Bean and Canadian society as a whole. Fisheries and Oceans Canada will support implementation of this strategy to the extent possible, given available resources and its overall responsibility for species at risk conservation. Implementation of the strategy by other participating jurisdictions and organizations is subject to their respective policies, appropriations, priorities, and budgetary constraints.

The goals, objectives and recovery approaches identified in the strategy are based on the best existing knowledge and are subject to modifications resulting from new findings and revised objectives. The Minister of Fisheries and Oceans will report on progress within five years.

This strategy will be complemented by one or more action plans that will provide details on specific recovery measures to be taken to support conservation of these species. The Minister will take steps to ensure that, to the extent possible, Canadians interested in or affected by these measures will be consulted.

RESPONSIBLE JURISDICTIONS

The responsible jurisdiction for these five species is Fisheries and Oceans Canada. These mussels occur only in Ontario, and the government of Ontario cooperated in the production of this recovery strategy.

AUTHORS

This document was prepared by Todd J. Morris and Mary Burridge on behalf of the Ontario Freshwater Mussel Recovery Team.

ACKNOWLEDGMENTS

The Ontario Freshwater Mussel Recovery Team would like to thank the following organizations for their support in the development of this recovery strategy: Fisheries and Oceans Canada, Environment Canada, Ontario Ministry of Natural Resources, 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, Lower Thames valley Conservation Authority and the Walpole Island Heritage Information Centre.

STRATEGIC ENVIRONMENTAL ASSESSMENT

In accordance with the *Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals*, the purpose of a Strategic Environmental Assessment (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 recovery planning process based on national guidelines directly incorporates consideration of all environmental effects, with a particular focus on possible impacts on non-target species or habitats.

This recovery strategy will clearly benefit the environment by promoting the recovery of five Endangered mussel species. 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.

RESIDENCE

SARA defines residence as: "*a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating*" **[SARA S2(1)]**.

Residence descriptions, or the rationale for why the residence concept does not apply to a given species, are posted on the SARA public registry: http://www.sararegistry.gc.ca/plans/residence_e.cfm

PREFACE

These five freshwater mussel species are under the jurisdiction of the federal government. The *Species at Risk Act* (SARA, Section 37) requires the competent minister to prepare recovery strategies for listed extirpated, endangered or threatened species. The Northern Riffleshell, Snuffbox, Mudpuppy Mussel and Rayed Bean were listed as Endangered under SARA in June 2003 while the Round Pigtoe was listed as Endangered in July 2005. Fisheries and Oceans Canada – Central and Arctic Region led the development of this recovery strategy. The proposed strategy meets SARA requirements in terms of content and process (Sections 39-41). It was developed in cooperation or consultation with:

- Jurisdictions – Environment Canada, Province of Ontario
- Aboriginal groups – Chippewa of Kettle and Stoney Point, Aamjiwnaang First Nation, Caldwell First Nation, Moravia of the Thames First Nation, Chippewa of the Thames, Oneida, Munsee-Delaware First Nation, Southern First Nation Secretariate, Mississauga of New Credit First Nation, Six Nations of the Grand, Walpole Island First Nation, Metis Nation of Ontario.
- Environmental non-government groups – Ausable Bayfield Conservation Authority, Grand River Conservation Authority, Lower Thames Valley Conservation Authority, Maitland Valley Conservation Authority, St. Clair Region Conservation Authority, Upper Thames River Conservation Authority, McMaster University, University of Guelph, University of Toronto/Royal Ontario Museum.

EXECUTIVE SUMMARY

Freshwater mussels are among the world's most imperiled 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 imperiled (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 34 (Metcalfe-Smith *et al.* 2003), however, recent evidence suggests that the Grand (Metcalfe-Smith *et al*. 2000) and Thames rivers, also with historic species counts of 34, were equally diverse.

Despite the historic 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 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 4 species have been lost from the Sydenham River, 10 species have disappeared from the Thames River and the community of the Grand River has been reduced by 9 species. These declines, coupled with the near complete collapse of the Great Lakes populations (Nalepa *et al*. 1996), have led to the listing of 10 Ontario mussel species as endangered by the Committee on the Status of Endangered Wildlife In Canada (COSEWIC).

Threats to the Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy 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 exotic zebra mussel (*Dreissena polymorpha*). Zebra mussels attach to the shells of native mussels and act to inhibit feeding, respiration, excretion and locomotion. Populations of Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean mussels 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 the Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy 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.

This Recovery Strategy was assembled by the Ontario Freshwater Mussel Recovery Team consisting of members from Fisheries and Oceans Canada, Environment Canada, Ontario Ministry of Natural Resources, University of Guelph, University of Toronto, Ausable-Bayfield Conservation Authority, Grand River Conservation Authority,

Maitland Valley Conservation Authority, St. Clair Region Conservation Authority, Upper Thames River Conservation Authority and the Walpole Island Heritage Centre.

The long-term goals of the strategy are:

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

The following specific short term objectives have been identified to assist with meeting the long term 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, Mudpuppy 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.
vii. Increase awareness of the significance of the Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy 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.

This Recovery Strategy represents one piece of a multi-faceted approach to ensure the preservation of these endangered mussels. The needs of Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean have been directly considered in the development of aquatic ecosystem recovery strategies for the Sydenham River, the Ausable River and the Thames River and the goals, objectives and approaches outlined in these ecosystem strategies will therefore benefit these five mussel species. Although not directly considered in the Grand River Fish Recovery Strategy or the Walpole Island Ecosystem Recovery Strategy, the Recovery Team feels that the actions proposed by these ecosystem oriented teams will likely benefit these five mussel species at risk through overall improvement of aquatic habitat. In addition to these recovery planning efforts, a number of ongoing research programs will assist with achieving the goals outlined in this strategy. A team at the University of Guelph has established a research facility to investigate potential host species for the Northern Riffleshell, Snuffbox, Rayed Bean and other mussel species at risk while a laboratory at the University of Toronto/Royal Ontario Museum has recently begun to examine the conservation genetics of mussel species at risk. Researchers from the Department of Fisheries and Oceans and the National Water Research Institute of Environment Canada are conducting ongoing surveys for mussel species at risk in southwestern Ontario and examining the feasibility of establishing managed refuge sites in the St. Clair delta region.

The specification of Critical Habitat is crucial to the recovery of endangered species under the Species at Risk Act and 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. At present, this information is not available for the five species; therefore, the Recovery Team has identified a series of tasks that will assist with collecting the information required to characterize critical habitat for the species.

Table of Contents

INTRODUCTION

Freshwater mussels are among the world's most imperiled 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 imperiled (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 34 (Metcalfe-Smith *et al.* 2003), however, recent evidence suggests that the Grand (Metcalfe-Smith *et al*. 2000) and Thames rivers, also with historic species counts of 34, were equally diverse.

Despite the historic 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 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 4 species have been lost from the Sydenham River, 10 species have disappeared from the Thames River and the community of the Grand River has been reduced by 9 species. These declines, coupled with the near complete collapse of the Great Lakes populations (Nalepa *et al*. 1996), have led to the listing of 10 Ontario mussel species as endangered 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 new Species at Risk Act (SARA). The National Recovery Strategy for the Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean 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.

I. BACKGROUND

1. Species Information – Northern Riffleshell

Common Name: Northern Riffleshell
Scientific Name: *Epioblasma torulosa rangiana*
Assessment Summary
Status: Endangered
Reason for designation[1]: The Northern Riffleshell has suffered a range reduction of more than 95% over the past century. In Canada, it occurs only in the Ausable River and a 50-km reach of the Sydenham River, with the latter population one of only three known reproducing populations in North America.
Occurrence: Ontario
Status history: designated endangered in 1999

[1]Reproduction has been confirmed for the Ausable River population since the time of listing.

The Northern Riffleshell is small to medium-sized and extremely 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 very 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.

Historically, this species was known from Alabama, Illinois, Indiana, Kentucky, Michigan, Ohio, Pennsylvania, Tennessee, West Virginia and Ontario. It was found throughout the Ohio drainage, the Great Lakes drainage including the western Lake Erie basin, Lake St. Clair and the Detroit River, the Sydenham River and recently was discovered in the Ausable River (Metcalfe-Smith *et al.* 1999).

Fig. 1. The Northern Riffleshell *Epioblasma torulosa rangiana*. Photo courtesy of S. Staton, Environment Canada.

The Northern Riffleshell in considered imperiled (G2T2) across its distribution and has undergone dramatic declines in the United States and Canada. In the United States, populations are thought to exist only in French Creek and the Allegheny River in Pennsylvania, Big Darby Creek in Ohio, and Elk and Oak rivers in West Virginia. It may also occur in Kentucky, Ohio and West Virginia. It has been listed as Endangered under the U.S. Endangered Species Act since 1993 and a recovery plan for this species in US waters was published in 1994 (USFWS 1994). In Canada, it is assumed to be eradicated 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 Sydenham River between 1973 and 1991 no live Northern Riffleshells were located (Clarke 1981; Mackie and Topping 1988) and the subspecies was assigned a conservation status of SH (no verified occurrences in the past 20 years) in Ontario by the Natural Heritage Information Centre (NHIC 1997). In 1998-1999 Metcalfe-Smith surveyed 66 sites in the Ausable, Grand, Maitland, Sydenham and Thames rivers. From the results of these surveys, the range of the Northern Riffleshell has been found to extend over a 50-km reach of the Sydenham River between Alvinston and Dawn Mills (Metcalfe-Smith *et al.* 1999). Due to these findings, the subspecies was downlisted to S1 (extremely rare). More recently, a single live individual was found in a wetland area of Lake St. Clair in 2000 (Zanatta 2002) and the presence of a reproducing population in the Ausable River was confirmed in 2006 (pers. comm. S. Staton, Fisheries and Oceans Canada).

The Northern Riffleshell occurs in the most heavily populated and intensively farmed region of Canada, notably southwestern Ontario. Agricultural, urban, and industrial impacts have likely resulted in a loss of habitat for this species in the Ausable and Sydenham rivers. Urban impacts on the East Sydenham River are less than in other southwestern Ontario rivers, and water quality may have improved in recent years due to an improvement in sewage treatment. Agricultural activities have increased, however, and run-off of silt and agricultural chemicals may continue to limit the distribution of the Northern Riffleshell in this system.

Three distinct subspecies of *Epioblasma* torulosa are recognized: *E. t. torulosa, E. t. rangiana* and *E. t. gubernaculum.* Neither *E. t. torulosa* nor *E. t. gubernaculum* have ever been found in Canada, and both are presumed extinct (Williams *et al.* 1993).

Distribution

Global Range: In the United States, the Northern Riffleshell currently occurs in Illinois, Indiana, Kentucky, Michigan, Ohio, Pennsylvania and West Virginia. In Canada, the Northern Riffleshell occurs in southwestern Ontario.

Canadian Range: The Canadian distribution of the Northern Riffleshell is limited mainly to a 50-km reach of the Sydenham River. A reproducing population was recently confirmed in the Ausable River although the full extent of its distribution is still being investigated. A single live individual was found in a wetland area of Lake St. Clair in 2000 (Dextrase *et al.* 2003).

Percent of Global Range in Canada: Approximately 5% of the Northern Riffleshell's global distribution is currently found in Canada (the remnant population in Lake St. Clair contributes negligibly to the global distribution).

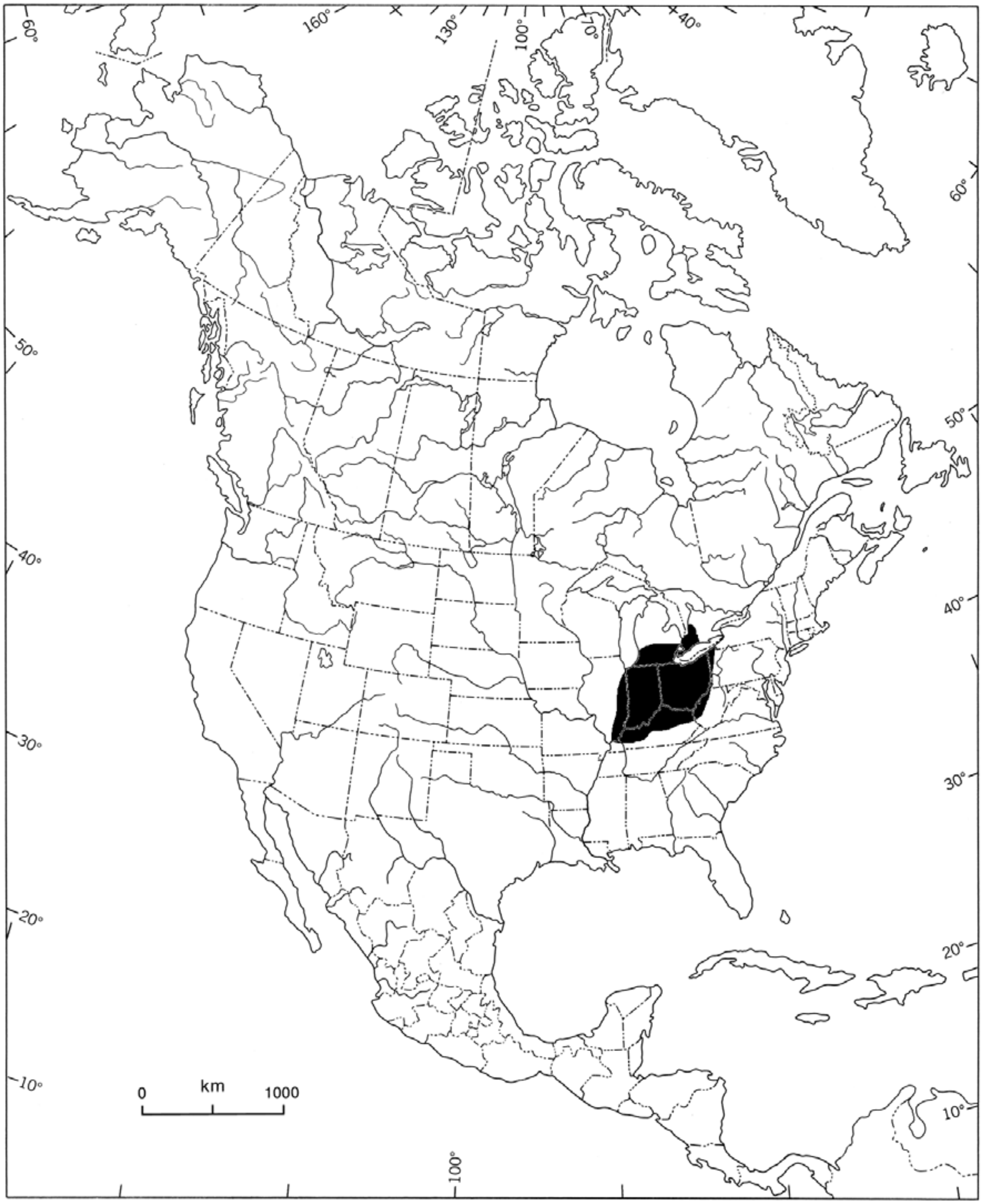

Figure 2. Global distribution of the Northern Riffleshell.

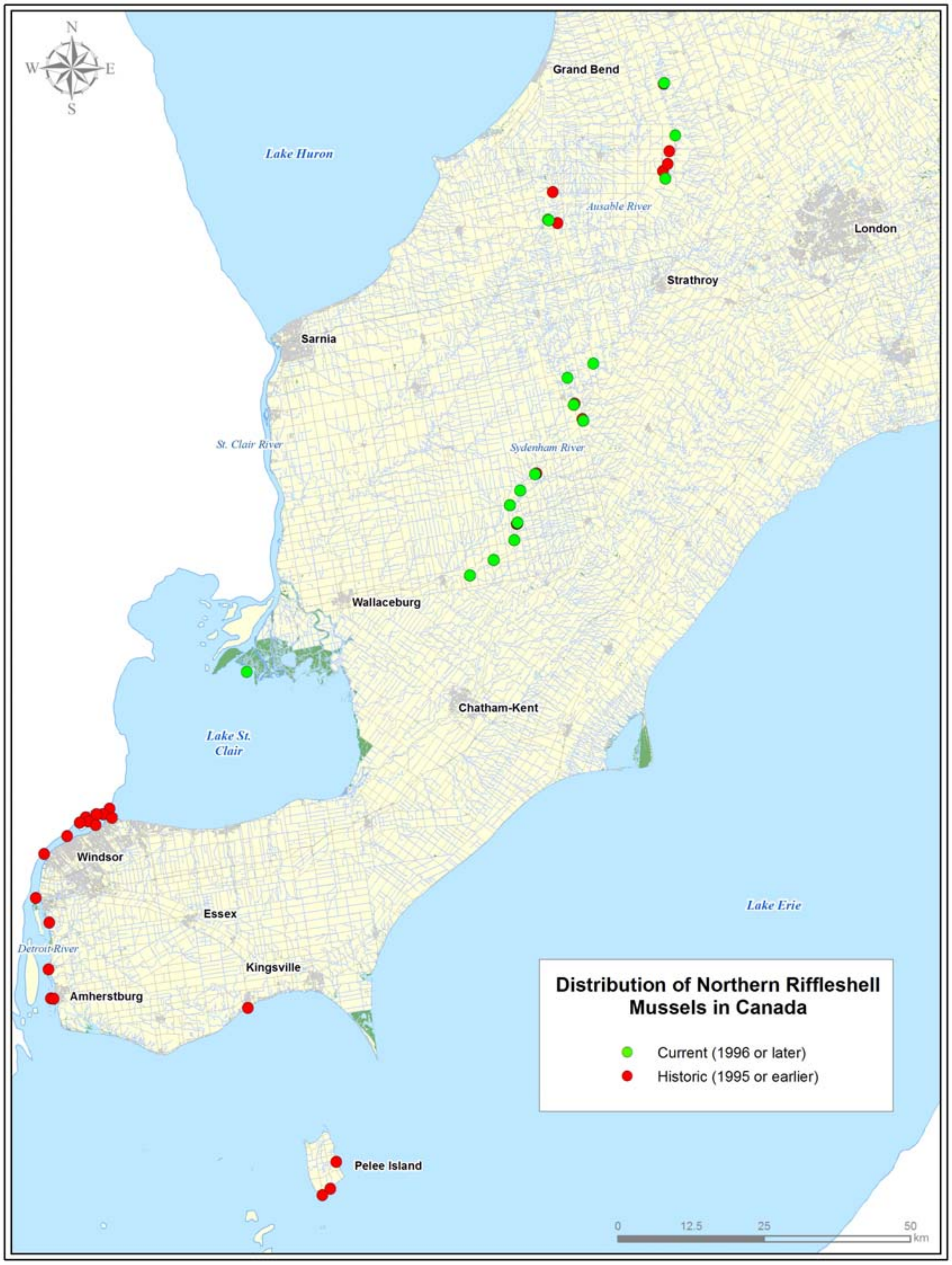

Figure 3. Current distribution of the Northern Riffleshell in Canada.

