Species at Risk Act
Recovery Strategy Report Series

Report on the Progress of Recovery Strategy Implementation for the Wavyrayed Lampmussel, Northern Riffleshell, Snuffbox, Round Pigtoe, Mudpuppy Mussel and Rayed Bean in Canada for the Period 2006–2011

2013

Canada

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Recommended Citation

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

For copies of the progress report, or for additional information on species at risk, including COSEWIC Status Reports, residence descriptions, action plans, and other related recovery documents, please visit the SAR Public Registry.

Cover illustrations: Top Picture – Wavyrayed Lampmussel (male/female). Bottom picture - Clockwise from upper left: male Northern Riffleshell, male Snuffbox, Round Pigtoe, Salamander (Mudpuppy) Mussel, male Rayed Bean (centre). All images courtesy Environment Canada.

Également disponible en français sous le titre
« Rapport sur les progrès de la mise en œuvre du programme de rétablissement de la lampsile fasciolée (*Lampsilis fasciola*), de l'épioblasme ventrue (*Epioblasma torulosa rangiana*), de l'épioblasme tricorne (*Epioblasma triquetra*), du pleurobème écarlate (*Pleurobema sintoxia*), de la Mulette du Necture (*Simpsonaias ambigua*), et de la villeuse haricot (*Villosa fabalis*) au Canada pour la période allant de 2006 à 2011 »

ISBN 978-1-100-22398-8
Catalogue no. 978-1-100-22398-8

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This document was prepared by Peter Jarvis (DFO Contractor) and Amy Boyko (DFO) on behalf of Fisheries and Oceans Canada.

Acknowledgements

Fisheries and Oceans Canada would like to thank the members of the Ontario Freshwater Mussel Recovery Team for their support in the development of this progress report.

Preface

Section 46 of the *Species at Risk Act* (SARA) requires the competent Minister to report on the implementation of the recovery strategy for a species at risk, and on the progress towards meeting its objectives within five years of the date when the recovery strategy was placed on the Species at Risk Public Registry.

Reporting on the progress of recovery strategy implementation requires reporting on the collective efforts of the competent Minister, provincial organizations and all other parties involved in conducting activities that contribute towards the species recovery.

Executive Summary

As a result of the overlap in the historical and current ranges of the Wavyrayed Lampmussel, Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel (formerly known as the Mudpuppy Mussel) and Rayed Bean, there is substantial commonality in threats to their continued survival. A key component in progress toward fulfilling recovery objectives has been the systematic collaboration with existing ecosystem recovery teams. This collaboration has taken the form of multiple research projects and stewardship teams that actively coordinate and monitor habitat improvement projects on the Ausable, Sydenham, Grand and Thames river systems, as well as Walpole Island. These collaborative efforts resulted in concrete progress in the form of habitat improvement and protection, and important biological insights of these species.

The following is a list of the most important accomplishments in meeting the recovery objectives as stated in the recovery strategies:

- Much of the current and historical ranges of these species have been surveyed, with understanding of population demographics improving as a result.
- Refinement of host fish knowledge has occurred, while fish surveys have advanced range and abundance knowledge for all known host fish species.
- Habitat requirements are adequately described in the recovery strategies for these species, which has allowed for the partial identification of critical habitat in the species' riverine habitat. The identification of critical habitat in lacustrine environments has yet to be defined but is in progress. Critical habitat identification for the Wavyrayed Lampmussel is not required given its current status as Special Concern
- Long-term monitoring programs have been developed, including provisions not only for the mussel species but also for their host fishes and habitat. Monitoring stations have been added and now cover important locations currently and formerly occupied by the six mussel species.
- Some threat mitigation has occurred, often in coordination with the applicable conservation authority, with a focus on reducing the impact of agricultural practices on lands adjacent to mussel habitat. The restriction of livestock from watercourses and the conservation and restoration of riparian habitat are expected to improve water quality and general habitat conditions.
- Advancement of husbandry and genetic techniques and knowledge specific to unionid mussels have reached a point where mapping of their genetic structure is ongoing and will be key to further efforts that may involve relocation and reintroduction programs.
- Outreach programs have successfully reached the general public within the applicable watersheds, with conservation authorities playing a leading role. Landowners have been targeted and numerous successful habitat stewardship programs have been completed as a result of direct contact with agricultural operators with land adjacent to mussel habitat.

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1. Background

1.1. COSEWIC assessment summary

COSEWIC assessment summary – April 2010

Common name: Wavyrayed Lampmussel
Scientific name: *Lampsilis fasciola*
COSEWIC status: Special Concern
COSEWIC reason for designation: This medium-sized freshwater mussel is confined to four river systems and the Lake St. Clair delta in southern Ontario. Since the original COSEWIC assessment of Endangered in 1999, surveys have identified a large, previously unknown reproducing population in the Maitland River. The mussels in the Thames River are also now reproducing. The largest population is in the Grand River; smaller but apparently reproducing populations are in the Ausable River and Lake St. Clair delta. Although water and habitat quality have declined throughout most of the species' former range in Canada, there are signs of improvement in some populations but habitats in Great Lakes waters are now heavily infested with invasive mussels and are uninhabitable for native mussels. The main limiting factor is the availability of shallow, silt-free riffle/run habitat. All riverine populations are in areas of intense agriculture and urban and industrial development, subject to degradation, siltation, and pollution. Invasive mussels continue to threaten the Lake St. Clair delta population and could be a threat to populations in the Grand and Thames rivers if they invade upstream reservoirs.
Occurrence: Ontario
COSEWIC status history: Designated Endangered in April 1999. Status re-examined and confirmed in October 1999. Status re-examined and designated Special Concern in April 2010.

COSEWIC assessment summary – April 1999

Common name: Northern Riffleshell
Scientific name: *Epioblasma torulosa rangiana*
COSEWIC status: Endangered
COSEWIC reason for designation: 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
COSEWIC status history: Designated Endangered in April 1999.

COSEWIC assessment summary – May 2001

Common name: Snuffbox
Scientific name: *Epioblasma triquetra*
COSEWIC status: Endangered
COSEWIC reason for designation[1]: Declines in extent of occurrence, area of occupancy and number of extant locations; total population extremely fragmented, all four extant sites in one river (Sydenham River); entire population could be eliminated by a single upstream catastrophic event. Habitats already exposed to high silt loading from agricultural practices and pollution from point and non-point sources.
Occurrence: Ontario
COSEWIC status history: Designated Endangered in May 2001.

COSEWIC assessment summary – May 2004

Common name: Round Pigtoe
Scientific name: *Pleurobema sintoxia*
COSEWIC status: Endangered
COSEWIC reason for designation: Species limited to a small area of occupancy in the Lake St. Clair and three watersheds in southern Ontario with continuing declines in habitat area, extent and quality. Threats include urban, industrial and agricultural development and irreversible impacts from zebra mussels in Lake St. Clair, with potential threats from introduction of zebra mussels in impoundments in the Sydenham River.
Occurrence: Ontario
COSEWIC status history: Designated Endangered in May 2004. Assessment based on a new status report.

