Species at Risk Act
Recovery Strategy Report Series

Report on the Progress of Recovery Strategy Implementation for the Northern Rifflеshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean in Canada for the Period 2012 to 2019

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

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

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«Rapport sur les progrès de la mise en oeuvre du programme de rétablissement de la l'épioblasme ventrue, de l'épioblasme tricorne, du pleurobème écarlate, de la Mulette du Necturus, et de la villeuse haricot au Canada pour la période allant de 2012 à 2019»

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Preface

The *Species at Risk Act* (S.C. 2002, c.29) (SARA) requires reporting on the implementation of the recovery strategy for a species at risk, and on the progress towards meeting its objectives within 5 years of the date when the recovery strategy was placed on the Species at Risk Public Registry, and in every subsequent 5 years, until the recovery strategy is no longer required under SARA or the species' recovery is no longer feasible. This reporting must be done by the competent Minister.

The Minister of Fisheries and Oceans is the competent minister under SARA for the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean and has prepared this progress report.

Reporting on the progress of recovery strategy implementation requires reporting on the collective efforts of the competent minister(s), provincial and territorial governments, and all other parties involved in conducting activities that contribute towards the species' recovery. Recovery strategies identify broad strategies and approaches that will provide the best chance of recovering species at risk. Some of the identified strategies and approaches are sequential to the progress or completion of others and not all may be undertaken or show significant progress during the timeframe of a report on the progress of recovery strategy implementation (progress report).

As stated in the preamble to SARA, success in the recovery of species at risk depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in the recovery strategy and will not be achieved by Fisheries and Oceans (DFO) or any other jurisdiction alone. The cost of conserving species at risk is shared amongst different constituencies. All Canadians are invited to join in supporting and implementing the recovery strategy for the benefit of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean and Canadian society as a whole.

Acknowledgements

This progress report was prepared by DFO. To the extent possible, this progress report has been prepared with input(s) from Environment and Climate Change Canada and the Ontario Ministry of Environment, Conservation and Parks. DFO would also like to express its appreciations to all individuals and organizations who have contributed to the recovery of the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean.

Executive summary

The Northern Riffleshell, Snuffbox, Salamander Mussel[1], and Rayed Bean were listed as endangered under the *Species at Risk Act* in 2003, while the Round Pigtoe was listed as endangered in 2005. The "Recovery Strategy for Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean in Canada" was finalized and published on the Species at Risk Public Registry in 2007[2].

The main threats identified for these 5 species include siltation and turbidity, nutrient loads, toxic compounds, thermal effects, and invasive species.

The long-term goals of the recovery strategy 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, 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 River delta
v. to return/maintain healthy self-sustaining populations of Salamander Mussel to the Sydenham and Thames rivers, and the St. Clair River delta
vi. to return/maintain healthy self-sustaining populations of Rayed Bean to the Sydenham and Thames rivers

This report documents the progress made in implementing the recovery strategy for the 5 mussels between 2012 and 2019. It summarizes progress that Fisheries and Oceans Canada, the province of Ontario, conservation authorities, and other stakeholders have made toward achieving the recovery objectives set out in the recovery strategy, which include:

- completing surveys in areas where the 5 mussel species occur, including extant and historical locations
- expanding the network of unionid index monitoring stations
- publishing maps of areas within which critical habitat can be found for each of the 5 mussels
- improved knowledge of the distribution of the Salamander Mussel in the Sydenham River
- improved understanding of the threats of invasive species (Round Goby and dreissenid mussels [Zebra Mussel and Quagga Mussel]), toxic compounds (a variety of chemical contaminants), and siltation and turbidity
- completing investigations into the reproductive timing windows (spawning, brooding, glochidial release and host infestation) for the Northern Riffleshell, Snuffbox, and Round Pigtoe
- starting research into the feasibility of culturing and rearing unionids (including Snuffbox and Northern Riffleshell) for potential reintroductions

[1] Formerly known as the Mudpuppy Mussel.
[2] An amended recovery strategy was posted in July 2019; however, this progress report addresses progress on the recovery approaches in the original recovery strategy.

- investigating patterns of genetic structure and diversity in the Snuffbox
- continuing to increase awareness and promote stewardship practices designed to reduce threats to aquatic species at risk through outreach activities
- providing funding to external agencies through the Habitat Stewardship Program, which has resulted in the construction of exclusionary cattle fencing, planting of riparian buffers, and many other activities designed to improve habitat conditions for the 5 mussels

Taken together, these ongoing or completed activities indicate that progress is being made toward the goal of recovering Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean populations in Canada; however, there are still a number of areas where further information is required. For example, information on the genetic structure and diversity is presently lacking for all species except Snuffbox. This knowledge is important to inform any potential translocation and reintroduction efforts. As the Salamander Mussel appears to have only 1 host (Mudpuppy), ascertaining the status of the Mudpuppy within the distribution of the Salamander Mussel is important. Further index station monitoring is required to determine population trajectories, which would help evaluate the effectiveness of restoration efforts, and allow for the focus of recovery activities in areas of greatest need.

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1. Introduction

This progress report outlines the progress made towards meeting the objectives listed in the "Recovery Strategy for Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean in Canada" (Morris and Burridge 2006) from 2012 to 2019. This report should be considered as part of a series of documents that are linked and should be taken into consideration together, including: the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status reports (COSEWIC 2010a; 2010b; 2011a; 2011b; 2014), the recovery strategy, and the initial progress report (DFO 2013).

Section 2 of the progress report reproduces and summarizes key information on the threats to the species, population and distribution objectives for achieving their recovery, approaches to meeting the objectives, and progress made in recovery. For more details, readers should refer to the recovery strategy. Section 3 reports on the progress of activities identified in the recovery strategy, to support achieving the population and distribution objectives. Section 4 provides a concluding statement about the progress of actions taken and outcomes of these recovery efforts.