Distribution Trend: The range of the Northern Riffleshell has been greatly reduced as it no longer occurs in Illinois or Indiana, and its range has been drastically reduced in all other areas. 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 and Sydenham rivers in Ontario. It is now limited to a 50 km reach of the Sydenham River, a 55 km reach of the Ausable River with a remnant population possibly occurring in Lake St. Clair.

Population Abundance

Global Range: The Northern Riffleshell is a rare subspecies. Although occasionally abundant, it is usually a minor component of the unionid community (Strayer and Jirka 1997). The Allegheny River and French Creek in Pennsylvania support the largest remaining populations in the United States.

Canadian Range: A few live specimens of the Northern Riffleshell occur over a 55-km reach of the Ausable River between Rock Glen and Brinsley and it occurs at low densities over a 50-km reach of the Sydenham River (Staton *et al.* 2000b). Twenty years ago, the Sydenham River population was described as the healthiest extant population of Northern Riffleshell in North America.

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 the Northern Riffleshell is restricted to three populations. The population remaining in the St. Clair delta is known from one live specimen observed in 2000, despite surveys in this region in 2003 and 2004 (D. McGoldrick, NWRI, pers. comm.). 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 Sydenham River. The population in the East Sydenham River is the largest remaining reproducing population in Canada. A survey of the Northern Riffleshell in the Sydenham River, found 228 live animals combined over the 2001 – 2003 field seasons.

Biological Limiting Factors

Reproductive Attributes: 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 it out of the water with their gills. Female mussels brood their young from the egg to the larval stage in specialized regions of their gills known as marsupia. 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. 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. Further development to the juvenile stage can not continue without a period of encystment on the host.

The glochidia are semi-circular and have a straight hinge line without hooks. This morphology is typical of glochidia that parasitize fish gills, rather than the fins of their host fish. The juveniles remain attached to the gills for 27 to 33 days, after which they fall to the substrate and complete their development into free-living adults.

To determine host fishes for the Northern Riffleshell, fourteen host species underwent infestation experiments in the laboratory at the University of Guelph from 2002 – 2005. The Northern Riffleshell successfully transformed on 7 of these: the logperch (*Percina. caprodes*), blackside darter (*P.* maculata), Iowa darter (*Etheostoma exile*), fantail darter (*E. flabellare*), johnny darter (*E. nigrum*), mottled sculpin (*Cottus bairdii*), and rainbow darter (*E. caeruleum*) (McNichols and Mackie 2003; McNichols *et al.* 2004).

Dispersal: Like most freshwater mussels, the Northern Riffleshell has very limited dispersal abilities. The Northern Riffleshell adults are essentially sessile with movement limited to only a few meters 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 fish host.

2. Species Information – Snuffbox

Common Name: Snuffbox
Scientific Name: *Epioblasma triquetra*
Assessment Summary
Status: Endangered
Reason for designation[1]: This species has been lost from 60% of its former range in North America. Remaining populations are fragmented, and most are in decline. In Canada, it is now restricted to a 50-km reach of the East Sydenham River. This population represents one of only about 50 extant occurrences in North America.
Occurrence: Ontario
Status history: Designated Endangered in 2001

[1]A small, reproducing population has been confirmed in the Ausable River since the time of listing.

The Snuffbox 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 two lateral teeth in the left valve and one in the right are short, straight, elevated and serrated (Watson *et al.* 2001a).

Fig. 4. The Snuffbox mussel *Epioblasma triquetra*. Photo courtesy S. Staton, Environment Canada.

Historically it was known to occur in 18 states throughout the Ohio-Mississippi River drainage and in the Great Lakes drainage in Lake Erie, Lake St. Clair, and tributaries to lakes Erie, St. Clair, Huron and Michigan. In Canada, the Snuffbox was only ever known from Ontario in the Ausable, Grand, Niagara, Sydenham and Thames rivers, Lake St. Clair, and Lake Erie. The distribution of the Snuffbox has become significantly reduced throughout its range. In the United States, it is no longer found in 60% of formerly occupied streams. Remaining populations are small and geographically isolated from one another, and not all of them are healthy and reproducing. The species has probably been extirpated from Iowa, Kansas, New York and Mississippi. Although it is not federally listed in the United States, it is listed as endangered or threatened in many states. The Nature Conservancy has assigned it a Global Rank of G3 (rare and uncommon globally), and it has an SRANK of S1 (very rare) in 10 states and Ontario. In Canada, there are 31 known historical records for the Snuffbox. Intensive surveys were conducted in 1997-1998 throughout its historical range and only seven live animals were found within a 50 km reach of the East Sydenham River between Alvinston and Dawn Mills (Metcalfe-Smith 1999). From 2001 – 2004, sections of the East Sydenham River were intensively surveyed again and the total number of live animals captured was 116 (McNichols and Mackie 2004). In July 2003, a single live juvenile was found in the lower reaches of the main Ausable River below the Arkona Gorge. Ongoing surveys in 2006 have uncovered 14 live specimens, including numerous juveniles, from the area of the 2003 discovery. Densities at this site average 0.3 animals/m^2 ranging from 0-4 /m^2. These surveys have also detected a single live immature animal at a site well upstream near the town of Nairn (pers. comm. S. Staton, Fisheries and Oceans Canada). These recent findings suggest that the Ausable River still supports a reproducing population.

Agricultural, urban, and industrial impacts have likely resulted in a loss of habitat for this species in the Ausable, Grand, Sydenham and Thames rivers. Urban impacts on the East Sydenham River are less than in other southwestern Ontario rivers, and water quality may have improved in recent years due to an improvement in sewage treatment. Agricultural activities have increased, however, and run-off of silt and agricultural chemicals may continue to limit the distribution of the Snuffbox in this system (Dextrase *et al*. 2003).

Distribution

Global Range: The Snuffbox currently occurs in Alabama, Arkansas, Illinois, Indiana, Kentucky, Michigan, Minnesota, Mississippi, Missouri, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, Wisconsin, and Ontario. In the United States, the Snuffbox is thought to be extant in only 37 of the 99 streams for which historical records are available (Watson *et al.* 2001a).

Canadian Range: In Canada, the Snuffbox was historically known from the Province of Ontario in the Ausable, Grand, Niagara, Sydenham and Thames rivers, Lake St. Clair, and Lake Erie (Watson *et al.* 2001a). Until recently, it was thought the only remaining population of the Snuffbox was in the East Sydenham River. However, a live juvenile was found in July 2003 by a Fisheries and Oceans Canada biologist in the lower reaches of the main Ausable River below the Arkona Gorge (ARRT 2005). Detailed sampling at this site in 2006 has demonstrated reproduction is occurring in the lower Ausable watershed and also produced evidence of recent reproduction at an additional site in the upper watershed near Nairn.

.

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

Figure 5. Global distribution of the Snuffbox.

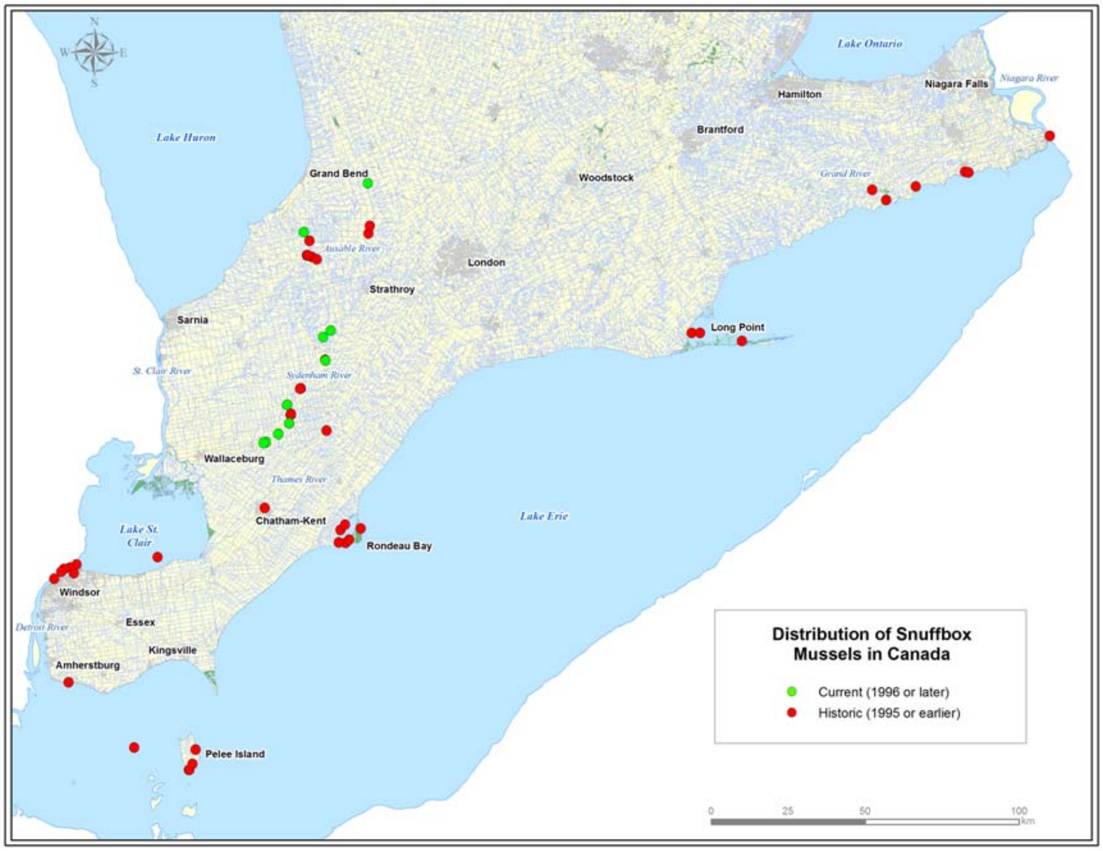

Figure 6. Distribution of the Snuffbox in Canada.

Distribution Trend: The range of the Snuffbox has been significantly reduced as it has been extirpated from Iowa and Kansas and probably New York. It is also believed to be extirpated from the Grand, Niagara and Thames rivers, Lake Erie and Lake St. Clair. The rate of change in geographical distribution is not available, but it has been lost from 60% of formerly occupied streams.

Population Abundance

Global Range: No abundance estimates are available for the global population (Dextrase *et al.* 2003). The Snuffbox typically occurs in low numbers in mussel communities where it is found, but it can be locally abundant. The Snuffbox is typically found at very low densities, representing <1% of the mussel assemblage. 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 (TNC 2000b). Most populations have become small and geographically isolated from one another. The Snuffbox has been extirpated from Iowa, Kansas and New York.

Canadian Range: The Snuffbox is currently known to occur only in a 50-km reach of the Sydenham River as well as at three sites within a 60 km reach of the

Ausable River. It has likely been extirpated from the Grand, Thames, Detroit and St. Clair Rivers and Lakes Erie and St. Clair. Metcalfe-Smith *et al*. (1998, 1999) surveyed 17 sites on the Sydenham River in 1997-1998. Since 1997 123 live animals have been found in the Sydenham River (Metcalfe-Smith *et al*. 1998; Metcalfe-Smith *et al*. 1999; McNichols and Mackie 2004) while 15 live animals have been found in the Ausable (pers. comm. S. Staton, Fisheries and Oceans Canada).

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

Population Trend: It is difficult to determine if there have been changes over time in the abundance of Snuffbox in the Sydenham River, because so few live animals have ever been collected. Current and historical catch rates show a decline between 1963-1973 and 1997-1999 (Watson *et al.* 2001a). No data are currently available for the Ausable River population.

Biological Limiting Factors

Reproductive Attributes: The reproductive biology of the Snuffbox follows the general reproductive biology of most mussels. During spawning, male mussels release sperm into the water column and females filter it out of the water with their gills. Fertilization is then able to occur in specialized regions of the gills known as marsupia. 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 Snuffbox is a long-term brooder as fertilization occurs in late summer and glochidia are held by the female over winter for release the following spring or summer. Development to the juvenile stage can not continue without a period of encystment on the host. Female Snuffbox have developed specialized structures including a mantle lure and shell denticles which permit a unique method of host capture increasing the likelihood of successful encystment.

Until recently, the blackside darter and logperch (*Percina* caprodes) have been considered as the only fish hosts for the Snuffbox in Ontario (Watson *et al.* 2001a). To positively determine host fishes for the Snuffbox, sixteen host species underwent infestation experiments in the laboratory at the University of Guelph from 2002 – 2005. The Snuffbox successfully transformed on six of these: the Iowa darter, logperch, rainbow darter, mottled sculpin, largemouth bass (*Micropterus salmoides*) and brook stickleback (*Culaea inconstans*) although the logperch is considered to be the primary host (McNichols and Mackie 2002; McNichols *et al.* 2004).

Glochidia of all members of the genus *Epioblasma*, are morphologically depressed (where valve height is equal to or less than valve length). These glochidia are less likely to make initial contact with a host than elongate glochidia due to a smaller valve gape, but are better adapted to holding on tightly once contact has been made (Hoggarth 1993). It is likely that species with morphologically depressed glochidia have a lower rate of recruitment, and be more at risk of extinction once numbers of breeding adults reach a critical threshold level. Species of the genus *Epioblasma* have hookless glochidia and are gill parasites.

Dispersal: Like most freshwater mussels, the Snuffbox has very limited dispersal abilities. The Snuffbox adults are essentially sessile with movement limited to only a few meters 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.

3. Species Information – Round Pigtoe

Common Name: Round Pigtoe
Scientific Name: *Pleurobema sintoxia*
<u>Assessment Summary</u>
Status: Endangered
Reason for designation: The Round Pigtoe is limited to three watersheds and Lake St. Clair in southern Ontario and is considered to be lost from 65% of its historical Ontario range. There are continuous declines in habitat because of urban, industrial and agricultural development. There is an irreversible impact from zebra mussels in Lake St. Clair and possibly impoundments in the Sydenham River.
Occurrence: Ontario
Status history: designated endangered in 2004

The Round Pigtoe 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 which 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.

Fig. 7. The Round Pigtoe (*Pleurobema sintoxia*). Photo courtesy J.L. Metcalfe-Smith, Environment Canada

It can be found in a wide range of habitats from small to large rivers and large lakes in sand, gravel, boulder and mud substrates. Historically, this species was known from throughout the Mississippi and Ohio drainages including Alabama, Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, New York, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, West Virginia, and Wisconsin. In Canada, the Round Pigtoe was found in the western basin of Lake Erie, Lake St. Clair and the Detroit, Grand, Niagara, Sydenham and Thames rivers.

The Round Pigtoe is broadly distributed but uncommon and rarely, if ever, abundant (COSEWIC 2004). In the United States, current and historic ranges of the 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 ranked as common (G4) in North America although it is listed as endangered in Iowa and Pennsylvania, threatened in Minnesota, special concern in Michigan and Wisconsin, and a species of special interest in Ohio. It is not currently listed under the U.S. Endangered Species Act.

In Ontario, the Round Pigtoe is assumed to be eradicated from the offshore waters of lakes Erie and St. Clair, and the Detroit and Niagara rivers. It has not been seen in the western basin of Lake Erie since the early 1950s, nor in the offshores of Lake St. Clair (outside the delta area) since 1990 (COSEWIC 2004). Small pockets of isolated populations may still be found in some nearshore areas although, to date, none have been found. A 2001 survey of the Niagara River found no live native mussel species. The Grand and Thames rivers have small, possibly relict, populations of the Round Pigtoe. The Sydenham River still has reproducing populations in several different localities in the east and north branches.

Distribution

Global Range: In the United States, the Round Pigtoe occurs in Alabama, Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, New York, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, West Virginia and Wisconsin.

Canadian Range: The populations of Round Pigtoe that are still reproducing are found in the St. Clair delta and the Sydenham River. Remnant populations still exist in the nearshores of Lake Erie and Lake St. Clair and the Grand and Thames rivers.

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

Distribution Trend: In the United States, the present range of the 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 the western basin of Lake Erie and the offshores of Lake St. Clair but these populations have been lost. The remaining population in Lake St. Clair is located entirely within the Walpole Island First Nation. The Round Pigtoe was widespread in the upper and lower Thames River, but is now restricted to a very small (possibly relict) population in the upper reaches of the Middle and South Thames rivers. In the Grand River the 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).

The Round Pigtoe is well distributed, although not common, throughout the Sydenham River.