COSEWIC assessment summary – May 2011

Common name: Salamander Mussel[2]
Scientific name: *Simpsonaias ambigua*
COSEWIC status: Endangered
COSEWIC reason for designation: This freshwater mussel was reported from two rivers in southern Ontario in 1998. Surveys since the original COSEWIC assessment (2001) have found live individuals still along the Sydenham River. Despite extensive additional sampling, the half-shell found in 1998 is the only evidence of this species along the Thames River. Habitat quality continues to decline from intense agriculture, urban development, and pollution from point and non-point sources. In addition, this mussel only uses the Mudpuppy, a salamander as its host; threats to the host are also threats to the mussel.
Occurrence: Ontario
COSEWIC status history: Designated Endangered in May 2001. Status re-examined and confirmed in May 2011.

[1] A small reproducing population has been confirmed in the Ausable River since the 2001 assessment.
[2] Previously known as the Mudpuppy Mussel.

COSEWIC assessment summary – April 2010

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

1.2. Threats

1.2.1. Threats to the species

Table 1 is an assessment of the threats to extant populations of the Wavyrayed Lampmussel (*Lampsilis fasciola*) as found in the previously published recovery strategy (Morris 2006), while Table 2 is an assessment of the threats to extant populations of the Northern Riffleshell (*Epioblasma torulosa rangiana*), Snuffbox (*Epioblasma triquetra*), Round Pigtoe (*Pleurobema sintoxia*), Salamander Mussel (*Simpsonaias ambigua*), and the Rayed Bean (*Villosa fabalis*) in the Sydenham and Ausable rivers, as found in the previously published recovery strategy (Morris and Burridge 2006).

Table 1. Threats to the Wavyrayed Lampmussel in Canada. Taken from Morris (2006).

Threat	Relative impact predominant/ contributing	Spatial/temporal widespread/local chronic/ephemeral	Certainty probable/speculative/ unknown
Siltation/suspended solids	predominant	widespread/chronic	probable
Exotics	predominant	local/chronic	probable
Impoundments	contributing	local/chronic	probable
Water quality – contaminants & nutrients	contributing	widespread/chronic	probable
Disruption of host fish relationship	contributing	local/chronic	speculative
Predation	contributing	local/ephemeral	speculative
Urbanization	contributing	local/ephemeral	speculative
Recreational activity	contributing	local/ephemeral	unknown

Table 2. Threats to Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean in Canada. Taken from Morris and Burridge (2006).

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

1.2.2. Threats to critical habitat

Note that critical habitat was not identified in the original recovery strategies for these species but is in the process of being identified, to the extent possible, in an updated proposed recovery strategy for the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean (herein referred to as the ”five mussel” recovery strategy) (DFO 2012). Critical habitat will not be identified for the Wavyrayed Lampmussel as it was re-assessed as Special Concern by the Committee on the Status of Endangered Wildlife in Canada in 2010 and its status was changed accordingly in the SARA list of wildlife species at risk in 2012. The identification of critical habitat is not required for Special Concern species. As critical habitat had not been identified by Morris (2006) and Morris and Burridge (2006), the original recovery strategies referenced threats to currently occupied habitat, which are summarized below.

Critical habitat for these six species could be negatively affected by a wide variety of activities. Some of the more probable and potentially deleterious threats to their habitat were identified in the recovery strategies and include the following:

- Direct habitat destruction could result from in-stream activities such as dredging, bridge and pipeline crossings or the construction of dams.

- Water quality or availability can be negatively affected by land-based activities, such as the input of nutrients, sediment and toxic substances through improperly treated storm water, cultivation of riparian lands, unfettered access of livestock to the river, channelization and drainage works, water taking, aggregate extraction and the release of improperly treated sewage.

- Any activity that disrupts the connectivity between mussel populations and their host species (e.g., various darter species), which can be considered habitat for mussels during the glochidial stage, may result in the destruction of habitat. Such activities can include damming, dewatering and sport or commercial harvest activities that harm host species.

2. Recovery

2.1. Recovery goals and objectives

Recovery goal

The long-term recovery goals as stated in the original recovery strategy for the five mussels (Morris and Burridge 2006) are:

i. To prevent the extirpation of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander 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;
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;
v. To return/maintain healthy self-sustaining populations of Salamander 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.

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.

The long-term recovery goals as stated in the original recovery strategy for the Wavyrayed Lampmussel (Morris 2006) are:

i. Protecting existing populations to prevent further declines;
ii. Restoring degraded populations to healthy self-sustaining levels by improving the extent and quality of habitat; and,
iii. Re-introducing the Wavyrayed Lampmussel into areas where it formerly existed where feasible.

Recovery objectives (short-term: 5-years)

For the five mussels:

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 habitats and those of their hosts;
v. Confirm/Identify threats, evaluate their relative importance and implement remedial actions to minimize their impacts;
vi. Examine the feasibility of relocations, reintroductions and the establishment of managed refuge sites; and,
vii. Increase awareness about the distribution, threats and recovery of these species.

For the Wavyrayed Lampmussel:

i. Determine extent, abundance and population demographics of existing populations;

ii. Determine/confirm fish hosts, their distributions and abundances;
iii. Define key habitat requirements to identify critical habitat;
iv. Establish a long-term monitoring program for Wavyrayed Lampmussel, its habitats and that of its hosts;
v. Identify threats, evaluate their relative impacts and implement remedial actions to reduce their effects;
vi. Examine the feasibility of relocations, reintroductions and artificial propagation; and,
vii. Increase awareness of the significance of the Wavyrayed Lampmussel and its status as a Canadian Species at Risk.

2.2. Performance measures

Performance measures were not identified in the original recovery strategies, therefore progress will be measured against the stated short-term recovery objectives as listed above (Section 2.1. Recovery objectives).

3. Progress towards recovery

The original recovery strategies for the Wavyrayed Lampmussel and five mussel species divided the recovery approaches into four categories: Research and Monitoring, Management, Stewardship, and Awareness. Progress in each of these four categories is addressed separately (Sections 3.1-3.4, Tables 3-6), providing a summary of the implementation of the documented recovery approaches. The emphasis of the current progress review is on approaches that were deemed Urgent and, where applicable, Necessary and Beneficial in the original recovery strategies. The assessment of Stewardship Activities (Section 3.3, Table 5) has been subdivided by watershed as these activities have been performed by distinct groups operating within watersheds. Due to the overlap in recovery approaches, instead of generating four separate tables for each recovery strategy, specific steps towards recovery of the Wavyrayed Lampmussel have been included in the tables that were derived from the five mussels' recovery strategy. Approaches that were prioritized as urgent in the Wavyrayed Lampmussel recovery strategy and not contained within the five-mussel recovery strategy have been included in the most suitable table category. The listing of results is meant to touch briefly on some of the more significant accomplishments and is not meant to be exhaustive.