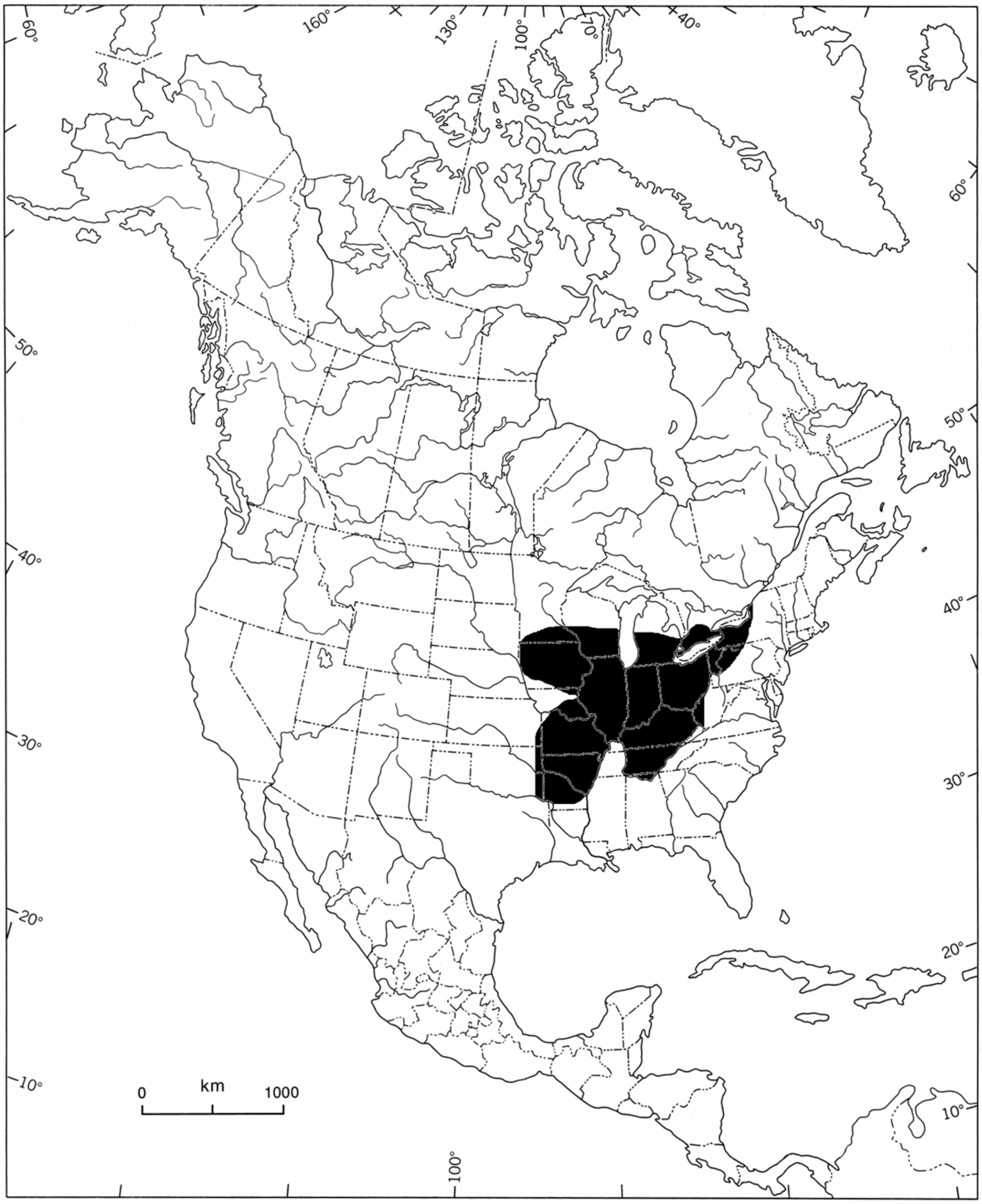

Figure 8. Global distribution of the Round Pigtoe.

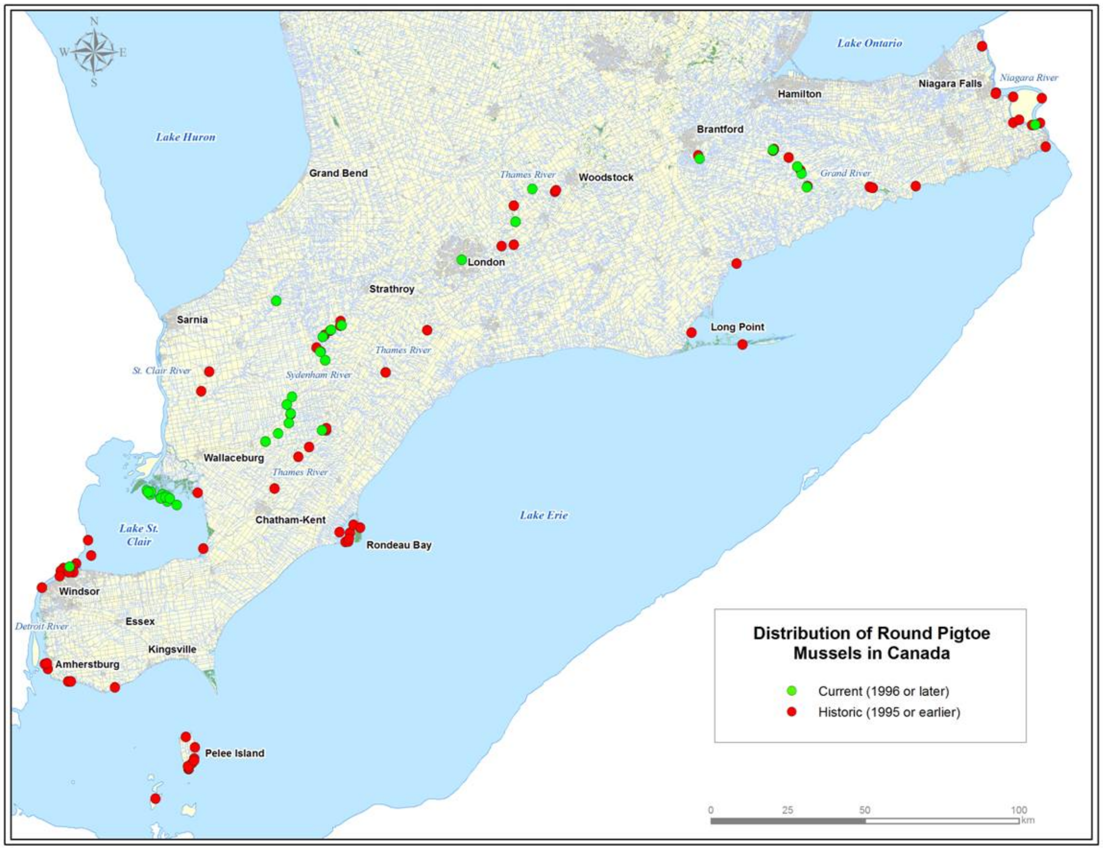

Figure 9. Distribution of the Round Pigtoe in Canada.

Population Abundance

Global Range: In the United States, many populations of Round Pigtoe have declined and there is no evidence of recent recruitment in some areas (COSEWIC 2004).

Canadian Range: The Round Pigtoe has not been seen in the western basin of Lake Erie since 1951-52, nor in the offshores of Lake St. Clair since 1990 (COSEWIC 2004). However, surveys in 2002 reported 42 Round Pigtoes from three nearshore sites off Squirrel Island in the St. Clair delta. Ninety-two other nearshore sites surveyed had no evidence of live specimens. Results from recent surveys of the Niagara River and Detroit River indicate that the Round Pigtoe is extirpated from these rivers. 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 population is restricted to a very small area in the upper reaches of the Middle and South Thames rivers between Thamesford and London. The 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 and one site in the north branch (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 the Round Pigtoe is restricted to the St. Clair delta and three southwestern Ontario rivers. The St. Clair delta has been identified as a possible refuge for unionids from impacts of the zebra mussel (Zanatta et al. 2002). Surveys in 2002 reported the 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 its confluence with the South Thames. In the East Sydenham River the Round Pigtoe was observed at seven different sites and another site in the north branch. The size of the specimens sampled indicates recruitment is occurring. The population in the Sydenham River is considered to be the healthiest in Ontario.

Biological Limiting Factors

Reproductive Attributes: The reproductive biology of the Round Pigtoe follows the general reproductive biology of most mussels. During spawning, male mussels release sperm into the water and females living downstream filter it out of the water with their gills. Female mussels brood their young from the egg to the larval stage in specialized regions of their gills known as marsupia. 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. Further development to the juvenile stage can not continue without a period of encystment on the host.

The glochidia are subovate and without hooks, measuring 150 µm in both height and width (Clarke 1981). The lack of hooks indicates they are gill parasites.

Known host fishes for the Round Pigtoe include the bluegill (*Lepomis macrochirus*), spotfin shiner (*Cyprinella spiloptera*), bluntnose minnow *(Pimephales notatus*), northern redbelly dace (*Phoxinus eos*) and the southern redbelly dace (*Phoxinus erythrogaster*) (Hove 1995). In Ontario, all of these species, except the southern redbelly dace, occur commonly with the Round Pigtoe and are assumed to serve as glochidial hosts although no potential hosts have yet been tested as gravid females have not been located.

Dispersal: Like most freshwater mussels, the Round Pigtoe has very limited dispersal abilities. The Round Pigtoe adults are essentially sessile with movement limited to only a few meters 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.

4. Species Information – Mudpuppy Mussel

Common Name[1]: Mudpuppy Mussel
Scientific Name: *Simpsonaias ambigua*
<u>Assessment Summary</u>
Status: Endangered
Reason for designation: The Mudpuppy Mussel has suffered declines in their range and the population is extremely fragmented. In Canada, there are only three extant sites remaining, all of which are in the Sydenham River. The Mudpuppy Mussel is host specific, using only the mudpuppy (*Necturus maculosus*) as host. Any threats to the mudpuppy are also threats to mussels.
Occurrence: Ontario
Status history: designated endangered in 2001

[1]This species is also known as the Salamander Mussel.

The Mudpuppy Mussel 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, 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*. 2001b).

Fig. 10. The Mudpuppy Mussel, *Simpsonaias ambigua* Photo Credit: D. Zanatta, University of Toronto

Historically, the Mudpuppy Mussel was known from Arkansas, Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, Tennessee, West Virginia, Wisconsin, and Ontario (TNC 2000a). It was found in the Lake St. Clair, Lake Huron, and Lake Erie drainages as well as the Ohio, Cumberland, and upper Mississippi river systems (Clarke 1985). In Ontario, only three historical records exist for this species, two from the Sydenham River in the 1960s and one from the Detroit River in 1934.

In the United States, the Mudpuppy Mussel is now thought to be extant in only 32 of the 80 rivers and streams for which historical records are available. It is believed to be extirpated from Iowa, New York and Tennessee. The Nature Conservancy has assigned this species a global rank of G3 (rare and uncommon globally), and an SRANK of S1 in six states and S2 in four others (TNC 2000a). The species is listed as endangered in Illinois, Michigan, and Tennessee; threatened in Minnesota, Ohio, and Wisconsin; and of Special Concern in Indiana.

In Ontario, the Mudpuppy Mussel had been ranked SH (historical; no occurrences verified in the past 20 years) until the late 1990s by the Ontario Natural Heritage Information Centre. Intensive surveys conducted on tributaries to Lake Erie, Lake St. Clair and lower Lake Huron in 1997-1999 (Metcalfe-Smith *et al*. 1998, 1999) produced a total of 90 specimens from 8 different sites on the Sydenham River, one site in the St. Clair delta, and one site on the Thames River. The largest remaining population of the Mudpuppy Mussel in Ontario is restricted to the middle reach of the East Sydenham River. Three live specimens were found in the St. Clair 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, the Mudpuppy Mussel was downlisted from SH to S1 in Ontario.

The Mudpuppy Mussel occurs in the most heavily populated and intensively farmed region of Canada, notably southwestern Ontario. Agricultural, urban, and industrial impacts have likely resulted in a loss of habitat for this species in the Sydenham and Thames rivers. Urban impacts on the East Sydenham River are less than in other southwestern Ontario rivers, and water quality may have improved in recent years due to an improvement in sewage treatment. Agricultural activities have increased, however, and run-off of silt and agricultural chemicals may continue to limit the distribution of the Mudpuppy Mussel in this system (Dextrase *et al*. 2003).

Distribution

Global Range: The Mudpuppy Mussel currently occurs in Arkansas, Illinois, Indiana, Kentucky, Minnesota, Missouri, Ohio, Pennsylvania, West Virginia, Wisconsin, and Ontario.

Canadian Range: There are only three historical records for the Mudpuppy Mussel in Canada, two from the Sydenham River in the mid 1960s and one from the Detroit River in 1934. The Mudpuppy Mussel currently occurs only in the East Sydenham River in Ontario, although a single fresh valve was found on the Thames River in the city of London in 1998. It has been suggested that the Mudpuppy Mussel is at the

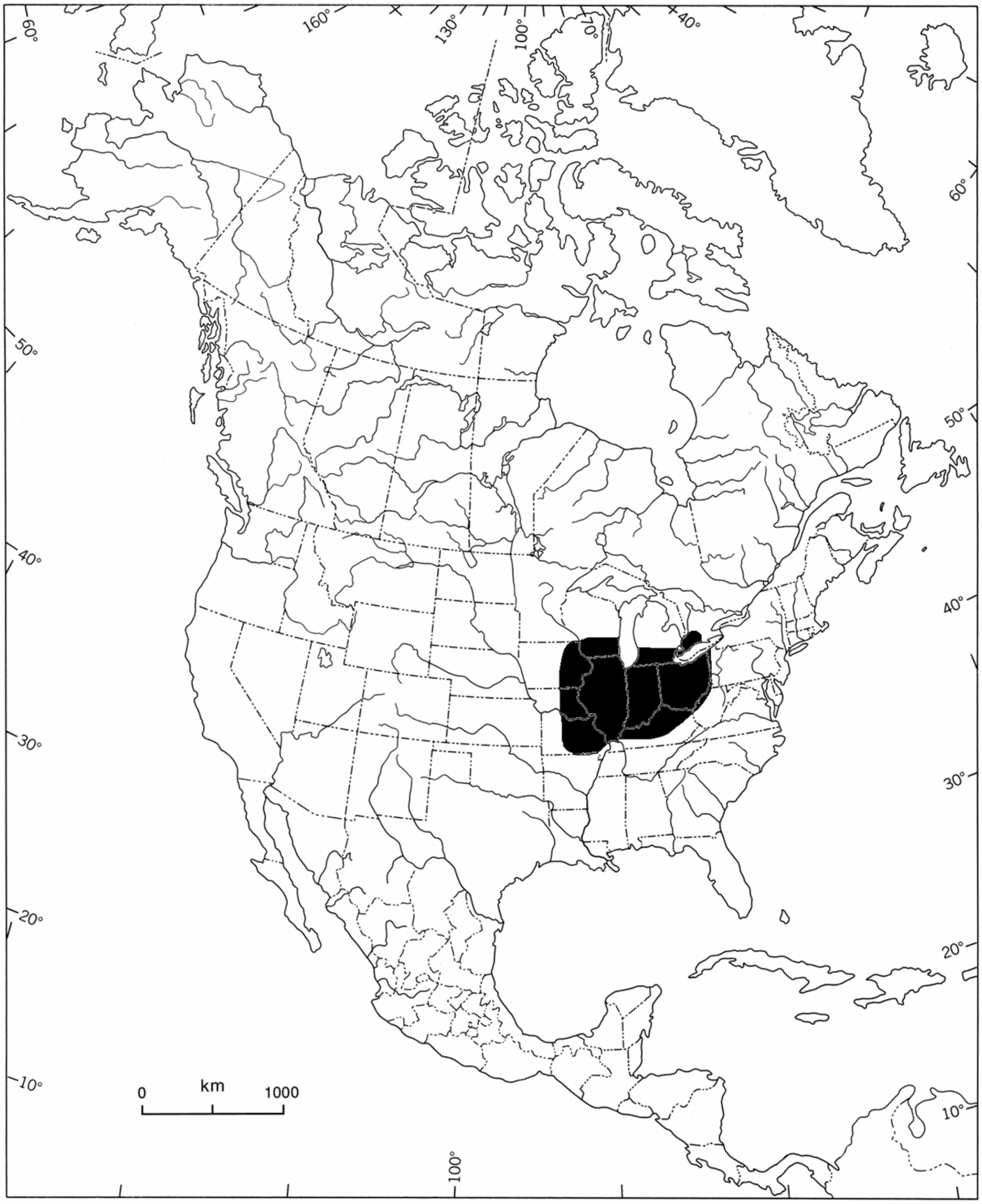

Figure 11. Global distribution of the Mudpuppy Mussel.