3.1. Research and monitoring activities

Table 3. Research and monitoring activities conducted/ongoing since the completion of the recovery strategies. WRL = Wavyrayed Lampmussel; NRS = Northern Riffleshell; SB = Snuffbox; RPT = Round Pigtoe; SM = Salamander Mussel; RB = Rayed Bean.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
(1-1) Continue fish host testing for the Snuffbox, Northern Riffleshell, Round Pigtoe and Rayed Bean (including Wavyrayed Lampmussel)					
Development of experimental protocol to test fish host (2006-2011)	i, ii, iv, v	• Experimental protocol developed for screening fish hosts • Determined fish hosts for WRL, NRS, SB, and RB in the laboratory • Determined most productive fish hosts for WRL, NRS and SB	U of G	CWF, DFO, EC, OMNR[3], WWF	In progress; McNichols (2007); McNichols et al. (2011)
Fish host identification	ii	• Iowa Darter (*Etheostoma exile*) is a preferred fish host for the NRS, no preferences found for RB • Length of glochidial attachment determined for NRS and SB • Determined the settling velocity of glochidia and juvenile mussel species at risk (WRL) • Determined presence and gravidity periods of species at risk (SAR) mussels in the Sydenham, Grand, Ausable, Maitland and Thames rivers (gravidity observed in WRL, NRS, SB and RB)	U of G	CWF, DFO, EC, OMNR, WWF	In progress; Morris and Granados (2007); McNichols (2007); Castanon et al. (2011); McNichols et al. (2011); Schwalb and Ackerman (2011)
(1-2) Determine the distribution and abundance of the host species					
Observed host fish and their distribution	ii	• Examined the dispersal relationships among SB and their host fish (Logperch [*Percina caprodes*]) • Logperch remain in small areas, limiting the dispersal of SB	U of G	DFO, NSERC	Schwalb (2009); Schwalb et al. (2010)
Collection of fish data in Sydenham, Thames, and Ausable rivers (2007)	ii	• Host fish population data gathered and levels of encystment recorded • Host fish predictive models developed for WRL, NRS, SB and RB; model ground-truthing initiated • Functional connectivities calculated for RB, SB and NRS in Sydenham River, WRL in the Thames River and the SB in the Ausable River	Trent U., U of G	DFO, EC, NSERC, OMNR, WWF	Woolnough et al. (2007)

Table 3 (Con't). Research and monitoring activities conducted/ongoing since the completion of the recovery strategies. WRL = Wavyrayed Lampmussel; NRS = Northern Riffleshell; SB = Snuffbox; RPT = Round Pigtoe; SM = Salamander Mussel; RB = Rayed Bean.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
(1-2) Determine the distribution and abundance of the host species					
Host fishes surveyed in the Ausable River (2009)	ii	• Host fish distributions assessed	ABCA, DFO	ABCA, DFO, OMNR, SARRFO	Upsdell et al. (2011)
Host fishes study conducted for the Upper Thames River (2011-2012)	ii	• Host fish status and distribution assessed for WRL, RP, and RB	UTRCA	OMNR	Schwindt 2012
Miscellaneous fish surveys (2006-2011)	ii	• Host species distribution and abundance data have been compiled as a result of non-specific fish sampling within the range of these six mussel species	e.g., DFO, OMNR, Trent U, U of G, U of T, UTRCA	e.g., DFO, NSERC, OMNR, WWF	e.g., Poos et al. (2010)
(1-3) Determine the habitat requirements for all life stages (critical habitat identification)					
Channel stability assessed and mussels and host fishes surveyed in the Ausable River (2009)	i, ii	• Increased understanding of the influence of geomorphology on mussel and host fish distributions • Comparison of mussel surveys to past efforts accomplished	ABCA, DFO	ABCA, DFO, OMNR, SARRFO	Upsdell et al. (2011)
Investigating early life stages	iii	• Early life stages of WRL in the Grand River examined to determine how sediment and water column processes influence the settlement and delivery of both glochidia and juvenile mussels	DFO, U of G, U of W	DFO, NSERC, SARRFO, WWF	Schwalb and Ackerman (2011); Schwalb et al. 2012
Refinement and inquiry into environmental conditions for all life stages	iii	• Chloride and copper limits refined • Increased knowledge of dissolved oxygen, flow and substrate requirements	EC, McMaster U, U of G	CDA, DFO, EC, WWF	Gillis et al. (2008); Gillis et al. (2010); Gillis (2011)
Measurement of chemical/physical characteristics of rivers and hyporheic zones	iii	• Characterization of surface and groundwater to aid identification of critical habitat	U of G	CWF, DFO, OMNR	In progress
Investigating reproductive attributes	iii, v	• Timing and water temperatures of gravid females observed (WRL, NRS, SB, RB)	U of G	CWF, DFO, EC, OMNR, WWF	McNichols (2007); Castanon et al. (2011)
(1-4) Prepare a distribution map of areas of suitable habitat (critical habitat identification)					
Mapping exercises for the Ausable River watershed (2008)	i, iii	• Development of suitable habitat criteria and mapping for NRS, SB and RB • Surveys for SB and RB completed	ABCA, DFO	ABCA (in kind), ABCF, DFO, OMNR, TTLT, WWF	Upsdell et al. (2010)

Table 3 (Con't). Research and monitoring activities conducted/ongoing since the completion of the recovery strategies. WRL = Wavyrayed Lampmussel; NRS = Northern Riffleshell; SB = Snuffbox; RPT = Round Pigtoe; SM = Salamander Mussel; RB = Rayed Bean.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
(1-6) Examine the feasibility of translocations and reintroductions (1-10) 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.					
Developing methods of artificial propagation in the laboratory (2008-11)	i, ii	• Successfully transformed and attempted to rear juvenile WRL, SB, NRS and RB • Developed new re-circulating system for rearing juvenile mussels, including determination of the role of substrate in the rearing process • Determined water source and optimal diet for rearing juvenile mussels	U of G	CWF, DFO, OMNR	In progress
Developing methods of artificial propagation in the field (2008-11)	iv	• Confirmed success of field enclosures • Determined methods for rearing infested fishes overwinter and successfully obtaining juvenile mussels	U of G	CWF, DFO, OMNR	In progress
Examined the dispersal ability of mussels and their conservation status	i, ii and v	• Found that, in southwestern Ontario, the mussels with the most precarious conservation status relied on host fishes that had short movement distances • Results suggest dispersal limitations should be included in conservation and management decisions	U of G	DFO, NSERC	In progress; Schwalb (2009); Schwalb et al. (2011, 2012)
Review of literature of genetic and environmental implications of reintroductions (2008)	v, vi	• Recommendations made to preserve genetic variability, maintain population fitness and reproductive success for future reintroductions	DFO, U of G	DFO	Hoftyzer et al. (2008)
Optimization of genetic techniques	vi	• Assessed methods for obtaining genetic material along with genetic marker development and optimization • Preliminary population analysis completed for SB • DNA extraction and amplification procedures for glochidia investigated	CMU, Trent U, U of G	DFO, NSERC, OMNR, WWF	In progress; McNichols et al. (2010)
Genetic characterization of mussel species	vi	• Description of the population structure of WRL, NRS and SB from Canadian and U.S. locations • Recommendations on conservation implications	ROM	DFO, IRF, NSERC	Zanatta and Murphy (2006, 2007, 2008); Zanatta et al. (2007)