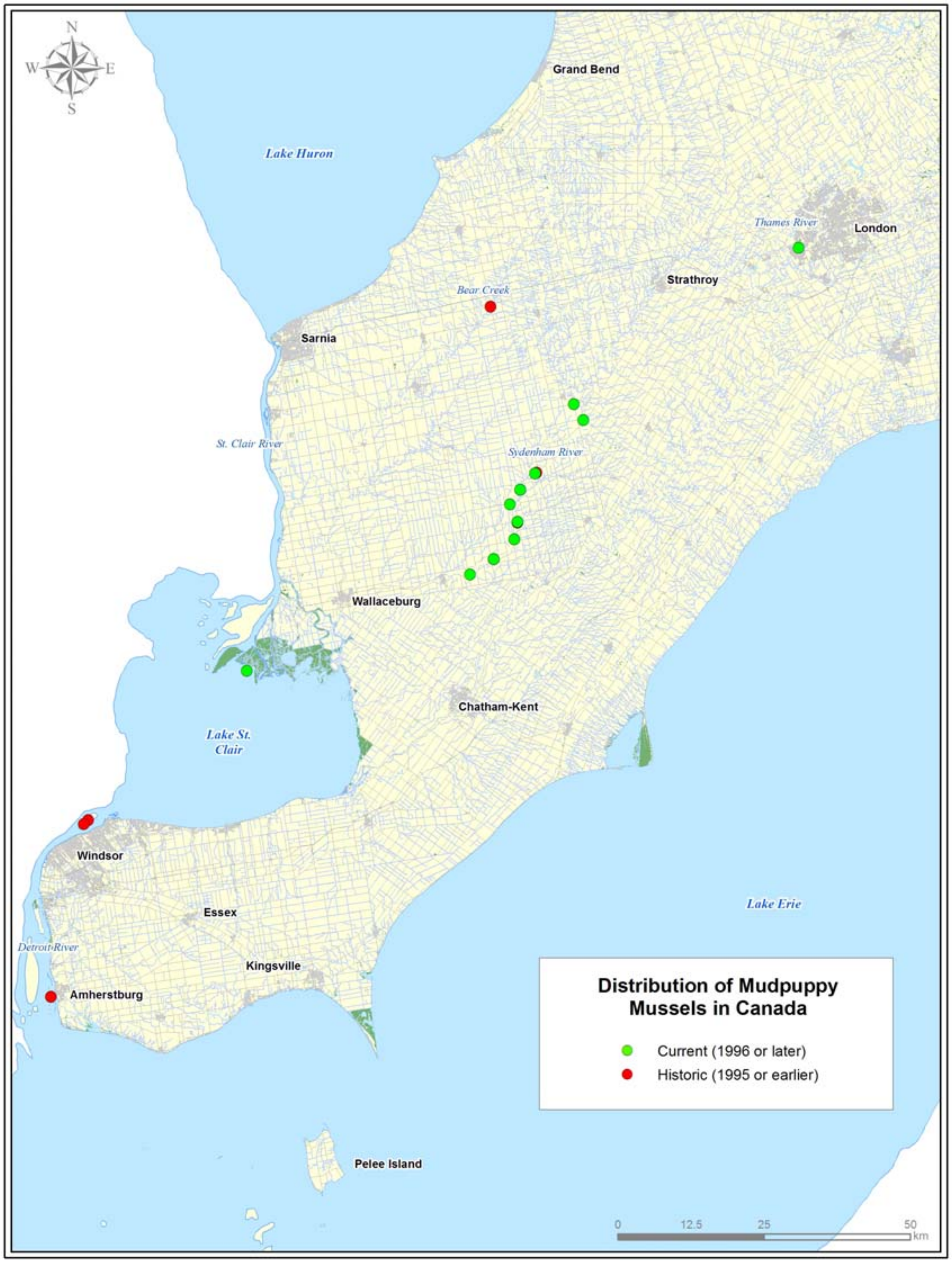

Figure 12. Distribution of the Mudpuppy Mussel in Canada.

northern most limit of its range in the Great Lakes region and may be naturally rare here.

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

Distribution Trend: The Mudpuppy Mussel is no longer found in 60% of formerly occupied rivers and streams in the United States and is extirpated from Iowa, New York, Tennessee, and Michigan. In Canada, it was historically known from the Detroit and Sydenham rivers, but recent surveys in both rivers show that it now occurs only in the Sydenham River. Live animals were collected from eight different sites within a 50-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.

Population Abundance

Global Range: In the United States, extant populations are known from 11 states and its range appears to be declining in most jurisdictions. The Mudpuppy Mussel is thought to be present in only 32 of the 80 rivers and streams for which historical records are available.

Canadian Range: Intensive surveys conducted at 66 sites on tributaries to Lake Erie, Lake St. Clair and lower Lake Huron in 1997-1998 (Metcalfe-Smith et al. 1998, 1999), and additional collections at some of these sites in 1998 and 1999, yielded a total of 90 specimens from 8 different sites on the Sydenham River and one site on the Thames River.

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: The Mudpuppy Mussel is no longer found in 60% of formerly occupied rivers and streams in the United States and is extirpated from Iowa, New York, Tennessee, and Michigan. In Canada, it was historically known from the Detroit and Sydenham rivers, but recent surveys in both rivers show that it now occurs only in the Sydenham River. Live animals were collected from eight different sites within a 50-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.

Biological Limiting Factors

Reproductive Attributes: Although the reproductive biology of the Mudpuppy 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. During spawning, male mussels release sperm into the water column and females filter it out of the water with their gills. Fertilization is then able to occur in specialized regions of the gills known as marsupia and are released by the female into the water column to undergo a period of parasitism on a suitable host species. Further development to the juvenile stage can not continue without a period of encystment on the host. The glochidia of the Mudpuppy Mussel have hooks that likely ensure a firm attachment to the external gills of their host. 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 6 days to over 6 months to complete the transformation from glochidium to juvenile mussel (Kat 1984). During this period, the glochidium is parasitic. Once metamorphosis is complete, the juvenile mussel ruptures the cyst by extending its foot (Lefevre and Curtis 1910). The mudpuppy, *Necturus maculosus*, is the only known host for the Mudpuppy Mussel. The mudpuppy is broadly distributed in lakes and rivers throughout Quebec, Ontario and Manitoba. The mudpuppy inhabits areas with flat rocks, submerged logs, wooden slabs and other debris. The habitat requirements of the mudpuppy host correspond with the habitat characteristics typically assigned to the Mudpuppy Mussel.

Dispersal: Like most freshwater mussels, the Mudpuppy Mussel has very limited dispersal abilities. The Mudpuppy Mussel adults are essentially sessile with movement limited to only a few meters 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 species.

5. Species Information – Rayed Bean

Common Name: Rayed Bean
Scientific Name: *Villosa fabalis*
Status: Endangered
Reason for designation[1]: The Rayed Bean was once widely distributed throughout its original range in North America, but has declined significantly in distribution and abundance in recent years. In Canada, it now occurs only in a 45-km reach of the East Sydenham River, where it is threatened by siltation and pollution associated with intensifying agricultural activities.
Occurrence: Ontario
Status history: Designated Endangered in 1999

[1]A new population was confirmed in the North Thames River in 2004.

The Rayed Bean 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. It was historically known from Alabama, Illinois, Indiana, Tennessee, New York, Virginia, West Virginia and Ontario. It was widely distributed throughout the Ohio and Tennessee drainages, western Lake Erie, Lake St. Clair and the St. Clair River and their tributaries. In Canada, the Rayed Bean was known from western Lake Erie, the Detroit, Sydenham and Thames rivers.

Fig.13. The Rayed Bean *Villosa fabalis*. Photo Credit: S. Staton, Environment Canada.

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. In the United States, the Rayed Bean is now most frequently found in the Ohio drainage. It is currently ranked as S1 in most areas by NatureServe. In Canada, this species has been extirpated from Lake Erie and the Detroit River and until recently was believed to be restricted to a 50 km reach of the East Sydenham River. However, a single live specimen and one fresh shell were recorded from the North Thames River upstream of Fanshawe reservoir in 2004.

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. the Rayed Bean currently occurs in Alabama, Indiana, Kentucky, Michigan, New York, Ohio, Pennsylvania, Tennessee and West Virginia. In Canada, it occurs only in southern Ontario.

Canadian Range: The current Canadian distribution of the Rayed Bean is limited to a 50 km stretch of the East Sydenham River and a small section of the North Thames River.

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

Distribution Trend: In Canada, the current range of the Rayed Bean has changed little over time. It is found throughout a 50 km-reach of the East Sydenham River where it is successfully reproducing (Woolnough and Mackie, 2001). A single live specimen and one fresh shell were recorded from the North Thames River upstream of Fanshawe Reservoir during 2004 (T. Morris, unpublished data).

Population Abundance

Global Range: In the United States the Rayed Bean currently occurs in Alabama, Indiana, Kentucky, Michigan, New York, Ohio, Pennsylvania, Tennessee and West Virginia. In Canada, it occurs only in southwestern Ontario.

Canadian Range: The current Canadian distribution of the Rayed Bean is limited to a 50-km stretch of the East Sydenham River and a small section of the North Thames River.

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

Population Trend: The Rayed Bean is considered to be a rare species, however, abundant populations have recently been seen in parts of Ohio and Pennsylvania. Other studies in the United States indicate that the species is in decline. The Rayed Bean is presumed extirpated from Illinois and Virginia. In Canada, populations of the 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 Sydenham or Thames river populations as historical abundance estimates are not available.

Figure 14. Global distribution of the Rayed Bean.

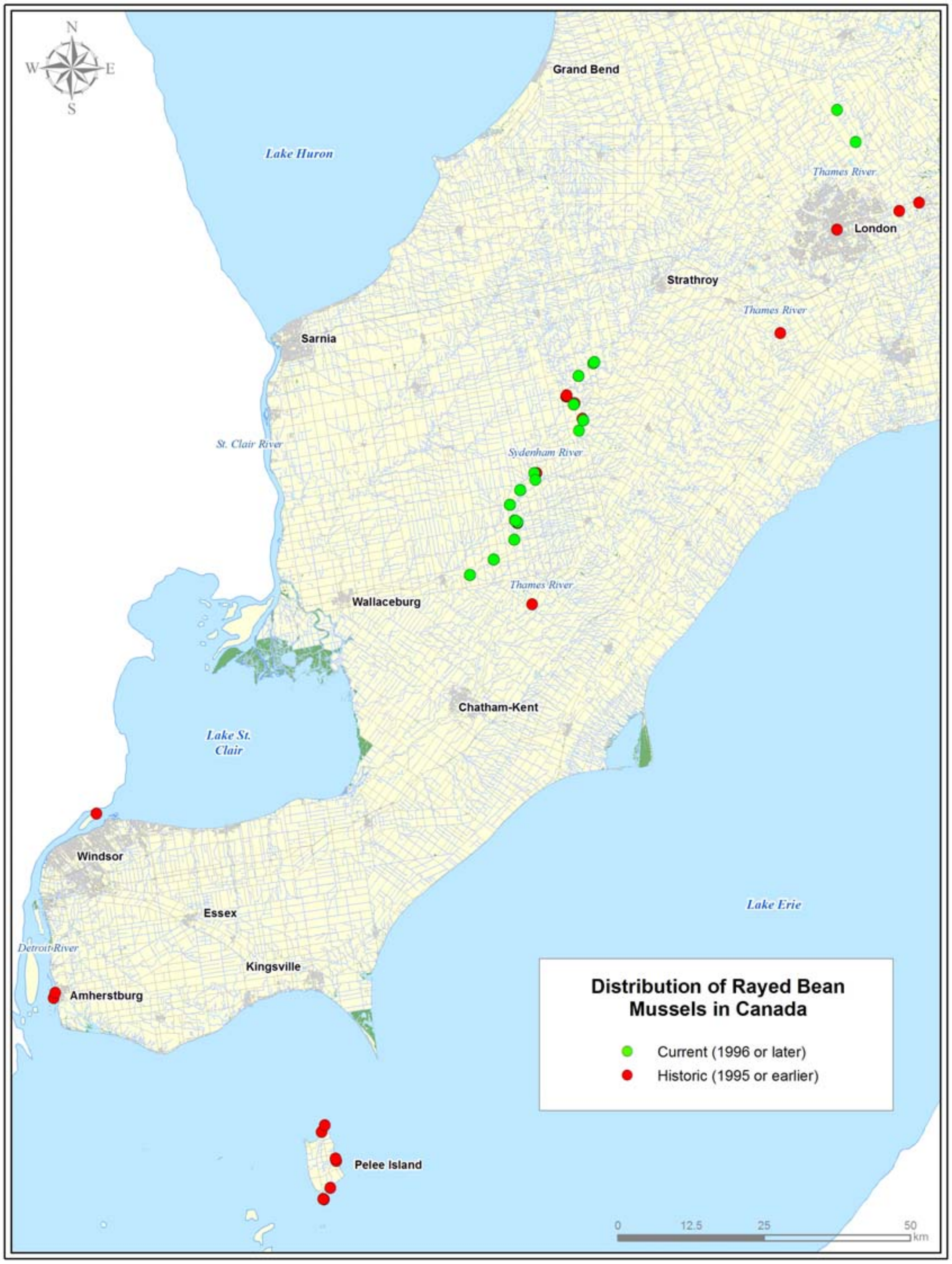

Figure 15. Distribution of the Rayed Bean in Canada.

Biological Limiting Factors

Reproductive Attributes: The reproductive biology of the Rayed Bean follows the general reproductive biology of most mussels. During spawning, male mussels release sperm into the water column and females filter it out of the water with their gills. Fertilization is then able to occur in specialized regions of the gills known as marsupia and are released by the female into the water column to undergo a period of parasitism on a suitable host fish species. The Rayed Bean is a long-term brooder that holds its glochidia over winter for spring release. Further development to the juvenile stage can not continue without a period of encystment on the host.

The glochidia are subspatulate or rounded with a straight hinge line (Bogan and Parmalee 1983; Hoggarth 1993). They are higher than long indicating that they are gill parasites.

To determine host fishes for the Rayed Bean, twelve host species underwent infestation experiments in the laboratory at the University of Guelph from 2002 – 2005. The Rayed Bean successfully transformed on seven of these: the brook stickleback, greenside darter (*Etheostoma blennioides*), Johnny darter, logperch, rainbow darter, mottled sculpin (*Cottus bairdii*), largemouth bass (Woolnough 2002; McNichols *et al.* 2004).

Dispersal: Like most freshwater mussels, the Rayed Bean has very limited dispersal abilities. The Rayed Bean adults are essentially sessile with movement limited to only a few meters 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.

6. 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 exotic species. These likely represent the most significant threats to these species across their entire Canadian range. The following discussion emphasizes threats in the Sydenham and Ausable rivers and St. Clair delta; areas where extant reproducing populations can still be found. Remnant populations of these five species, existing in the Detroit, Thames, Grand, and Niagara rivers, as well as the offshore waters of Lake Erie and Lake St. Clair are discussed under Threats in Historically Occupied Habitats.

Threats to Extant Populations

Sydenham, Ausable and St. Clair Delta Populations:

Siltation: Loading of suspended solids causing turbidity and siltation is presumed to be the primary limiting factor for most species at risk in the Sydenham and Ausable 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. Clarke (1992) noted that all of the species missing from the Sydenham River during his 1991 survey were riffle-dwelling species such as the Northern Riffleshell and Snuffbox. The Snuffbox and Rayed Bean are the only two species in Ontario that burrow completely in the substrate. These species 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 concentrations below the surface (Watson *et al.* 2001b). Although the Mudpuppy Mussel may be directly impacted by siltation due to silt settling around the flat rocks, logs and other debris under which it is found, it is more likely indirectly impacted as there is some evidence that siltation has extirpated the mudpuppy from some areas by reducing its access to nesting sites and hiding places (Gendron 1999).

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 0.125 to 0.147 mg/L, with levels as high as 2.9 mg/L reported; mean total phosphorus levels for sites in the North Sydenham basin were about three times higher. 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 dissolved oxygen at night. Nutrients enter the system from several sources and long-term water quality monitoring data indicate that much of the nutrient load is bound to suspended solids and thus likely originates from farmland. Manure spills also occur and can have significant nutrient-enriching effects, as well as being acutely toxic to fish and invertebrates. Urban areas are not extensive in the watersheds but contribute to total nutrient loadings through municipal wastewater discharges. Loadings from domestic septic systems may also be significant.

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

Contaminants: Herbicides and insecticides associated with agricultural practices and urban areas run off into the Sydenham River watershed 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. 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). The impacts of high chloride concentrations on species at risk in the North Sydenham watershed are unknown.

Pesticide runoff (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 (J. Struger, Environment Canada cited in Ausable River Recovery Team 2005). The extent and impact of these and other toxic contaminants (e.g., chloride) to species at risk have not been assessed and thus, the significance of their threat is unknown. It is likely that this threat is widespread as the primary source of pesticides is from agricultural land. The risks from toxic contaminants to some species may be heightened at juvenile life stages (particularly for mussels) and at times of increased stress.

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 significant reservoirs in the Sydenham watershed at conservation areas in Strathroy, Coldstream, Petrolia, Alvinston, Henderson, and Warwick. 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 warm-water 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 dissolved oxygen levels at night.

Exotic species: The introduction and spread of the Dreissenid mussels throughout the Great Lakes in the late 1980s have decimated native mussel populations in the Lower Great lakes region of Ontario (Schloesser *et al.* 2006; Schloesser *et al.* 1996; Schloesser and Nalepa 1994). Zebra and quagga mussels attach to a mussel's shell and interfere with feeding, respiration, excretion ad locomotion (Haag *et al.* 1993, Baker and Hornback 1997). The recent discovery of a refuge for native mussels including the Round Pigtoe in the delta region of lake St. Clair 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). It is clear that Dreissenid mussels pose the most significant threat to all native mussels within the St. Clair delta.

Currently, Dreissenid mussels are found only in the lower reaches of the Sydenham River. It does not threaten existing populations of these five mussel species as the river is not navigable by boats and has no significant 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 however, should they become established within the river or reservoirs (e.g., Morrison Dam reservoir) they will likely represent a significant threat to these species.

Another exotic species which 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 they can potentially consume juvenile mussels, their uprooting of plants and feeding on sediment-associated fauna can significantly increase turbidity, which is likely a far greater impact (Dextrase *et al.* 2003).
The round goby (*Neogobius melanostomus*) has decimated populations of mottled sculpins and possibly logperch in the St. Clair River (French and Jude 2001). This species may pose a direct threat to fish species at risk and an indirect threat to mussel species if host fish populations are affected. The round goby has not yet been documented from the reaches of the Sydenham and Ausable rivers where these mussels occur, but it is abundant in Lake St. Clair and its connecting channels (Ray and Corkum 2001). This species has recently been confirmed from Running Creek in Wallaceburg near the mouth of the Sydenham River (E. Holm, Royal Ontario Museum, personal communication). Additional introductions of exotic species into these waters are most likely to occur through the movement of boats from infested areas, the use of live bait fish, or the natural invasion of species introduced into the Great Lakes basin.