Table 3 (Con't). Research and monitoring activities conducted/ongoing since the completion of the recovery strategies. WRL = Wavyrayed Lampmussel; NRS = Northern Riffleshell; SB = Snuffbox; RPT = Round Pigtoe; SM = Salamander Mussel; RB = Rayed Bean.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
(1-6) Examine the feasibility of translocations and reintroductions (1-10) 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.					
Determination of co-evolutionary relationship between mussel and host fish	vi	• Comparison of geographic genetic structure of SB and their host fish (Logperch) • Repercussions to mussel reintroduction and augmentation discussed	CMU, OMNR	FRCE, NSERC, OMNR	Zanatta and Wilson (2011)
(1-7) Establish a network of permanent monitoring stations throughout historical and present ranges. (1-8) Establish permanent monitoring sites for tracking changes in habitat.					
Ausable River watershed monitoring program development (2006-2008)	i, iv	• Seven permanent monitoring stations established • Baseline density estimates and population demographics established for NRS and SB • A monitoring program was developed for the Ausable River • Physical site characteristics (e.g., substrate type, water depth and velocity) were related to mussel presence	ABCA, DFO	ABCA (in kind), DFO, IRF	Baitz et al. (2008)
Survey monitoring stations in the Ausable River watershed (2011)	i, iv	• Seven permanent monitoring stations surveyed five years after they were established • Preliminary data show a possible decline in mussel densities	ABCA, DFO	ABCA, ABCF, DFO, HSP, OMNR	In progress; Upsdell et al. (2012)
Grand River monitoring program establishment and implementation (2007 - present)	i, iv	• Four index stations were established in the upper Grand River • Mussel communities and reproduction were assessed at each site (WRL was the dominant species in three of four sites) • No SB or RPT encountered	DFO	DFO	MS in preparation: Morris and McNichols-O'Rourke (In Prep.)
Sydenham River monitoring program establishment and implementation (1999-2007, 2012)	iv	• A monitoring program was developed for the Sydenham River • 15 stations established • Physical site characteristics (e.g., substrate type, water depth and velocity) were related to mussel presence	EC	DFO, IRF	Metcalfe-Smith et al. (2007b)

Table 3 (Con't). Research and monitoring activities conducted/ongoing since the completion of the recovery strategies. WRL = Wavyrayed Lampmussel; NRS = Northern Riffleshell; SB = Snuffbox; RPT = Round Pigtoe; SM = Salamander Mussel; RB = Rayed Bean.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
1-7) Establish a network of permanent monitoring stations throughout historical and present ranges. (1-8) Establish permanent monitoring sites for tracking changes in habitat.					
Thames River monitoring program establishment and implementation and expansion of Grand River monitoring program (2010)	i, iv	• Surveys were completed in the lower Grand and Thames river systems • No SB, SM or RB encountered; RPT found in the Grand River (2010 and 2011) and the Thames River (2010); WRL found in the Grand River (2010) • Six permanent monitoring stations were established on the lower Thames River and three on the lower Grand River	DFO	DFO	MS in preparation: Morris and McNichols-O'Rourke (In Prep.)
WRL monitoring program in the Maitland River establishment and implementation (2008)	i, iv	• Index monitoring stations established throughout the range of the WRL in the Maitland River watershed • Critical information provided on the size, density and reproductive status of this population as well as vital information on habitat use	DFO	DFO	Report in progress
St. Clair River delta (Walpole Island) monitoring program establishment and implementation (2003 - 2011)	iv	• A monitoring program was developed for the St. Clair delta • Nine sites were established in the Canadian waters of the delta in 2003-2004 • Eight of these sites were revisited in 2011 • Established to assess population changes and monitor threat of Dreissenid mussels • Studies reveal that, despite declining Dreissenid levels, freshwater mussels continue to decline.	DFO, EC, WIFN	DFO, WWF	MS in preparation; Metcalfe-Smith et al. (2007a)
Surveys in the lower Thames and Grand river systems (2010)	i	• Exploration of new methods (dredging and trawling) for sampling lower river mussel populations • Due to low unionid densities and unfavourable habitat conditions, these methods are not being further investigated	DFO	DFO	N/A
Mussel surveys – Welland River (2008)	i	• Surveys were completed in the Welland River drainage • No WRL, NRS, SB, RPT, SM, RB encountered	DFO	DFO	Morris et al. (2012b)
Mussel surveys – Bayfield River, Nottawasaga River (2007-2009)	i	• Surveys were completed in the Bayfield River and Nottawasaga River drainages • No WRL, NRS, SB, RPT, SM, RB encountered	DFO	DFO	Minke-Martin et al. (2012); Morris et al. (2012a)

Table 3 (Con't). Research and monitoring activities conducted/ongoing since the completion of the recovery strategies. WRL = Wavyrayed Lampmussel; NRS = Northern Riffleshell; SB = Snuffbox; RPT = Round Pigtoe; SM = Salamander Mussel; RB = Rayed Bean.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
1-7) Establish a network of permanent monitoring stations throughout historical and present ranges. (1-8) Establish permanent monitoring sites for tracking changes in habitat.					
Abundance and population demographic determination	i	• Marked and measured the size of all SAR mussels found in the field, which provided mark-recapture and growth data	U of G	CWF, DFO, EC, OMNR WWF	In progress; McNichols (2007); Castanon et al. (2011); McNichols et al. (2011)
(1-9) Identify and evaluate threats to all life stages.					
Determine the sensitivity of glochidia to copper and examine the role of dissolved organic carbon in protecting mussels from acute copper exposure. (2006-2010)	iii, v	• Increased understanding of toxicity of copper to glochidia (including WRL, NRS, SB and RB), including the influence of water hardness and dissolved organic carbon on copper sensitivity • Compiled data on copper levels (and other water chemistry parameters) in key mussel habitats in Ontario and compared to concentrations shown to be toxic to larval mussels • Determined that the levels of water hardness and dissolved organic carbon in many mussel habitats in southern Ontario will provide protection from copper exposure, but episodic pulses or spills may exceed protective capacity	EC, U of G	CDA, DFO, WWF	Gillis et al. (2008, 2010)
Assess the effect of environmentally relevant chronic copper exposure on juvenile freshwater mussels (2010-2011)	iii, v	• Assessed effects of copper on survival and growth, as well as biomarkers of metal exposure, respiration and oxidative stress • Determined the toxic mode of action of copper in juvenile mussels	EC, Federal U of Rio Grande (Brazil), McMaster U.	CRC Program, IDRC	MS in preparation: Jorge et al. (In Prep.)
Examine the impact of urban inputs (municipal wastewater effluents and road runoff) on wild mussel health (2008-2011)	iii, v	• Demonstrated significantly reduced condition factor and mussel age and some impacts on immune status in mussels living downstream of multiple municipal wastewater effluents and urban runoff when compared to mussels from upstream locations	EC	EC	MS in review: Gillis (In Review)

Table 3 (Con't). Research and monitoring activities conducted/ongoing since the completion of the recovery strategies. WRL = Wavyrayed Lampmussel; NRS = Northern Riffleshell; SB = Snuffbox; RPT = Round Pigtoe; SM = Salamander Mussel; RB = Rayed Bean.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
(1-9) Identify and evaluate threats to all life stages.					
Studying the sensitivity of glochidia to road salt run-off and assessing the potential for chloride induced toxicity in mussel habitats (2008-2011)	iii, v	• Assessed the toxicity of sodium chloride (NaCl) to various mussel glochidia (including NRS and WRL) • Compiled data on chloride levels for key mussel habitats in Ontario and compared to concentrations shown to be acutely toxic to larval mussels • Determined that chloride levels in some mussel habitats in southern Ontario reach levels acutely toxic to glochidia • Provided results to the CCME for the development of the Chloride Canadian Water Quality Guidelines for the Protection of Aquatic Life	EC	EC	Gillis (2011)
Examine the effect of municipal wastewater effluents on caged freshwater mussels (2010-2011)	iii, v	• Deployed (i.e., caged) mussels both upstream and directly downstream of the outfall of municipal wastewater effluent outfalls in multiple rivers • Results of an assessment of biomarkers of stress and immune status of field-deployed mussels are pending	EC, Trent U., U of A, UNB, U of O, U of W	CWN, EC	MS in preparation: Gillis et al. (In Prep.)
Identify those exotic species than may be deleterious to SAR mussels	ii, v	• The Round Goby (*Neogobius melanostomus*) was tested as a host fish for WRL, RB, SB and NRS • The Round Goby has been identified as a threat to mussel populations due to the potential disruption of their reproductive cycle	DFO, OMNR, U of G, U of T	DFO, NSERC, OGS, OMNR, Trent U, WWF	McNichols et al. (2010); Poos et al. (2010)
Quantify sediment and nutrient inputs from agricultural drainage systems and point sources	v	• Research on sediment and nutrient input has informed recommendations for more effective strategies for reduction of loading to rivers	AAFC, DFO	AAFC, IRF	Ball Coelho et al. (2010)

[1] Refers to all relevant recovery objectives from the recovery strategies as stated within Section 2.1 [2] For a list of acronyms see ACRONYMS [3] OMNR funding may have come various OMNR sources, such as: Species at Risk Stewardship Fund, Species at Risk Research Fund, Aquatic Research and Development Section, Biodiversity Branch, Southern Region etc.

3.2. Management activities

Table 4. Management activities conducted/ongoing since the completion of the recovery strategies.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
(2-1) Promote and enhance expertise in freshwater mussel identification/biology and provide for the transfer of knowledge.					
Ontario Freshwater Mussel Identification Workshop	vii	• DFO freshwater mussel identification course has been developed and trained over 200 people	DFO, EC, U of T	DFO	N/A
Development of a Canadian Freshwater Mussel Guide	vii	• A national freshwater mussel identification application for smartphone devices is under development	DFO, LU	DFO	N/A
Development of Ontario Field Guide	vii	• A freshwater mussel field-guide has been produced and is being promoted	EC, DFO, NHIC, SCRCA, SCRCF, STFN	EC, HSP, OMNR[3], SCRCF, STFN	Metcalfe-Smith et al. (2005)
Mussel sampling standardization and relocation techniques	i, iv, vi	• Publication of protocols and methods for addressing the presence and relocation of mussel species	DFO, U of G	DFO	Mackie et al. (2008)
(2-2) Work with existing ecosystem recovery teams to implement recovery actions.					
Collaborative efforts; further details are contained in Section 3.3 (ongoing)	v	• Ongoing collaboration with applicable recovery teams (e.g., Sydenham and Ausable rivers) on stewardship and research activities has maximized knowledge and resource transfer and minimized redundancy	ABCA, DFO, ERCA, GRCA, SCRCA, UTRCA	HSP, OMNR	N/A
Other Activities:					
Proclamation of *Ontario's Clean Water Act*	v	• The *Act*, which came into effect in 2006, protects Ontario's source water via local committees that list existing and potential threats and implement actions that will reduce or eliminate these threats • Based on sound science, this approach allows for communities to take a "hands on" approach to conserve and protect their own watersheds	OMOE	N/A	OMOE (2012)

[1] Refers to all relevant recovery objectives from the recovery strategies as stated within Section 2.1 [2] For a list of acronyms see ACRONYMS [3] OMNR funding may have come various OMNR sources, such as: Species at Risk Stewardship Fund, Species at Risk Research Fund, Aquatic Research and Development Section, Biodiversity Branch, Southern Region etc.

3.3. Stewardship activities

Table 5. Stewardship activities conducted/ongoing since the completion of the recovery strategies.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
Ausable River watershed					
Habitat enhancement and protection programs in the Ausable River watershed (2005-2009; ongoing)	v	• These projects resulted in the protection or improvement of nearly 60 km^2 of habitat or riparian zone and approximately 36 km of shoreline • Project examples include agricultural equipment modification, livestock restriction from watercourses and tree planting • Impacts of stewardship programs are being evaluated by the collection and monitoring of water quality and mussels	ABCA, DFO	HSP plus matching funds (e.g., OMNR[3]), private landowners	N/A
Sydenham River watershed					
Best management practices on watershed lands in Sydenham River watershed (2001-2010; ongoing)	v	• Best management practices on rural properties, including livestock restrictions, riparian buffers, streambank stabilization, wetland creation or enhancement, well decommissioning, septic upgrades and sediment control/trapping • The implementation of these best management practices have translated to over 2.9 km^2 of habitat or riparian zone protected or improved, 55 km of shoreline restored, 14 wells decommissioned, 23 septic systems upgraded, nine manure storage facilities improved and 20 km of watercourse restricted from livestock access	DFO, RLSN, SCRCA	DUC, HSP, OMNR, SCRCA (in kind), private landowners	N/A

Table 5 (con't). Stewardship activities conducted/ongoing since the completion of the recovery strategies.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
Thames River watershed					
Habitat Stewardship Programs in the upper Thames River watershed (2003-2009; ongoing)	v	• Water quality improvement through agricultural best management practices and projects, including milkhouse washwater system installation, livestock fencing and clean water diversion • Fish and benthos sampling was undertaken to provide insight into the effectiveness of habitat improvement efforts • Water quality improvements have been noted in several portions of the watershed	UTRCA	HSP plus matching funds (e.g., OMNR), private landowners	UTRCA (2010)
Grand River watershed					
Habitat enhancement and protection programs in the Grand River watershed (2005-2010)	v	• Tree planting and the promotion of nutrient management plans • Improvement of water quality and increased riparian habitat	GRCA	HSP plus matching funds (e.g., OMNR), private landowners	N/A

[1] Refers to all relevant recovery objectives from the recovery strategies as stated within Section 2.1 [2] For a list of acronyms see ACRONYMS [3] OMNR funding may have come various OMNR sources, such as: Species at Risk Stewardship Fund, Species at Risk Research Fund, Aquatic Research and Development Section, Biodiversity Branch, Southern Region etc.

3.4. Awareness activities

Table 6. Awareness activities conducted/ongoing since the completion of the recovery strategies.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
(4-1) Increase public knowledge of stewardship options and financial assistance available to participate in activities. (4-3) Encourage public support and participation by developing awareness materials and programs.					
Increase awareness through public outreach in Ausable River watershed (2006-2011)	vii	• Multipronged promotion of HSP (e.g., article on HSP included in ABCA's "Your Watershed" publication, display boards at community events, flyer distribution, public service announcements and press releases) • Annual meeting of Stewardship and Outreach Recovery Implementation Group to coordinate efforts and foster partnerships • Increase student awareness and engagement by delivering information regarding natural heritage, distribution, threats and recovery of mussel SAR	ABCA	A Channel (in kind), ABCA (in kind), ABCF, HSC, HSP, OMNR[3]	N/A
Increase awareness through public outreach in Sydenham River watershed (2006-2011)	vii	• Annually, 65 000 landowners and community members are provided with the SAR newsletter • Community outreach through activities, such as media releases, public service announcement and the maintenance of the sydenhamriver.on.ca website	DFO, RLSN, SCRCA	HSP, OMNR, SCRCA (in kind)	N/A
Walpole Island Heritage Centre (WIHC) stewardship and outreach	i, vii	• Provided presentations on threats and protection measures to Walpole Island First Nation schools and gatherings on SAR found in their area • Mussel identification workshop and local surveys were performed to help raise awareness	WIFN	OMNR	WIHC (2009, 2010)
Increase awareness through public outreach in Thames River watershed (2006-2011)	vii	• Outreach on species at risk using public service announcements on CFPL-TV was estimated to reach at least 855 000 viewers per week • Species-specific community education and awareness through multimedia presentations to schools, community groups, special interest groups, and at public events is estimated to have reached over 5000 individuals • The yearly Thames River Clean Up (approximately 2000 yearly participants) has harnessed public interest and support to remove garbage from up to 200 km of river shoreline each year	UTRCA	HSP + matching funds (e.g., OMNR)	N/A

Table 6 (con't). Awareness activities conducted/ongoing since the completion of the recovery strategies.