Table 1. Assessment of threats to the extant populations of the Northern Riffleshell, Mudpuppy Mussel, Round Pigtoe, Rayed Bean and Snuffbox in the Sydenham and Ausable rivers.

Threat	Relative Impact	Spatial Nature	Temporal Nature	Certainty of Effect
Siltation and turbidity	Predominant	Widespread	Chronic, episodic	Probable
Nutrient loads	Contributing	Widespread	Chronic, episodic	Probable
Toxic compounds	Contributing	Widespread	Chronic, episodic	Probable
Thermal effects	Contributing	Widespread	Chronic	Probable
Exotic species	Contributing	Widespread	Chronic	Probable

Host Fish Species: Due to the parasitic stages in their life cycle, the Northern Riffleshell, Mudpuppy Mussel, Round Pigtoe, Rayed Bean and Snuffbox 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 the mussel populations.

Until recently, the glochidial hosts for the Northern Riffleshell were completely unknown in Canada. Host fish determination studies at the University of Guelph (McNichols and Mackie 2002; McNichols and Mackie 2003; McNichols *et al.* 2004) have found that the Northern Riffleshell may have seven host species, including the blackside darter, fantail, Iowa darter, Johnny darter, logperch, mottled sculpin and rainbow darter. Of these five host species, only the blackside darter, johnny darter and logperch are common in the Sydenham River. The mottled sculpin may have served as a host historically, but now is likely restricted to the colder headwater regions where the Northern Riffleshell does not occur (Staton *et al.* 2000).

The Snuffbox was thought to have had two host species in Ontario, namely the blackside darter and logperch. Historical data of the distribution of these two species indicated that the logperch was likely the primary host as its distribution is more similar to that of the Snuffbox (Watson *et al.* 2001a). Recent records of the blackside darter show that it presently occupies the same reach of the Sydenham River as the Snuffbox. However, it is a less likely host since it was never found in the reaches of the Grand and Thames rivers where the Snuffbox historically occurred. Host fish determination studies at the University of Guelph (McNichols and Mackie 2002; McNichols and Mackie 2003; McNichols *et al.* 2004) have found that the Snuffbox successfully transformed on six host species including the brook stickleback, Iowa darter, logperch, mottled sculpin, largemouth bass and rainbow darter. The logperch was confirmed during repetitive studies, while the three other species still require further studies. The blackside darter has been repeatedly tested at the University of Guelph but has never lead to the successful development of juvenile Snuffbox.

In the United States, the glochidial hosts of the Round Pigtoe are known to be the bluegill, spotfin shiner, bluntnose minnow, northern redbelly dace and southern redbelly dace. All but the southern redbelly dace are known to occur in the Sydenham River and are likely hosts for the Round Pigtoe. However, laboratory testing and field confirmation is required to identify the functional host(s) with certainty.

The only known host for the Mudpuppy Mussel is the mudpuppy (*Necturus maculosus*). The status of the mudpuppy in Canada is considered "Not at Risk" (Gendron 1999). Significant limiting factors for the mudpuppy 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 Ontario, Erie and St. Clair in 1995. McDaniel and Martin (2003) conducted surveys of mudpuppies in the Sydenham River in 2002-2003 and found a total of 61 animals with densities estimated at between 13-22 animals per $100m^2$. The highest densities were observed between Dawn Mills and Shetland with no records above Alvinston.

Until recently, the glochidial hosts for the Rayed Bean were completely unknown in Canada. Host fish determination studies at the University of Guelph (Woolnough 2002; McNichols and Mackie 2002; McNichols and Mackie 2003; McNichols *et al.* 2004) have found that seven host species served as successful hosts for the Rayed Bean including the brook stickleback, greenside darter Johnny darter, logperch, rainbow darter, mottled sculpin, largemouth bass. The greenside and rainbow darters have been confirmed as hosts during repetitive studies. All of these species, except the brook stickleback, have been confirmed to inhabit the Sydenham River.

Threats in Historically Occupied Habitats

Grand and Thames rivers: The Northern Riffleshell, Snuffbox and Mudpuppy Mussel historically occurred in Thames River and the Round Pigtoe is still represented by small isolated non-reproducing populations in both the Thames and Grand rivers. The Rayed Bean was once distributed throughout the South Thames River in the area near Dorchester however this population is no longer believed to exist. Although not historically known from the North Thames River, a single live Rayed Bean was found in this river in 2004. It is difficult to attribute a cause to the historic loss of mussel populations in the Grand River although untreated wastewater inputs from major urban centres likely contributed to the declines. Aquatic species at risk in the Thames River are threatened by the highly-developed urban and rural portions of the upper watershed. The watershed is also intensively used for both livestock and row crop agriculture. The main threats faced by aquatic species at risk within the Thames River ecosystem include siltation and turbidity, nutrient loading, toxic compounds, altered water flow, barriers to movement, non-native species, disturbance and thermal pollution (Thames River Recovery Team 2004). While single threats may be associated with the decline of certain populations of species at risk, in most cases, population declines are likely a result of the cumulative effect of multiple widespread and chronic stresses. Potential colonization of these rivers with zebra mussels is a concern as large sections are impounded. Zebra mussels have recently been found in the Fanshawe and Springbank reservoirs on the Thames River (S. Hohn, Upper Thames River Conservation Authority, September 2003) and have been found and very low densities throughout the Thames River from Fanshawe reservoir downstream to Wardsville. In the lower Thames River near Big Bend zebra mussels have been found attached to adult unionids (Todd J. Morris, Fisheries and Oceans Canada, unpublished data). Round gobies have been detected in the lower Thames River as far upstream as Thamesville (pers. comm. A. Dextrase, Ontario Ministry of Natural resources).

Lake St. Clair, Detroit River, Lake Erie and Niagara River: The loss of the Northern Riffleshell, Mudpuppy Mussel, Round Pigtoe, Rayed Bean and Snuffbox from historical habitat in these water bodies can be largely attributed to the detrimental effects of zebra mussels. Mussel species that are long-term brooders, such as the Northern Riffleshell, Mudpuppy Mussel, Rayed Bean and Snuffbox, are generally more sensitive than short-term brooders, as they tend to have greater energy requirements for growth and reproduction and may be more vulnerable to energy depletion caused by the zebra mussel (Strayer 1999). The

Round Pigtoe is a short-term brooder and may be less susceptible to the harmful effects of the zebra mussel. The Rayed Bean and Snuffbox are the only two species in Ontario that burrow completely in the substrate and may escape serious infestation due to their preferred habitat. The Mudpuppy Mussel has several traits that suggest it may be very sensitive to zebra mussels, however, it also tends to burrow under rocks and mud which may help it escape from infestation. In the Detroit River, populations of the Northern Riffleshell and Round Pigtoe have been extirpated due to the zebra mussel.

7. Habitat – Northern Riffleshell

Habitat Identification: 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 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 of thermal tolerance of the Northern Riffleshell, however, water temperatures at sites where live specimens were found in the Sydenham and Ausable rivers in 1997-1998 ranged from 18-27°C. The extent of preferred habitat in the 50-km reach of the East branch of the 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).

Currently Occupied Habitat: Important habitat for all five mussel species has been geospatially located using the methods developed by McGoldrick *et al* (in press) (Figures 16 & 17) who recommend using the Ontario Ministry of Natural Resource's Aquatic Landscape Inventory Software (ALIS version 1) (Stanfield and Kuyvenhoven 2005) as the base unit for definition of important habitat 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. For Great Lakes populations where ALIS segments can not be employed, McGoldrick *et al* (*in press*) recommend using a 5km buffer around known species occurrences. The 5km buffer was selected in light of the spatial extent of historic sampling within Lake St. Clair. Within all identified river 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.

Geospatial Description: Currently occupied habitat for the Northern Riffleshell can be defined as a 50 km reach of the East Sydenham River (Figure 16) where the Northern Riffleshell is currently found live as well as a 55 km stretch of the Ausable River (Figure 16) and small portion of the St. Clair delta (Figure 17).

Functional Description: Within the area defined under Currently Occupied Habitat only areas meeting the characteristics described below are deemed to represent habitat in need of conservation:

- permanently wetted and
- of a stream order greater than 2 (riverine population only) and
- having packed sand (< 2mm) or fine to coarse gravel (2 – 60mm) and
- steady and moderate flows (riverine populations only)
- well-oxygenated riffle areas or
- nearshore areas with firm sand substrate (Great Lakes populations).

Activities Likely to Impact Currently Occupied Habitat

The currently occupied habitat of the Northern Riffleshell could be negatively affected by a variety of activities. Direct destruction could result from in-stream activities such as dredging, bridge and pipeline crossings or the construction of dams. Habitat could also be negatively affected by any land-based activities that affect water quality or quantity. Such activities would include, but are not limited to, the input of nutrients, sediment and toxic substances through improperly treated storm water, cultivation of riparian lands, unfettered access of livestock to the river, spills, channelization and drainage works, water taking, aggregate extraction, and the release of improperly treated sewage.

When dealing with freshwater mussels it is necessary to consider not only the physical and chemical components of habitat but also the biological. Any activity which disrupts the connectivity between Northern Riffleshell populations and their host species (see section on Reproduction) may result in the destruction of habitat. Activities which 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 fish into the zone during the period of mussel reproduction (May 1 – December 1)). 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.

Historically Occupied Habitat: Historically occupied habitat for the Northern Riffleshell includes a portion of the lower Ausable River, the Detroit River and the western basin of Lake Erie.

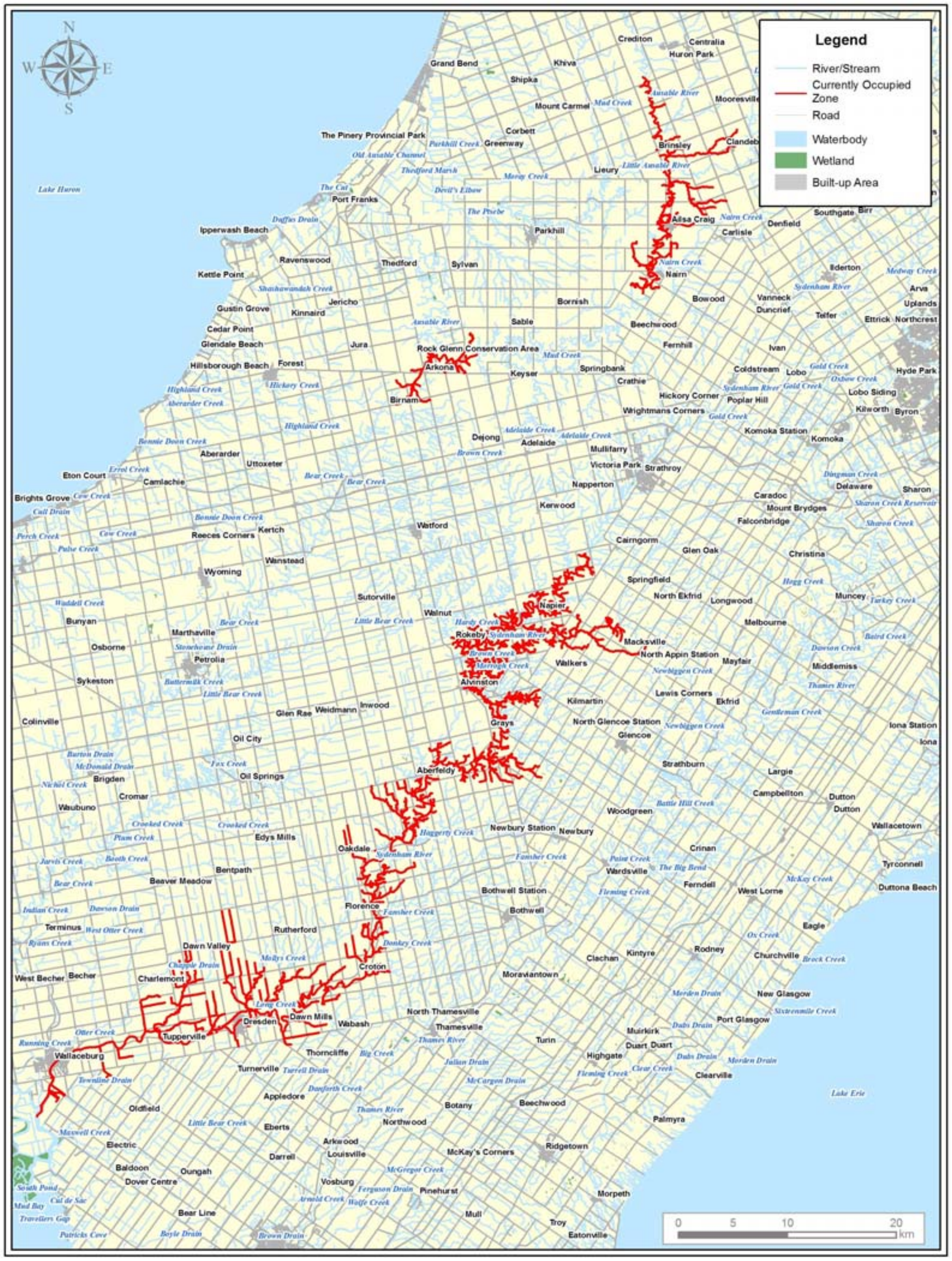

Figure 16: Currently occupied habitat of the Northern Riffleshell in the Sydenham and Ausable rivers.

Figure 17: Currently occupied habitat of the Northern Riffleshell in the Lake St. Clair delta.

8. Habitat - Snuffbox

Habitat Identification: 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 sandy to (Clarke 1981) to gravel, cobble and boulder (Buchanan 1980). It has been reported at depths of 0.5-2.5 m (Buchanan 1980; Baker 1928), and is found in areas with swift currents. 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 the 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).

Habitats where the Snuffbox was found alive in the Sydenham River in 1998-1999 were consistent with those described above, i.e., shallow riffle/run areas with coarse substrates in a medium-sized river.

Currently Occupied Habitat: Methods for delineating currently occupied habitat for the Snuffbox follow the methods described for the Northern Riffleshell.

Geospatial Description: Currently occupied habitat for the Snuffbox can be defined as a 50 km reach of the East Sydenham River as well as two smaller portions of the Ausable River near Nairn and downstream in the vicinity of the Arkona Gorge (Figure 18).

Functional Description: Within the area defined under Currently Occupied Habitat only areas meeting the characteristics described below are deemed to represent habitat in need of conservation:

- permanently wetted and
- of a stream order greater than 2 (riverine population only) and
- well-oxygenated riffles or runs (riverine populations only)
- sand (< 2mm) or gravel (2 – 60mm) dominated substrate
- steady to moderate flows (riverine populations only)
- nearshore areas with firm sand or gravel substrate (Great Lakes populations).

Historically Occupied Habitat: The historically occupied habitat for the Snuffbox consists of the lower 60 km of the Thames River, the lower Grand River, Niagara River, Detroit River and the nearshore areas within Lake Erie and lake St. Clair (Figure 6).

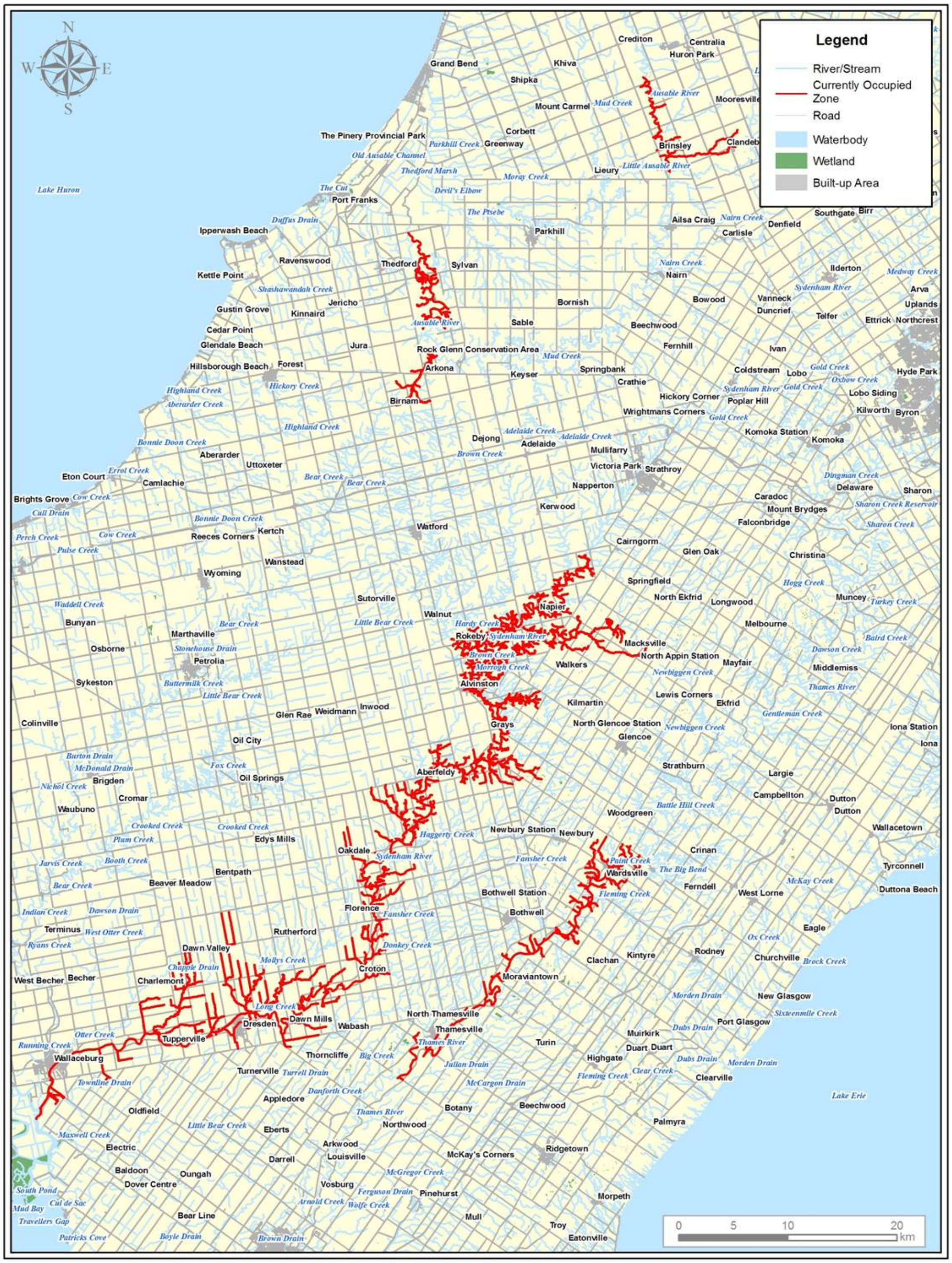

Figure 18: Currently occupied habitat of the Snuffbox in the Sydenham and Ausable rivers.