Activities	Recovery objectives addressed[1]	Results[2]	Agencies involved[2]	Funding sources[2]	References
(4-2) Increase public awareness of the potential impacts of transporting/releasing exotic species.					
Implementation of the Invasive Alien Species Strategy (ongoing)	vii	• Dissemination of aquatic invasive species information through the Watercraft Inspection Program • Distribution of aquatic invasive species educational information through public postings and direct engagement	DFO	DFO	N/A
Implementation of Hazard Analysis and Critical Control Point (HACCP) training	vii	• Licensed commercial baitfish harvesters in Ontario have completed HACCP training, which focuses on impacts and prevention of the spread of aquatic invasive species • As of 2006, baitfish licence holders must prepare a Hazard Analysis and Critical Control Point (HACCP) plan to address the threat of invasive species associated with their operations	BAO, OFAH, OMNR	OMNR	N/A
Other Activities:					
Conference presentations (2007-2011)	vii	• Presentations delivered at multiple conferences (e.g., ASLO, NABS, FMCS, SETAC, ATW), which forged connections with the academic community, including graduate students	N/A	DFO, EC, NSERC, OMNR, WWF	See listings
Presentations to naturalist groups, schools, etc.	vii	• Presentations delivered to multiple groups (e.g., Niagara restoration council, Halton Peel Naturalists, Nature London, Our Lady of Fatima Elementary School)	DFO	DFO	See listings

[1] Refers to all relevant recovery objectives from the recovery strategies as stated within Section 2.1 [2] For a list of acronyms see ACRONYMS [3] OMNR funding may have come various OMNR sources, such as: Species at Risk Stewardship Fund, Species at Risk Research Fund, Aquatic Research and Development Section, Biodiversity Branch, Southern Region etc.

3.5. Summary of progress towards recovery

An overview of progress towards each short-term recovery objective is presented below. As the recovery objectives from the five-mussel and Wavyrayed Lampmussel recovery strategies are nearly identical they have been addressed concurrently.

i. Determine extent, abundance and population demographics of existing populations.

Recent sampling of Wavyrayed Lampmussel populations in the Grand, Maitland (Morris, unpubl. data) and Ausable rivers (Baitz et al. 2008) has occurred involving more detailed and extensive quantitative surveys than used in previous sampling efforts. As a result, estimates of area of occupancy and density have been generated for populations of the Ausable, Grand, Maitland and Thames rivers watersheds (see COSEWIC 2010). From this work it appears that populations in the Grand, Maitland and Thames rivers are larger than originally believed and recruitment is occurring. A fuller understanding of the population demographics of these species has occurred with the cataloging of size and age class distributions and sex ratios. Additionally, for the Wavyrayed Lampmussel, this knowledge has allowed for population modelling to assess allowable harm, determine population-based recovery targets and conduct long-term projections of population recovery (Young and Koops 2010).

Recent surveys have updated the known distribution of the Northern Riffleshell. It has been encountered over a 60 km reach of the Ausable River at a density of approximately $0.029m^{-2}$ (S. Staton et al., DFO, unpubl. data), while a few live specimens have been encountered over a 122 km reach of the Sydenham River at a density of approximately $0.091m^{-2}$ (Metcalfe-Smith et al. 2007b).

The Snuffbox is currently known to occur in a 122 km reach of the Sydenham River and at four sites within a 100 km reach of the Ausable River. From 2002 to 2009, sections of the East Sydenham River were intensively resurveyed during searches for gravid females and the total number of live animals captured was found to be more than 200 (J. Ackerman, University of Guelph, unpubl. data). In 2006, quantitative surveys at seven different sites in the Ausable River were completed and 26 live Snuffbox were found at four of these, making this the second reproducing population in Canada (Baitz et al. 2008).

It now appears that the Rayed Bean is restricted to a 122 km reach of the East Sydenham River and a 13 km reach of the North Thames River.

Updated information on the Round Pigtoe and Salamander Mussel is lacking.

Further surveys have been performed in significant habitat of mussel species at risk where some or all of the six species are thought to be extirpated, namely the Grand, Welland and Thames rivers. These surveys did not yield any new records of species believed to be extirpated.

ii. Determine host fishes and their distributions and abundances.

The work of the research group dedicated to unionids at the University of Guelph (led by Drs. Ackerman and Mackie) has resulted in additional information pertaining to the host fishes of these species in the laboratory. The Iowa Darter and Mottled Sculpin (*Cottus bairdii*) appear to be the primary host fishes for the Northern Riffleshell, while the Smallmouth Bass (*Micropterus dolomieu*) may serve this function for the Wavyrayed Lampmussel (McNichols et al. 2011). Infestation experiments have shown that the primary and most likely functional host of the Snuffbox mussel is the Logperch (McNichols 2007, Schwalb et al. 2011). No potential host fishes have been tested for the Round Pigtoe as gravid females have not been located. For the Rayed Bean, the Greenside Darter (*E. blennioides*), Rainbow Darter (*E. caeruleum*), and Logperch have been confirmed as hosts during repetitive studies (McNichols 2007). Furthermore, the Round Goby, an exotic species, may serve as a host fish for these mussel species, with further investigations ongoing (McNichols et al. 2010).

Additional research is needed to fully identify primary hosts (i.e., high infestation and metamorphosis rates for glochidia and juvenile mussels) and marginal hosts (i.e., low rates), as well as to confirm functional hosts (e.g., distributional overlap between species, availability and density). Furthermore, there may be other species that act as hosts for these six mussel species that have yet to be examined in Canada.

Numerous fish surveys, both targeted and otherwise, have been performed in the Ausable, Thames and Sydenham rivers. Data from these surveys can provide a clearer understanding of population characteristics and ranges for known host fishes for these six mussel species at risk.

Research on the functional connectivity of mussel species at risk and their fish hosts has resulted in the production of host fish predictive models that indicate there are river reaches (>100 m) in the Sydenham and Ausable rivers where recovery habitat may be possible.

iii. Define key habitat requirements to identify critical habitat.

Recent sampling of Wavyrayed Lampmussel has resulted in a clearer understanding of habitat requirements of the species. Although these surveys have contributed information necessary for the identification of critical habitat, it has not been identified for Wavyrayed Lampmussel at this time. As this species has been down-listed (from Endangered to Special Concern under SARA), an identification of critical habitat is not required.

The five-mussel recovery strategy is in the process of being updated to include a partial identification of critical habitat for all species, to the extent possible (DFO 2012). The approach and the methods used to identify reaches of critical habitat will be consistent with the approaches recommended by DFO (2011) for freshwater mussels.

Critical habitat identification is in progress for riverine populations of the five mussel species within the following watersheds:

1. Sydenham River (all five species)
2. Ausable River (Northern Riffleshell and Snuffbox)
3. Thames River (Round Pigtoe and Rayed Bean)

4. Grand River (Round Pigtoe)

The areas to be identified may be insufficient to achieve the recovery objectives for these species. As such, the schedule of studies will be updated to further refine the description of critical habitat (in terms of its biophysical functions, features and attributes, as well as spatial extent) to support its protection. Additional areas of potential critical habitat within the St. Clair River delta will be considered in collaboration with Walpole Island First Nation.

iv. Establish a long-term monitoring program for all species, their habitats and those of their hosts.

To meet this objective, monitoring stations have been established and baseline data collected in the Ausable River (seven stations), Sydenham River (15), Thames River (six), and Grand River (seven) (Metcalfe-Smith et al. 2007b, Baitz et al. 2008, T. Morris, DFO, unpubl. data). Additionally, nine stations have been established in the St. Clair River delta (Metcalfe-Smith et al. 2007a). These monitoring programs include provisions for the assessment of host fish populations, as well as mussel and host fish habitat monitoring.

v. Confirm/identify threats, evaluate their relative importance and implement remedial actions to minimize their impacts.

Various aspects of chemical contamination have been investigated. It is now thought that the glochidial stage is the most vulnerable and specialized life stage, because it is during this stage that the mussels must successfully attach to an appropriate host to complete their metamorphosis to the juvenile stage and that they are most sensitive to contaminant exposure (Gillis et al. 2008, 2010, Gillis 2011).

Threats from exotic species, such as the Round Goby, have also been identified (Poos et al. 2010); a graduate student at the University of Guelph is currently studying the potential impacts of Round Goby on mussel species at risk. In the Thames River, Dreissenid mussels can now be found from Fanshawe Reservoir downstream to Thamesville (UTRCA 2012). In the lower Thames River near Big Bend, Zebra Mussel (*Dreissena polymorpha*) have been found attached to adult unionids (Morris and Edwards 2007).

Nutrient and sediment enrichment may not be the only threats to mussel species at risk in the Ausable River watershed. Data related to the size distribution of Snuffbox suggest a possible threat to species at risk from high flow events that result from the incapacity of the Ausable River watershed to store water under high snowmelt conditions (M. Veliz, Ausable Bayfield Conservation Authority, pers. comm. 2012). New research looking at the effects of shear stress on freshwater mussels (Gangloff and Feminella 2007) is providing a more complete understanding of the threats limiting the distribution and abundance of mussels, and indicates that threats might be more complicated than initially documented in the Ausable River.

Additional research conducted on quantifying sediment and nutrient inputs from agricultural drainage systems and point sources has informed recommendations for more effective strategies for reduction of loading to rivers (e.g., Ball Coelho et al. 2010).

vi. Examine the feasibility of relocations, reintroductions and the establishment of managed refuge sites.

Methods have been developed for artificial propagation of mussel species in both the laboratory and the field and continued efforts are expected to refine and improve current approaches. For example, efforts in the laboratory are yielding large numbers of juvenile Snuffbox and improved understanding of rearing requirements (e.g., dietary requirements) has occurred.

The feasibility of relocations and reintroductions of mussel species has been partially assessed through investigations into the genetic and environmental implications of these conservation approaches (Hoftyzer et al. 2008). Additionally, a mussel relocation protocol has been developed by Mackie et al. (2008) and is currently being implemented when development projects require that mussels be moved to prevent harm from habitat alterations. A recent example of this occurred in the Thames River where mussel species, including the Wavyrayed Lampmussel, were relocated prior to the installation of a new bridge (Mackie 2011).

Efforts to expand understanding of the genetic structure of mussel populations has been advanced with studies on genetic parentage analyses of glochidia, and genetic diversity within and among mussel populations, driven by genetic marker development and optimization (McNichols et al. 2010). For example, an examination of various Snuffbox populations within the Sydenham River demonstrated substantial genetic diversity with all populations in Hardy-Weinberg equilibrium. Individual-based population assignment revealed that all analyzed Snuffbox belonged to a single genetic population. These findings indicate that genetic organization within the sampled populations is primarily at the watershed scale, rather than among local populations. The observed patterns of diversity also indicate that population structure reflects historical connectivity (gene flow) and show little if any losses to date from anthropogenic disturbances. Therefore, local population (site) losses may not result in an irreversible loss to the species, and other mussel beds within the same watershed could be used as sources for restoration. Collaborative engagement with researchers at Central Michigan University has resulted in further genetic investigations including comparisons between U.S. and Canadian populations and co-evolutionary relationships between mussels and host fishes (Zanatta and Murphy 2006, 2007, 2008, Zanatta et al. 2007, Zanatta and Wilson 2011).

An investigation into the feasibility of establishing actively managed refuge sites in the St. Clair delta still needs to be addressed. Collaborative efforts with the Walpole Island First Nation are planned to determine the effectiveness of managed refuge sites.

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

Outreach programs have been successful in reaching the public at large (e.g., naturalists clubs, farming communities, schoolchildren). The Stewardship and Outreach Recovery Implementation Group (Sydenham River Recovery Team) has held annual meetings to engage landowners in stewardship programs. Further emphasis on presenting research findings at conferences has increased awareness of the plight of mussel species at risk, highlighted key knowledge gaps and fostered valuable collaborative efforts.

Action Plans: DFO, in partnership with the Sydenham River Recovery Team, has developed a proposed multi-species, ecosystem-based action plan for the Sydenham River to be completed in 2013. This action plan will include the Wavyrayed Lampmussel, Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean.

4. Recommendations

The long-term goals of preventing extirpation, maintaining or returning self-sustaining populations and re-establishing populations to historical sites are still valid. As a result of the five-year accumulation of knowledge regarding the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel and Rayed Bean, the recovery strategy is currently being updated to include a partial identification of critical habitat for these species, as well as slightly revised recovery goals (based on new distribution data).

The following discoveries or changes may be deemed important in redirecting recovery approaches:

- Recent surveys have identified large, previously unknown populations, and evidence of reproduction in some of the previously known populations, of the Wavyrayed Lampmussel. COSEWIC re-examined the status of the Wavyrayed Lampmussel and changed its designation to Special Concern (COSEWIC 2010). The listing of the species under SARA is also under consideration (Morris et al. 2009, Bouvier and Morris 2010, DFO 2010).
- Further refinement of host fish relationships has occurred in the laboratory; these relationships require field confirmation.
- Some success in laboratory rearing has occurred along with a more complete understanding of genetic structuring of mussel populations. It appears that genetic organization within populations is primarily at the watershed scale, rather than among local populations.
- An upstream invasion of the Round Goby in the Ausable, Sydenham, Thames and Grand rivers is in progress (Poos et al. 2010), furthering concern of impacts on host fish species. The impacts of Round Goby on mussel species at risk are currently being investigated by a graduate student at the University of Guelph. An expansion of Dreissenid mussels into unionid mussel habitat has also been detected.
- The glochidium of a mussel species at risk (Wavyrayed Lampmussel) has been demonstrated to be acutely sensitive to sodium chloride, which is used as a road de-icing agent in winter (Gillis 2011). This is an important finding as these species reside in Canada's most road-dense region where chloride levels have been increasing over time.
- A projected decrease in water quantity, resulting from climate change and changing water use patterns, may result in severe reductions in mussel and fish species richness (Spooner et al. 2011).
- There are many sources of nutrients and sediment inputs throughout the watersheds inhabited by these mussel species at risk. This non-point source pollution continues to be a threat to aquatic species at risk and continued effort is required to address this complicated threat (e.g., continue to support retirement of land, encourage multiple landowners in priority areas to undertake stewardship activities to maximize benefits to species at risk).
- Further protection to Ontario's source water was enacted in 2006 via the *Clean Water Act* and is supported by local committees that list existing and potential threats and implement actions that will reduce or eliminate these threats (OMOE 2012).