9. Habitat – Round Pigtoe

Habitat Identification: 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 Lake St. Clair, the Round Pigtoe inhabits shallow (<1 m) nearshore areas with firm, sandy 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).

Currently Occupied Habitat: Methods for delineating currently occupied habitat for the Round Pigtoe follow the methods described for the Northern Riffleshell.

Geospatial Description: Currently occupied habitat for the Round Pigtoe can be defined as a 50 km reach of the East Sydenham River, a 20 km portion of Bear Creek through Petrolia, a 30 km stretch of the lower Thames River from Thamesville to Wardsville (Figure 19), three small reaches on the Middle and South Thames rivers near Thamesford and London (Figure 20), a 60 km reach of the lower Grand River from Caledonia to Dunnville (Figure 21) and a large area within the Lake St. Clair delta (Figure 22).

Functional Description: Within the area defined under Currently Occupied Habitat only areas meeting the characteristics described below are deemed to represent habitat in need of conservation:

- permanently wetted and
- of a stream order greater than 2 (riverine population only) and
- mud, sand (< 2mm) or gravel (2-60mm)
- steady to moderate flows (riverine populations only)
- nearshore areas with firm sand or gravel substrate (Great Lakes populations).

Historically Occupied Habitat: Historically occupied habitat for the Round Pigtoe consists primarily of nearshore habitats in lakes St. Clair and Erie as well as the Detroit and Niagara rivers.

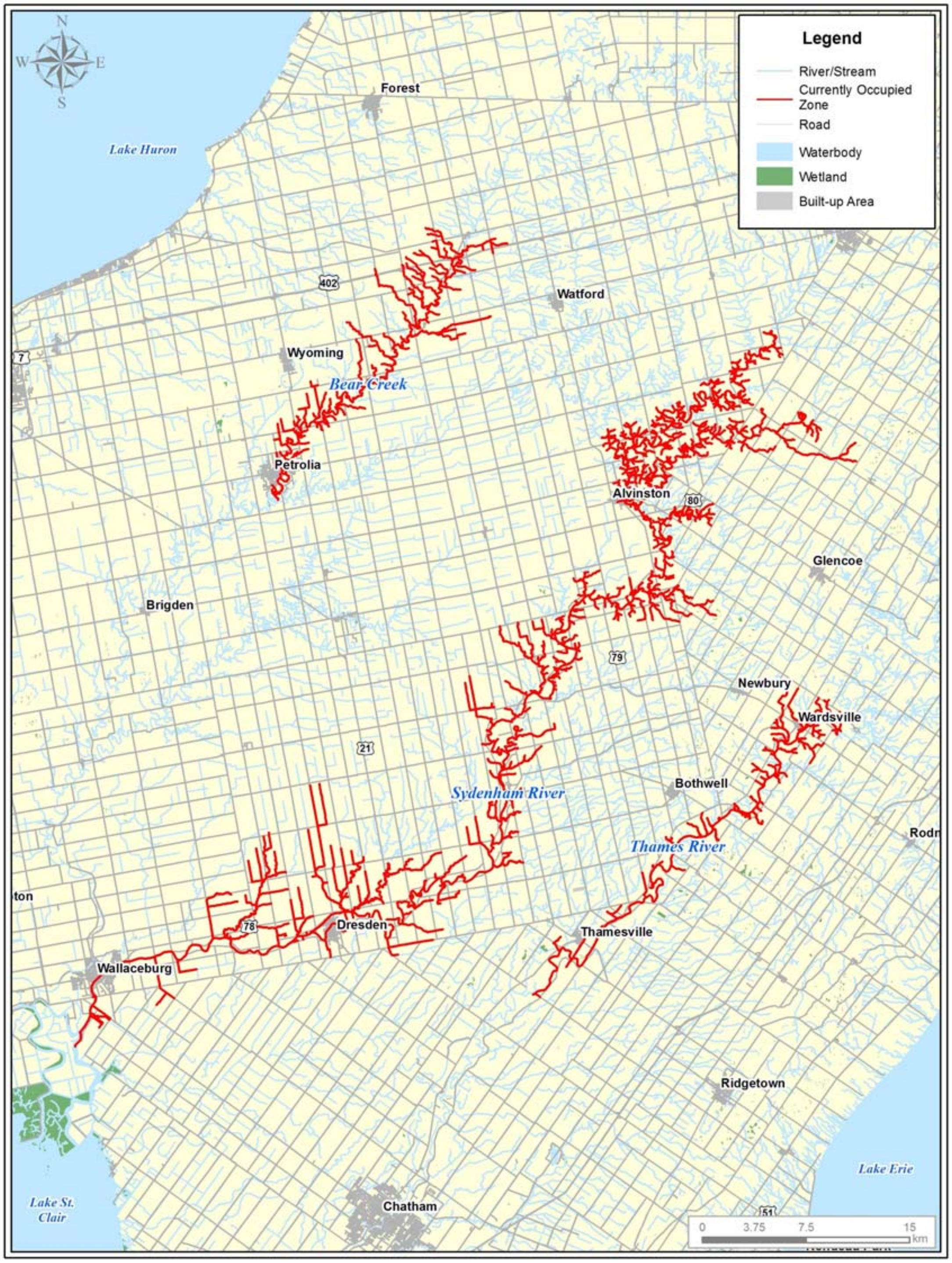

Figure 19: Currently occupied habitat of the Round Pigtoe in the Sydenham and Thames rivers.

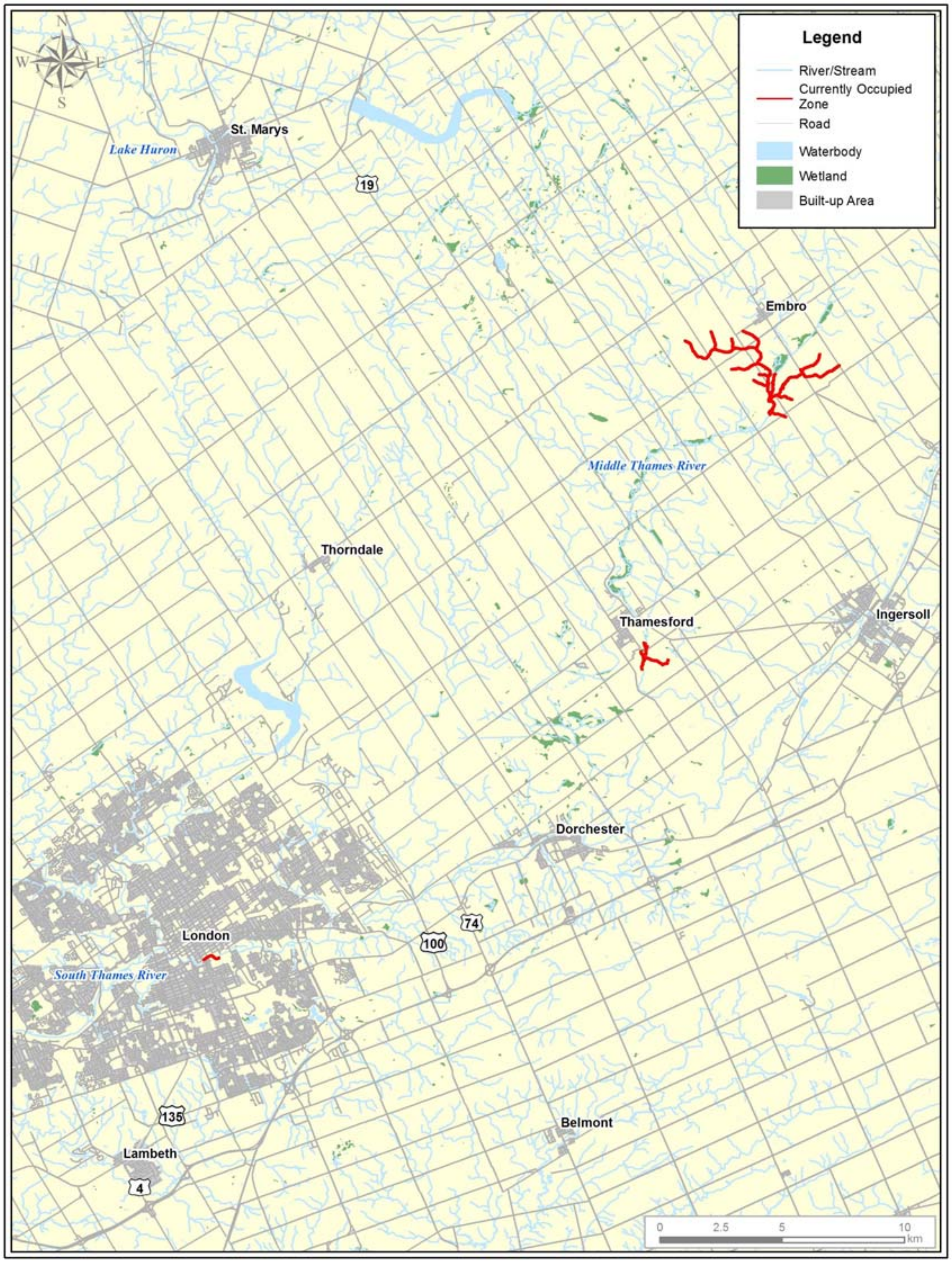

Figure 20: Currently occupied habitat of the Round Pigtoe in the Middle Thames and South Thames rivers.

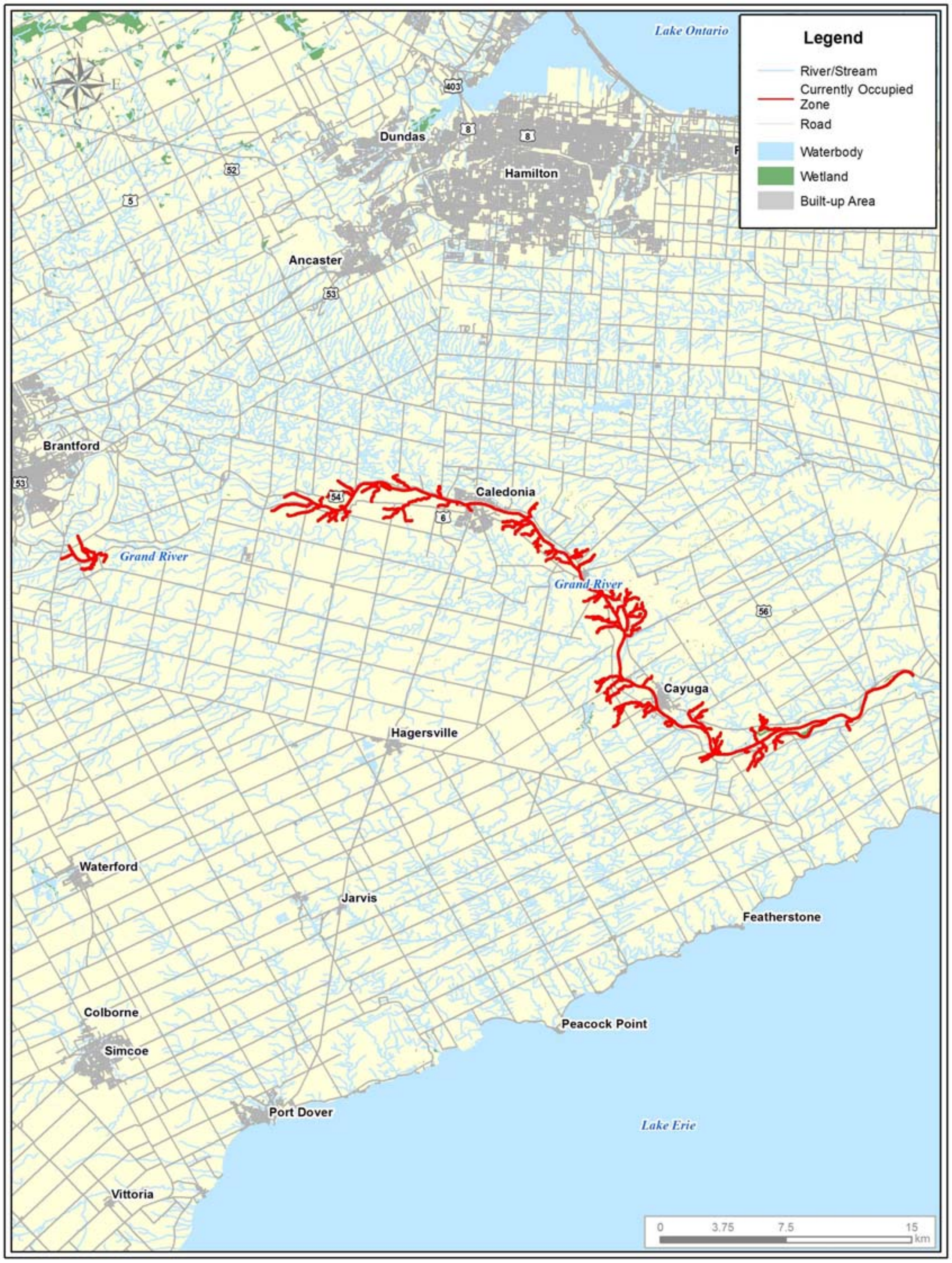

Figure 21: Currently occupied habitat of the Round Pigtoe in the Grand River.

Figure 22: Currently occupied habitat of the Round Pigtoe in the Lake St. Clair delta.

10. Habitat – Mudpuppy Mussel

Habitat Identification: The Nature Conservancy (TNC 1999) states that the Mudpuppy Mussel is most commonly found in sand or silt under flat stones in areas of swift current, where it may be locally abundant. Such a habitat is consistent with the habitat of its host, the mudpuppy. 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 Mudpuppy Mussels "…under large flat rocks in a gravel, cobble and boulder substrate in 3 inches of water in swift current." In 1999, thirteen live specimens were located on the East Sydenham River near Florence in a similar habitat.

Mudpuppy Mussels are often found in great numbers, with up to several hundred individuals packed tightly together under a single flat rock. The reason why Mudpuppy Mussels are found in such large concentrations is related to the close association between the mussel and its host (Parmalee and Bogan 1998). Howard (1951) speculated that the mudpuppy feeds on adult Mudpuppy Mussels 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 another large, flat stones.

Currently Occupied Habitat: Methods for delineating currently occupied habitat for the Mudpuppy Mussel follow the methods described for the Northern Riffleshell.

Geospatial Description: Currently occupied habitat for the Mudpuppy Mussel can be defined as a 50 km reach of the East Sydenham River (Figure 23).