- The Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean are listed as Endangered under Ontario's new *Endangered Species Act*, *2007*, which came into force in 2008, while the Wavyrayed Lampmussel is listed as Threatened. Under the *Act*, individuals of each species are protected and, with the exception of Wavyrayed Lampmussel, their habitat will be protected under the general habitat protection provisions as of June 30, 2013 unless a species-specific habitat regulation is developed by the provincial government at an earlier date. Wavyrayed Lampmussel received general habitat protection upon its down-listing to a Threatened species in September 2010.

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Morris, T.J., N.E. Mandrak, and B. Cudmore. 2007. Threats to species at risk in large lakes: a Canadian perspective. SIL 2007, Montreal, PQ. August 2007.

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Morris, T.J., V. Mink-Martin, A. Robinson, and I. Sagan. 2011. Daily, seasonal and annual patterns of unionid burrowing behaviour with emphasis on species at risk. Freshwater Mollusk Conservation Society Symposium. Louisville Kentucky, April 2011.

Morris, T.J., J.A.M. Young, and M.A. Koops. 2011. Using life history to predict the sensitivity of freshwater mussel populations to human induced perturbations. Freshwater Mollusk Conservation Society Symposium. Louisville Kentucky, April 2011.

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Roy, J.W., P.L. Gillis, R. McInnis, and G. Bickerton. 2011. Risk to benthic organisms, such as the freshwater mussel *Lampsilis siloqueodea* from groundwater contaminated with road salt and discharging to an urban stream. Geological Society of America Annual Meeting & Exposition, Minneapolis, MI, Oct. 2011. Geological Society of America.

Schwalb, A.N. and J.D. Ackerman. 2009. Hitching a ride and going with the flow – dispersal of unionid mussels (Bivalvia: Unionidiae). 57th Annual Meeting of *North American Benthological Society*, Grand Rapids, MI, May, 2009.

Schwalb, A.N. and J.D. Ackerman. 2010. Early life history traits in Lampsilini-mussels in relation to their host infection strategy. *Aquatic Sciences Meeting (ASLO-NABS)*. Santa Fe, NM, June, 2010.

Schwalb, A.N., M. Garvie, and J.D. Ackerman. 2008. Freshwater mussel larval dispersal in rivers – a transport model and its empirical evaluation in the field. *Ontario Ecology & Ethology Colloquium.* April 2008. Guelph, ON.

Schwalb, A.N., M. Poos, and J.D. Ackerman. 2008. Can a bad hitchhiking choice slow you down? Limitations to the dispersal of the endangered Snuffbox mussel (*Epioblasma triquetra*). 56th Annual Meeting of *North American Benthological Society*, Salt Lake City, May, 2008.

Tremblay, M., T.J. Morris, and J.D. Ackerman. 2011. The round goby, *Neogobius melanostomus*, as a host for unionid species at risk. *7th Biennial Syposium of the Freshwater Mollusk Conservation Society*, Louisville, KY, April 2011.

Group Presentations

Morris, T.J. 2008. Freshwater mussels of Niagara Region. Invited Speaker. Niagara Restoration Council Annual meeting. October 2008.

Morris, T.J. 2009. Towards the recovery of Canada's freshwater mussels: population and life history characters of the Endangered Wavyrayed Lampmussel. Invited Speaker, University of Guelph, Loaves and Fishes Seminar Series. February 2009.

Morris, T.J. 2009. Protecting and preserving Ontario's freshwater mussels: more than just a shell game. Invited Speaker, Niagara College. March 2009.

Morris, T.J. 2009. An introduction to Ontario's freshwater mussels. COSEWIC Mollusc SSC annual meeting. September 2009.

Morris, T.J. 2009. Ontario's Freshwater Mussels: A vanishing treasure. Invited Speaker, Peninsula Naturalists Annual General Meeting. November 2009.

Morris, T.J. 2010. Ontario's freshwater mussels: a vanishing treasure. Invited Speaker, Halton Peel Naturalists Annual General Meeting. February 2010.

Morris, T.J. 2010. Introduction to pondlife. Building Blocks Nursery School. May 2010.

Morris, T.J. 2011. Species at risk and aquatic invasive species. Our Lady of Fatima Elementary School. Invited presentation to primary grades. May 2011.

Morris, T.J. 2011. Freshwater mussels of the Thames River: an historical perspective. Invited presentation to Nature London, London, ON. October 2011.

Morris, T.J. 2011. Freshwater mussels of the SOSMART area. Invited presentation to SOSMART working group. Toronto, ON. December 2011.

ACRONYMS

AAFC	Agriculture and Agri-Food Canada
ABCA	Ausable Bayfield Conservation Authority
ABCF	Ausable Bayfield Conservation Foundation
ATW	Aquatic Toxicity Workshop
BAO	Bait Association of Ontario
CCME	Canadian Council of Ministers of the Environment
CDA	Copper Development Agency
CMU	Central Michigan University
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CRC	Canadian Research Chair
CWF	Canadian Wildlife Federation
CWN	Canadian Water Network
DFO	Fisheries and Oceans Canada
DUC	Ducks Unlimited Canada
EC	Environment Canada
ERCA	Essex Region Conservation Authority
FRCE	Faculty Research and Creative Endeavors grant
GRCA	Grand River Conservation Authority
HSC	Huron Stewardship Council
HSP	Habitat Stewardship Program
IDRC	International Development Research Centre
IRF	Interdepartmental Recovery Fund
LU	Lakehead University
NHIC	Natural Heritage Information Centre
NRS	Northern Riffleshell
NSERC	Natural Sciences and Engineering Research Council
OFAH	Ontario Federation of Anglers and Hunters
OGS	Ontario Graduate Scholarship
OMNR	Ontario Ministry of Natural Resources
OMOE	Ontario Ministry of the Environment
RB	Rayed Bean
RLSN	Rural Lambton Stewardship Network
ROM	Royal Ontario Museum
RPT	Round Pigtoe
SAR	Species at Risk
SARRFO	Species at Risk Research Fund for Ontario
SB	Snuffbox
SCRCA	St. Clair Region Conservation Authority
SCRCF	St. Clair Region Conservation Foundation
SETAC	Society of Environmental Toxicology and Chemistry
SM	Salamander Mussel
STFN	St. Thomas Field Naturalists
TTLT	Thames Talbot Land Trust
U of A	University of Alberta
U of G	University of Guelph
U of O	University of Ottawa
U of T	University of Toronto
U of W	University of Waterloo

UNB	University of New Brunswick
UTRCA	Upper Thames River Conservation Authority
WIFN	Walpole Island First Nation
WIHC	Walpole Island Heritage Centre
WRL	Wavyrayed Lampmussel
WWF	World Wildlife Fund