Functional Description: Within the area defined under Currently Occupied Habitat only areas meeting the characteristics described below are deemed to represent habitat in need of conservation:

- permanently wetted and
- of a stream order greater than 2 and
- sand (< 2mm) or silt deposits under large flat rocks
- steady to moderate flows (riverine populations only)

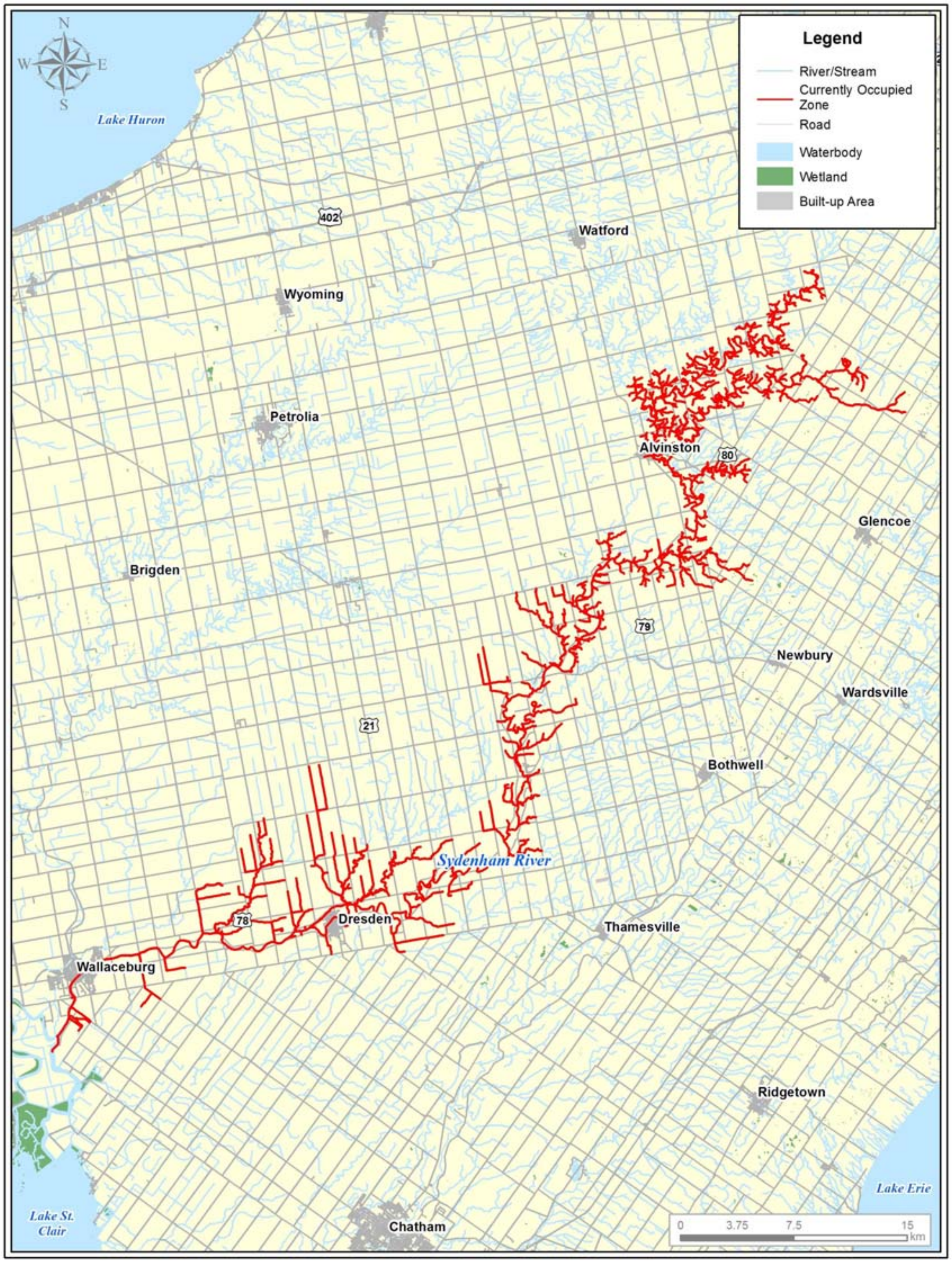

Figure 23: Currently occupied habitat of the Mudpuppy Mussel in the Sydenham River.

d or silt under large, flat

Historically Occupied Habitat: The Mudpuppy Mussel was historically known from several locations in the Detroit River as well as single records from Bear Creek in the Sydenham River watershed, the Thames River in London and the Lake St. Clair delta.

11. Habitat – Rayed Bean

Habitat Identification: Cummings and Mayer (1992) describe its habitat as "lakes and small to large streams in sand or gravel". It is occasionally reported from shallow water areas of lakes 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 in the substrate, among the roots of aquatic vegetation. As a result, this species may not be as sensitive to flow rate fluctuations in its habitat as some other mussel species (TNC 1987). Live specimens encountered in the Sydenham River (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.

Currently Occupied Habitat: Methods for delineating currently occupied habitat for the Mudpuppy Mussel follow the methods described for the Northern Riffleshell.

Geospatial Description: Currently occupied habitat for the Rayed Bean can be defined as a 50 km reach of the East Sydenham River (Figure 24) and small reach in the North Thames River above London (Figure 25).

Functional Description: Within the area defined under Currently Occupied Habitat only areas meeting the characteristics described below are deemed to represent habitat in need of conservation:

- permanently wetted and
- of a stream order greater than 2 and
- sand (< 2mm) or fine gravel (2 – 30mm) with
- low to moderate flows

Historically Occupied Habitat: The Rayed Bean is historically known from the Detroit River, South Thames River near Dorchester, several locations in the Thames River between London and Chatham and portions of Lake Erie around Pelee Island.

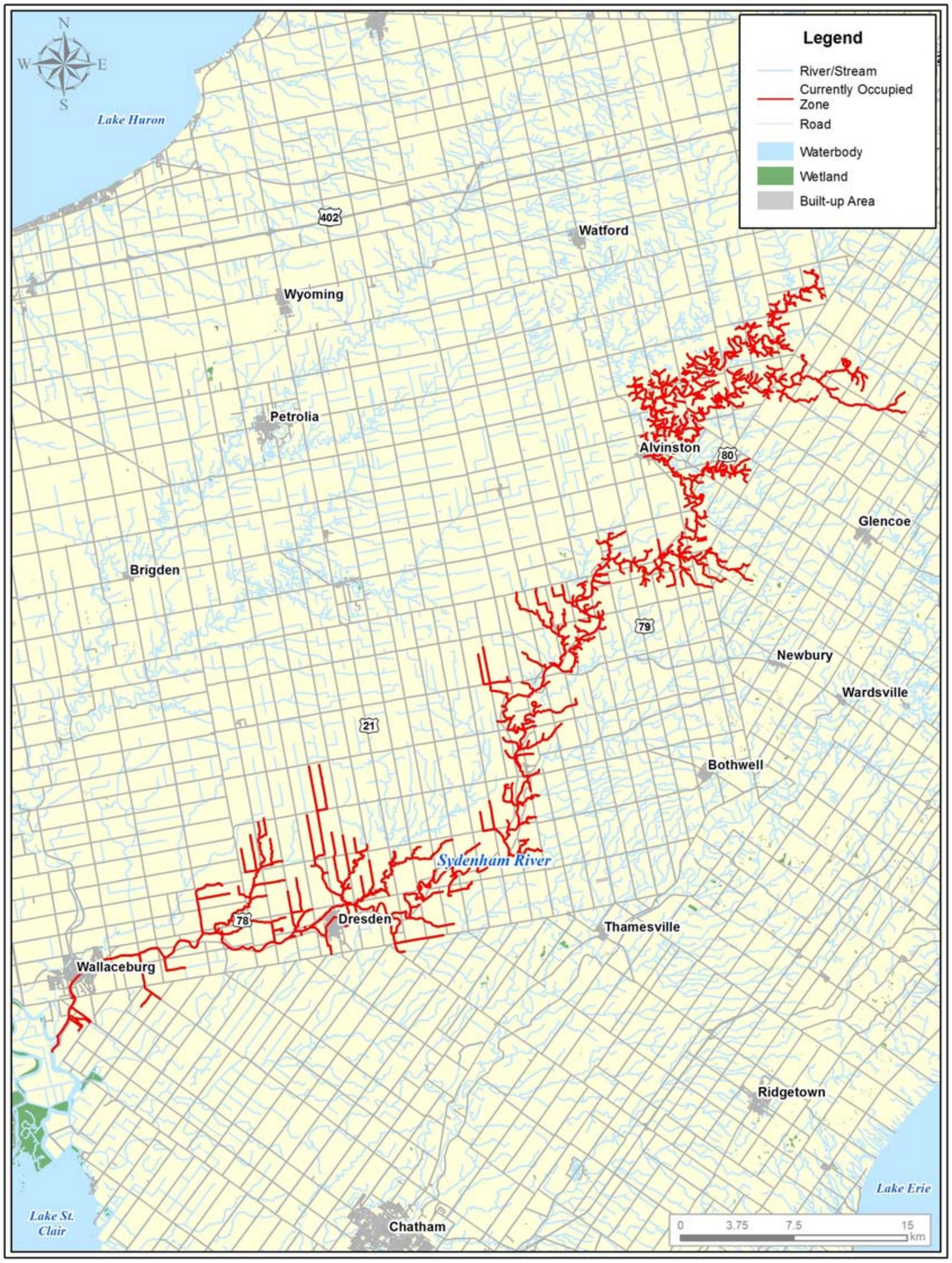

Figure 24 Currently occupied habitat of the Rayed Bean in the Sydenham River.

Figure 25: Currently occupied habitat of the Rayed Bean in the Thames River.

12. Critical Habitat

Critical Habitat is defined in SARA as the habitat required for the survival or recovery of a listed species. 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. At present, this information is not available for these species although Table 2 outlines activities that would assist with obtaining the required information. The activities listed in Table 2 are not exhaustive but outline the range and scope of actions identified by the OFMRT as necessary to identify critical habitat for all five species. It is likely that the process of investigating the actions in Table 2 will lead to the discovery of further knowledge gaps that will have to be addressed. Until Critical Habitat can be defined the OFMRT has identified the areas listed in the Currently Occupied Habitat and Historically Occupied Habitat sections as areas in need of conservation.

Table 2: Schedule of activities to identify Critical Habitat for these five mussel species.

Activity	Approximate Time Frame[1]
Conduct mussel population surveys	2006-2008
Assess habitat conditions in occupied areas (e.g., flow, substrate, water clarity and quality)	2006-2008
Determine any life stage differences in habitat use	2007-2009
Survey and map areas of suitable but unused habitat within historical range	2008-2010
Assess genetic structure of populations	2006-2008
Complete host fish studies	2006 - 2008
Conduct host fish population surveys	2006-2008
Assess habitat use by host species	2006-2008
Determine areas of overlap between mussel and host habitat	2009-2010

[1] timeframes are subject to change as new priorities arise or as a result of changing demands on resources or personnel

13. Habitat Trend

The loss of these five mussel species from historical habitat in the Lower Great Lakes region can be largely attributed to the detrimental effects of Dreissenid mussels including competition for food, resources and space. The introduction and spread of the zebra and quagga mussel throughout the Great Lakes in the late 1980s decimated native mussel populations (Schloesser *et al.* 1996). Native mussel communities were virtually extirpated from the offshore waters of western Lake Erie by 1990 (Schloesser and Nalepa 1994) and the offshore waters of Lake St. Clair by 1994 (Nalepa *et al.* 1996). The mussel communities of Lake Erie were already in decline, probably due to a general decline in water quality over the past 40 years (Nalepa *et al.* 1991), but Lake St. Clair still supported an abundant and diverse mussel assemblage as recently as 1986 (Nalepa and Gauvin 1988). The continue presence of Dreissenid mussels throughout much of the historical range of these species results in large areas of formally suitable habitat remaining unavailable.

The Round Pigtoe was recently reported from three sites in the St Clair River delta; however, repeated sampling of the same sites reported declines in all three sites. Isolated patches of the Northern Riffleshell continue to survive in some nearshore wetland areas with very shallow water, a high degree of connectivity to the lake (which ensures access to host fishes), and harsh conditions for zebra mussels (high water temperatures and considerable wave action in summer; ice scour in winter). However, such “refugia” are rare, and most of the mussel habitat in the Great Lakes has been permanently lost (COSEWIC 2003).

The Northern Riffleshell and Snuffbox historically occurred in the Ausable, Grand and Thames rivers and may still have remnant populations in the Ausable and Thames rivers. The Round Pigtoe historically occurred in the Thames and Grand rivers, and remnant populations have been identified in both watersheds. The Mudpuppy Mussel and Rayed Bean historically only occurred in the Sydenham and Thames rivers. In the Ausable River, former habitat has been lost due to siltation, high turbidity levels, alterations to the flow regime, toxic contaminants, thermal changes, and exotic species. In the Grand River, untreated wastewater inputs from major urban centres likely contributed to the declines. In the Thames River, agricultural impacts such as siltation and turbidity, nutrient loading, toxic compounds, altered water flow, barriers to movement, as well as non-native species, and thermal pollution have all contributed to the degradation of habitat for these five mussel species.

14. Habitat Protection

The federal *Species at Risk Act* (SARA) was proclaimed in June of 2003. Under SARA there are general prohibitions against killing, harming, taking, possessing, capturing, and collecting these mussels and against damaging or destroying its residences, as well as prohibitions on the destruction of Critical Habitat. The *Fisheries Act* represents an important tool for habitat protection and along with other federal environmental legislation is complementary to the *Species at Risk Act*. Under the federal *Fisheries Act* mussels are considered shellfish, falling under the definition of ‘fish’, and their habitat is therefore protected from harmful alteration, disruption or destruction unless authorized by the Minister of Fisheries and Oceans, or his/her delegate. Planning authorities must be consistent with the Provincial Policy Statement under Section 3 of *Ontario’s Planning Act*, which prohibits development and site alteration in the significant habitat of endangered species. The *Ontario Lakes and Rivers Improvement Act* prohibits the impoundment or diversion of a watercourse if siltation will result while the voluntary Land Stewardship II program of the Ontario Ministry of Agriculture, Food and Rural Affairs is designed to reduce erosion on agricultural lands. Stream-side development in Ontario is managed through floodplain regulations enforced by local conservation authorities. Ontario Regulation 97/04 addresses “Development, Interference with Wetlands & Alteration to Shorelines & Watercourses.” This Regulation was enacted as a result of an amendment to Section 28 of the Conservation Authorities Act, and replaces the “Fill, Construction and Alteration to Waterways Regulation”. The Generic Regulation controls the following activities: development within a regulated area; interference and alterations to watercourses; interference and alteration to wetlands (defined by the Conservation Authorities Act); and Interference and alteration to shorelines.

15. Ecological Role

Freshwater mussels play an integral role in the functioning of aquatic ecosystems. Vaughn and Hakenkamp (2001) have summarized much of the literature relating to the role of unionids and identified numerous water column (size-selective filter-feeding; species-specific phytoplankton selection; nutrient cycling; control of phospohorus abundance) and sediment processes (deposit feeding decreasing sediment organic matter; biodeposition of feces and pseudofeces; epizoic invertebrates and epiphytic algae colonize shells; benthic invertebrate densities positively correlated with mussel density) mediated by the presence of mussel beds. Welker and Walz (1998) have demonstrated 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.

16. Importance to People

In the past, the Round Pigtoe has been a commercially valuable species, being used in the pearl button industry (Oesch, 1995). The Round Pigtoe is one of 12 commercially valuable species in Kansas (Busby and Horak, 1993) and there has been a shift in market demand for larger mussels including several pigtoe species (Baker, 1993). Over harvesting seriously depleted some mussel stocks in the United States and the commercial harvest is now closed in many states. There was a brief mussel fishery in the Grand River in the early 1900s (Detweiler 1918) but there is no commercial harvest presently (COSEWIC 2004).

These five mussel species have otherwise no apparent economic significance. However, freshwater mussels are sensitive to environmental pollution and a diverse mussel community indicates a healthy ecosystem. Besides decreased biodiversity in Canada, the loss of the Mudpuppy Mussel, Northern Riffleshell, Round Pigtoe, Rayed Bean and Snuffbox may indicate further environmental degradation of southwestern Ontario watercourses which would adversely affect those people who depend on surface water for drinking, recreation or watering livestock.

17. Biological and Technical Feasibility of Recovery

Recovery of the Mudpuppy Mussel, Northern Riffleshell, Round Pigtoe, Rayed Bean and Snuffbox 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 mussels on Northern Riffleshells and Round Pigtoes.

II. RECOVERY

1. Recovery Goal

The long-term goals of this recovery strategy are:

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

These populations will only be considered recovered when they have returned to historically estimated ranges and/or population densities and are showing signs of reproduction and recruitment.

2. Recovery Objectives (5 year)

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 of both.
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.
vii. Increase awareness about the distribution, threats and recovery of these species.

3. Approaches to Meeting Recovery Objectives

The approaches to recovery have been organized into four distinct categories – research and monitoring, management, stewardship and awareness. Successful recovery will require consideration of approaches from all categories. A narrative has been included after each table where appropriate.

a) Research and Monitoring Approaches

Priority	Number	Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
URGENT	1-1	ii, v	Research – host fishes.	Continue fish host testing for the Snuffbox, Northern Riffleshell, Round Pigtoe and Rayed Bean.	Will help determine if host abundance is limiting factor for the four mussel species. Will assist with identifying critical habitat.	Host Fishes
URGENT	1-2	ii, v	Surveys – host fishes.	Determine the distribution and abundance of the host species.	Will help determine if host abundance is limiting the five mussel species.	Host Fishes
URGENT	1-3	iii	Research – Critical Habitat.	Determine the habitat requirements for all life stages.	Will assist with defining critical habitat for the Mudpuppy Mussel, Northern Riffleshell, Round Pigtoe, Rayed Bean and Snuffbox.	
URGENT	1-4	iii, vi	Surveys – Critical Habitat.	Prepare a distribution map of areas of suitable habitat.	Will assist with identifying critical habitat and potential areas of reintroduction.	
URGENT	1-5	vi	Research – managed refuge sites.	Investigate the feasibility of establishing actively managed refuge sites in the St. Clair River delta.	Will determine if the Northern Riffleshell and Round Pigtoe in the St. Clair River delta can be insulated from the effects of zebra mussels.	Exotic Species

Priority	Number	Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
Urgent	1-6	vi	Population augmentation	Examine the feasibility of translocations and re-introductions.	Will determine if small populations can be augmented or if the species can be reintroduced in historical range.	
NECESSARY	1-7	i, iv	Monitoring – mussel and host fish populations.	Establish a network of permanent monitoring stations throughout historic and present ranges.	Will permit tracking of populations, analysis of trend patterns, and permit the evaluation of recovery actions.	
NECESSARY	1-8	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.	
NECESSARY	1-9	v	Research – threats.	Identify and evaluate threats to all life stages.	Will assist with determining reasons for declines and developing remedial actions.	All threats.

Priority	Number	Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
NECESSARY	1-10	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.	

1-1 & 1-2: The necessity for a period of encystment represents a potential bottleneck in the lifecycle 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. In order 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 Mudpuppy Mussel is host specific with the mudpuppy. Host species for Canadian populations of the Northern Riffleshell, Rayed Bean and Snuffbox have been identified, however, further testing should continue as results are still in progress for the Northern Riffleshell and Snuffbox (McNichols and Mackie 2004). Host species for Canadian populations of the Round Pigtoe are based on results from the United States. Once the Canadian hosts have been confirmed for these species it is necessary to ensure that host species distributions overlap with the mussel distributions. Since adult mussels are essentially sessile this can be accomplished by confirming that members of the hosts species occur in reaches with mature female mussels at times when the female mussels possess mature glochidia.

1-3 & 1-4: Determination 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 and attention must also be paid to the habitat preferences of the hosts. Identification of critical habitat will be a multi-stage process. For more information on the required steps see Critical Habitat sections for each species.

1-5: Remnant populations of both Northern Riffleshells and Round Pigtoes can be found in the delta area of Lake St. Clair despite the presence of zebra mussels. Metcalfe-Smith *et al.* (2004) reported zebra mussel infestation rates ranging from <1 to 36 zebra mussels/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) (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. Since these sites are still affected by zebra mussels it is likely that unionids will need to be actively managed with regular zebra mussel removal and the active relocation of riffleshells and other mussel SAR to these locations from the more heavily infested sites.

1-7 & 1-8: A network of detailed, permanent monitoring stations should be established throughout the present and historic ranges of the five mussel species. 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.) 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 exotic species (i.e. zebra mussels). Reservoirs represent the likely seed locations for zebra mussels in the Grand, Thames, Sydenham and Ausable rivers. Monitoring sites should be established within or close to these reservoirs to permit the early detection of zebra mussels in the event that they invade these systems. Monitoring of exotics in the St. Clair River delta will likely be conducted in close association with the managed refuge sites.

b) Management Approaches

Priority	Number	Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
URGENT	2-1	i-vi	Capacity Building	Promote and enhance expertise in freshwater mussel identification/biology and provide for the transfer of knowledge.	Will ensure correct identification 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 Recovery Goals in official plans.	Will provide further protection for the Northern Riffleshell, Mudpuppy Mussel, Round Pigtoe, Snuffbox and Rayed Bean to ensure that future development does not degrade important habitat.	Siltation and turbidity, nutrient loads, toxic compounds, thermal effects.
NECESSARY	2-4	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	Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
NECESSARY	2-5	ii, iii, v	Fish Management Plans	Encourage the development of management plans for non SAR fish species within watersheds inhabited by the Northern Riffleshell, Snuffbox, Round Pigtoe, and Rayed Bean.	Will provide protection for potential host species.	Host fishes.
NECESSARY	2-6	v	Baitfish	Work with the baitfish industry to reduce the impacts of commercial baitfishing on host species.	Will provide protection for potential host species.	Host fishes, exotic 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.

Priority	Number	Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
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 5 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 of several key researchers is expected prior to the 5-year re-evaluation period for this strategy. 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.
- Producing a field guide to the mussels of Ontario.
- Encourage graduate and post-graduate research aimed at fulfilling the needs identified under Research and Monitoring.

2-2: Many of the threats to the Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy 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 II.5, 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, Mudpuppy Mussel and Rayed Bean are to recover. The greenside darter, which functions as a host for the Rayed Bean, is listed as a species of special concern by COSEWIC. This species is given consideration in the aquatic ecosystem recovery strategies for the Sydenham River (Dextrase *et al*. 2003), Ausable River (ARRT 2005) and Thames River (TRRT 2004) and will therefore be actively monitored and managed within these systems. The remaining host species for the five mussel species including the bluegill, bluntnose minnow, brook stickleback, greenside darter, Iowa darter, Johnny darter, largemouth bass, logperch, mottled sculpin, northern redbelly dace, rainbow darter and spotfin shiner are not listed by COSEWIC and therefore 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, Mudpuppy Mussel and Rayed Bean are not typically targeted as baitfish 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.

c) Stewardship Approaches

Priority	Number	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 management	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 management	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.

Priority	Number	Objective Addressed	Broad Approach/ Strategy	Specific Steps	Anticipated Effect	Threat Addressed
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	Agency Interaction	Cooperating and coordinating efforts with stewardship councils and CAs	Will improve the implementation of stewardship activities.	Siltation and turbidity, nutrient loads, thermal effects.
BENEFICIAL	3-8	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” 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.

d) Awareness Approaches

Priority	Number	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 Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean.	All threats.
URGENT	4-2	vii	Exotic species	Increase public awareness of the potential impacts of transporting/releasing exotic species.	Will reduce the risk of zebra mussels becoming established in the reservoirs.	Exotic 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 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 can not 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.

4. Potential Impacts of Recovery Strategy on Other Species/Ecological Processes

The Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean are sensitive species, particularly to issues of water quantity and quality. For this reason, we expect 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 (Pimephales 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.

5. Actions Already Completed or Underway

Sydenham River Aquatic Ecosystem Recovery Strategy: The Sydenham River Recovery Team became the first group in Canada to adopt an ecosystem approach for recovering aquatic species when they completed the Sydenham River Aquatic Ecosystem Recovery Strategy (SRAERS) in 2003 (Dextrase *et al.* 2003). The recovery strategy focuses on 14 aquatic species (5 mussels, 8 fishes, 1 turtle) within the basin that are listed as endangered, threatened or of special concern by COSEWIC. The Northern Riffleshell, Snuffbox, Mudpuppy Mussel and Rayed Bean are all considered in the Sydenham River Strategy; however, the Round Pigtoe is not.

Thames River Recovery Ecosystem Strategy: The Thames River Recovery Team (TRRT) has set out to develop an ecosystem based recovery strategy for the Thames River watershed. 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" (Thames River Recovery Team 2004). This recovery strategy addresses 25 COSEWIC listed species including 7 mussels, 12 fishes and 6 reptiles. Four of the five mussel species are being considered in the development of this strategy: Northern Riffleshell, Round Pigtoe, Mudpuppy 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.

Ausable River Ecosystem Recovery Strategy: The Ausable River Recovery Team is developing an ecosystem Recovery Strategy for the 14 COSEWIC listed aquatic species in the Ausable River basin. This plan covers 4 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" (Ausable River Recovery Team 2005). The Ausable River Recovery Team (2005) has also established a species-specific recovery goal for mussels to maintain existing populations of species at risk and restore self-sustaining populations to areas of the river where they formerly occurred.

Grand River Fish Species at Risk Recovery Strategy: The Grand River Recovery Team has developed a draft recovery strategy for fish species at risk in the Grand River. 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 mussels 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).

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 Fishes 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 Aqua Lab on the grounds of the University in Guelph, Ontario, Canada. This facility has been used to investigate potential hosts for four species of endangered mussels including the Northern Riffleshell, Rayed Bean and Snuffbox (McNichols and Mackie 2004). Between 2002-2004 they identified five host species for the Northern Riffleshell including the blackside darter, Iowa darter, Johnny darter, mottled sculpin and rainbow darter; five for the Rayed Bean including the brook stickleback, greenside darter, Johnny darter, logperch and rainbow darter; and four for the Snuffbox including the Iowa darter, logperch, mottled sculpin, and largemouth bass. These results still need to be confirmed with further testing in the lab, particularly for the Northern Riffleshell and Snuffbox.

Stewardship Activities: Stewardship activities, through partnerships with local landowners, conservation authorities, MNR stewardship councils and other provincial and federal agencies, have been initiated in many of the watersheds where these species currently or historically occurred. For example stewardship programs have been available in the St. Clair Region Conservation Authority since 2000 for projects involving construction of fencing, watercourses crossings and alternate watering systems in order to prevent livestock from accessing watercourse; construction, repair or improvement of manure storage, clean water diversions and/or runoff collection systems; planting of riparian buffers along watercourses; construction or enhancement of wetlands; repair or replacement of malfunctioning private septic systems; naturalization, construction or improvement to streambank to improve bank stability; construction of traps and ponds to collect sediment from drainage.

Currently, the Ausable-Bayfield Conservation Authority is able to provide funding for stewardship activities such as: tree planting, windbreaks, buffer strips, Nutrient Management Plans, well-decommissioning, wellhead protection, livestock washwater, manure spreading equipment modifications, conservation tillage modifications, clean water diversion, livestock restriction, fertilizer, fuel and chemical storage and handling, erosion control, conservation tillage equipment modifications and septic system upgrades. Implementation of these projects improves water quality and habitat for aquatic species at risk. Funding for many stewardship activities has been provided through the federal Habitat Stewardship Program.

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.

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 the mussels.

Allowable Harm Analysis: Fisheries and Oceans Canada, in partnership with other interested parties, has initiated an analysis of the potential for populations of these species to withstand any additional level of human-induced mortality without impeding recovery of the species.

Source Protection Planning: A White Paper on Watershed-based Source Protection Planning was released in February 2004 (Ontario Ministry of the Environment 2004). The Clean Water Act was introduced in provincial parliament in December 2005. This legislation will identify potential sources of contamination to the surface water and groundwater, determine how much water is readily available, evaluate where that water is vulnerable to contamination and implement programs to minimize threats to water quality and water quantity.

6. Action Plans

One or more action plans relating to this recovery strategy will be produced within five years of the strategy being completed. Wherever possible, recovery action plans should be linked to 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.

7. 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 aids in tracking the populations and habitats of the Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean. This will form the basis of an adaptive management program. Recovery Implementation Groups will develop specific targets in the Recovery Action Plans to provide a further basis for evaluating success. The entire Recovery Strategy will be reviewed in 5 years at which time all goals, objectives and approaches will be re-evaluated.

REFERENCES

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

Amyot, J.P. and J.A. Downing. 1997. Seasonal variation in vertical and horizontal movement of the freshwater bivalve *Elliptio complanata* (Mollusca: Unionidae). Freshwater Biology 37: 345-354.

Ausable River Recovery Team. 2005. Recovery Strategy for species at risk in the Ausable River. An ecosystem approach 2004-2009. Draft 5 – June 2005. xi + 128 pp.

Baker, F.C. 1928. The fresh water mollusca of Wisconsin. Part II: Pelecypoda. Bulletin 70, Wisconsin Geological and Natural History Survey: 495 pp.

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.

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

Bogan A. E. and Parmalee. 1983. Tennessee's Rare Wildlife. Volume II: The Mollusks. Tennessee Wildlife Resources Agency. 123 pp.

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

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.

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

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

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.

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 pp.

Cummings, K.S., and C. A. Mayer. 1992. Field guide to the freshwater mussels of the midwest. Illinois Natural History Survey Manual 5. 194 pp.

Dextrase, A. J., S. K. Staton, 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 pp.

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.

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 pp.

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 + 99pp.

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.

Hogarth 1993. Glochidial functional morphology and rarity in the Unionidae. Pages 76-80 *in* Conservation and Management of Freshwater Mussels, Proceedings of the upper Mississippi River Conservation Committee Symposium St. Louis, Missouri. *Edited by* K. S. Cummings, A. C. Buchanan, and L. M. Koch, Illinois Natural History Survey, Champaign Illinois.

Holm, E., and N. E. Mandrak. 1996. The status of the eastern sand darter, *Ammocrypta pellucida* in Canada. Canadian-Field Naturalist 110(3): 462-469.

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

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

Jacques Whitford Environment Ltd. 2001. Sydenham River Recovery Project: Synthesis and analysis of background data. Report to the Sydenham River Recovery Team.

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

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, Te. 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.

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

McGoldrick, D.J., T.J. Morris, J.L Metcalfe-Smith and V.S. Jackson. 2006. Developing critical habitat descriptions for Threatened and Endangered freshwater mussels – A case study using the Wavyrayed Lampmussel (*Lampsilis fasciola*). Draft Canadian Science Advisory Secretariate Research document 2006/xxxx.

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

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

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 pp.

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 Canada, National Water Research Institute, Burlington, ON, NWRI Contribution No. 98-019.

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 Canada, National Water Research Institute, Burlington, ON, NWRI Contribution No. 99-058.

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

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

Nalepa, T. F., and J. M. Gauvin. 1988. Distribution, abundance, and biomass of freshwater mussels (Bivalvia: Unionidae) in Lake St. Clair. Journal of Great Lakes Research 14(4): 411-419.

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.

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 pp.

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

Ontario Ministry of the Environment. 2004. White Paper on Watershed-based Source Protection Planning. February 2004. Integrated Environmental Planning Division, Strategic Policy Branch, Ministry of the Environment. Queen's Printer for Ontario. 45pp.

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 pp.

Parmalee, P.I W., and A. E. Bogan. 1998. The freshwater mussels of Tennessee. The University of Tennessee Press, Knoxville. 328 pp.

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.

Ray, W. J. and L.D. Corkum 2001. Habitat and site affinity of the round goby. Journal of Great Lakes Research 27: 329–334.

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.

Richter, B.D., D.P. Braun, M.A. Mendelson, and L.L. Master. 1997. Threats to imperiled freshwater fauna. Conservation Biology 11: 1081-1093.

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.

Staton, S.K., J.L. Metcalfe-Smith, and E.L. West. 2000a. Status of the Northern Riffleshell, *Epioblasma torulosa rangiana* (Bivalvia: Unionidae), in Ontario and Canada. The Canadian Field-Naturalist 114(1): 224–235.

Staton, S.K., D. Woolnough and K. McNichols. 2000b. Sydenham River aquatic habitat survey. Unpublished report of the National Water Research Institute, Burlington, ON and the University of Guelph, Guelph, ON.

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

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

Thames River Recovery Team. 2004. Recovery strategy for the Thames River Aquatic Ecosystem: 2005-2010. December 2004 Draft. 146 pp.

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

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

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

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

USFWS (United States Fish and Wildlife Service). 1994. Clubshell (*Pleurobema clava*) and Northern Riffleshell (*Epioblasma torulosa rangiana*) Recovery Plan. Hadley Massachusetts. 68 pages.

Veliz, M. 2003. Ausable River Water Quality Report: A background report to the Ausable River Recovery Plan. Ausable Bayfield Conservation Authority: Exeter, ON.

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 pp + Plates I-XII.

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.

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. 16pp.

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 pp.

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 pp.

Watters G.T., S.H. O'Dee and S.C. Chordas. 2001. Patterns of Vertical Migration in Freshwater Mussels (Bivalvia: Unionidae). Journal of Freshwater Ecology 16:541-549.

West, E.L., J.L. Metcalfe-Smith, and S.K. Staton. 2000. Status of the Rayed Bean, *Villosa fabalis* (Bivalvia: Unionidae), in Ontario and Canada. The Canadian Field-Naturalist 114(2): 248–258.

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 pp.

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.

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

RECORD OF COOPERATION AND CONSULTATION

Fisheries and Oceans Canada has attempted to engage all potentially affected aboriginal communities in Southern Ontario during the development of the proposed recovery strategy for these five mussel species. Information packages were sent to the Chief and Council of the Chippewas of Kettle and Stoney Point, Aamjiwnaang First Nation, Caldwell First Nation, Delaware Nation Council (Moravian of the Thames First Nation), Chippewas of the Thames, Oneida Nation of the Thames, Munsee-Delaware First Nation, Mississaugas of New Credit First Nation, Six Nations of the Grand, Walpole Island First Nation and the Southern First Nations Secretariat. Information packages were also sent to Metis Nation of Ontario (MNO) Captains of the Hunt for Region 7, 8, and 9 and the MNO senior policy advisor. Members of these communities may have traveled or harvested fish or freshwater mussels from the waters of the Ausable, Sydenham River, Thames River, Grand River, Lake St. Clair or Lake Erie where these mussel species were historically found. Follow-up telephone calls were made to each community office to ensure that packages were received and to ask if they would like to schedule a meeting to learn more about species at risk in general and proposed recovery strategies.

Meetings were held with Oneida Nation of the Thames Councillor for environmental issues, Chief and council of Kettle and Stoney Point First Nation, the environment committee from Aamjiwnaang First Nation, Wapole Island First Nation – Heritage Centre Staff, and a Council meeting of the Metis of Nation of Ontario. No comments have been received.

In addition to the above activities, DFO had established an ongoing dialogue with the policy advisor to the Southern First Nations Secretariat and had engaged the London Chiefs Council (an association of the 8 area First Nation governments in Southwestern Ontario) on several occasions. Meetings were held with the director of the Walpole Island Natural Heritage Centre and the Fish and Game Enforcement Officer from Walpole Island First Nation. Walpole Island First Nation has been represented in the membership of the Ontario Freshwater Mussel Recovery Team since the formation of the recovery team in 2003. DFO also discussed SARA issues with a representative of the Six Nations of the Grand who works for the Six Nations EcoCentre and who also represents First Nation interests on the Grand River Fishes at Risk Management Plan, the Thames River Fish Management Plan and the St. Clair River Management Strategy.

The Ontario Freshwater Mussel Recovery Team had representatives from all of the Conservation Authorities responsible for managing the rivers where these mussels are presently or were historically found. In addition to this, DFO had prepared a list of non-governmental organizations, federal agencies and municipalities which may be impacted by the proposed recovery strategy. Information packages were prepared to inform these groups that the proposed recovery strategy had been drafted, and inviting each group to comment on the strategy. As well an announcement was prepared and placed in newspapers with circulation in the area where these mussels are found to inform landowners and the general public about the strategy and to request their comments. These packages were sent and the announcements published at the time the proposed recovery strategy was posted on the SARA registry. Comments were received from the McIlwraith Field Naturalists of London Ontario, Canadian Wildlife Service-Ontario, Parks Canada, Public Utilities Commission for the Municipality of Chatham-Kent and the Town of Lakeshore.

The province of Ontario was represented on the Ontario Freshwater Mussel Recovery Team by the Ministry of Natural Resources (OMNR) and has actively participated in the development of this proposed recovery strategy. A letter was sent to OMNR to request further Provincial comment on the proposed recovery strategy when it was posted on the SARA Registry. Comments were received from OMNR.

The National Water Research Institute of Environment Canada had been actively engaged in the development of this recovery strategy providing two members to the Ontario Freshwater Mussel Recovery Team.

The Recovery Team contacted representatives from Resource Management agencies at the state and federal levels in the USA where these mussels occur. This mussel is only found in Canada and the United States of America. Information packages were sent to each U.S. agency when the strategy was posted on the Sara Registry. No comments were received.