2. Background

2.1 COSEWIC assessment summary and threats to the species and their critical habitats

The listing of Northern Riffleshell (*Epioblasma rangiana*), Snuffbox (*E. triquetra*), Salamander Mussel (*Simpsonaias ambigua*), and Rayed Bean (*Villosa fabalis*) under the *Species at Risk Act* (S.C. 2002, c.29) (SARA) in 2003, and the listing of Round Pigtoe (*Pleurobema sintoxia*) in 2005, led to the development and publication of the recovery strategy for the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean in 2007. The recovery strategy is consistent with the information provided in the COSEWIC status reports (COSEWIC 2000a; 2000b; 2001a; 2001b; 2004). The more recent COSEWIC assessment summaries are included below (COSEWIC 2010a; 2010b; 2011a; 2011b; 2014).

Northern Riffleshell

Assessment summary: April 2010

Common name: Northern Riffleshell

Scientific name: *Epioblasma torulosa rangiana**

Status: Endangered

Reason for designation: This small freshwater mussel is restricted to 2 rivers in southern Ontario. Since the original COSEWIC assessment (2000), a small, possibly reproducing population was discovered in the Ausable River although only 16 live individuals, including 1 juvenile, have been found over the last 10 years. Recruitment is occurring at several sites along the Sydenham River and the population appears to be stable, but the perceived recovery could be due to increased sampling effort over the past 12 years. The main limiting factor is the availability of shallow, silt-free riffle habitat. Both riverine populations are in areas of intense agriculture and urban and industrial development, subject to siltation and pollution. Only 4 populations in the world, including the 2 in Canada, show signs of recruitment.

Occurrence: Ontario

Status history: Designated endangered in April 1999. Status re-examined and confirmed in May 2000 and April 2010.

* subspecies subsequently elevated to the species *Epioblasma rangiana*

Snuffbox

Assessment summary: November 2011

Common name: Snuffbox

Scientific name: *Epioblasma triquetra*

Status: Endangered

Reason for designation: This small freshwater mussel is currently found in 2 rivers in southern Ontario; another population may still survive in the Thames River where 1 fresh shell was found in 1998. The original COSEWIC assessment (2001) concluded that it had been lost from most of its Canadian range and was confined to the Sydenham River but live mussels from a reproducing population were subsequently found in the Ausable River beginning in 2006. The 2 remaining populations are in areas of intensive farming and subject to siltation and pollution with siltation being particularly problematic. Invasive Zebra Mussels have rendered much of the historical habitat unsuitable. An invasive fish species, the Round Goby, may pose a new threat by competing with the mussel’s 2 known larval host fishes and by eating juvenile mussels.

Occurrence: Ontario

Status history: Designated endangered in May 2001. Status re-examined and confirmed in November 2011.

Round Pigtoe

Assessment summary: May 2014

Common name: Round Pigtoe

Scientific name: *Pleurobema sintoxia*

Status: Endangered

Reason for designation: This mussel species occupies a small area in the Lake St. Clair watershed and 3 other watersheds in southern Ontario, where its habitat has been declining in extent and quality. Urban development, agricultural runoff, and impacts from the Zebra Mussel and the Round Goby are threatening the survival of the species in Canada.

Occurrence: Ontario

Status history: Designated endangered in 2004. Status re-examined and confirmed in May 2014.

Salamander Mussel

Assessment summary: May 2011

Common name: Salamander Mussel

Scientific name: *Simpsonaias ambigua*

Status: Endangered

Reason for designation: This freshwater mussel was reported from 2 rivers in southern Ontario in 1998. Surveys since the original COSEWIC assessment (2001) have found live individuals still along the Sydenham River. Despite extensive additional sampling, the half-shell found in 1998 is the only evidence of this species along the Thames River. Habitat quality continues to decline from intense agriculture, urban development, and pollution from point and non-point sources. In addition, this mussel only uses the Mudpuppy, a salamander, as its host; threats to the salamander are also threats to the mussel.

Occurrence: Ontario

Status history: Designated endangered in May 2001. Status re-examined and confirmed in May 2011.

Rayed Bean

Assessment summary: April 2010

Common name: Rayed Bean

Scientific name: *Villosa fabalis*

Status: Endangered

Reason for designation: This freshwater mussel is one of the smallest in Canada. It is found in 2 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 1 river but a new, albeit small, population was discovered in 2004 in the North Thames River. Thirteen live individuals were found between 2004 and 2008 in this river. The main limiting factor is the availability of shallow, silt-free riffle habitat. Both riverine populations are in areas of intense agriculture and urban development, subject to siltation and pollution. Invasive Zebra Mussels have rendered much of the historic habitat unsuitable and pose a continuing threat to one of the last remaining populations.

Occurrence: Ontario

Status history: Designated endangered in April 1999. Status re-examined and confirmed in May 2000 and April 2010.

2.2 Distribution

Since the publication of the initial progress report in 2013 (for years 2006 to 2011), Northern Riffleshell continues to be detected in the Sydenham and Ausable rivers (figure 1), although the Ausable River detections were more limited in distribution. Additionally, no detections were recorded from the St. Clair River delta or the Maitland River. Snuffbox continues to be detected in the Sydenham and Ausable rivers (figure 2), while Round Pigtoe continues to be detected in the St. Clair River delta, and the Sydenham, Grand, and Thames rivers (figure 3). Round Pigtoe was also detected in the Detroit River (3 individuals from 1 site), and a single individual was found in Rondeau Bay. Salamander Mussel continues to be detected in the Sydenham River (figure 4), but no detections were recorded from the St. Clair River delta, while Rayed Bean continues to be detected in the Sydenham and Thames rivers (figure 5).

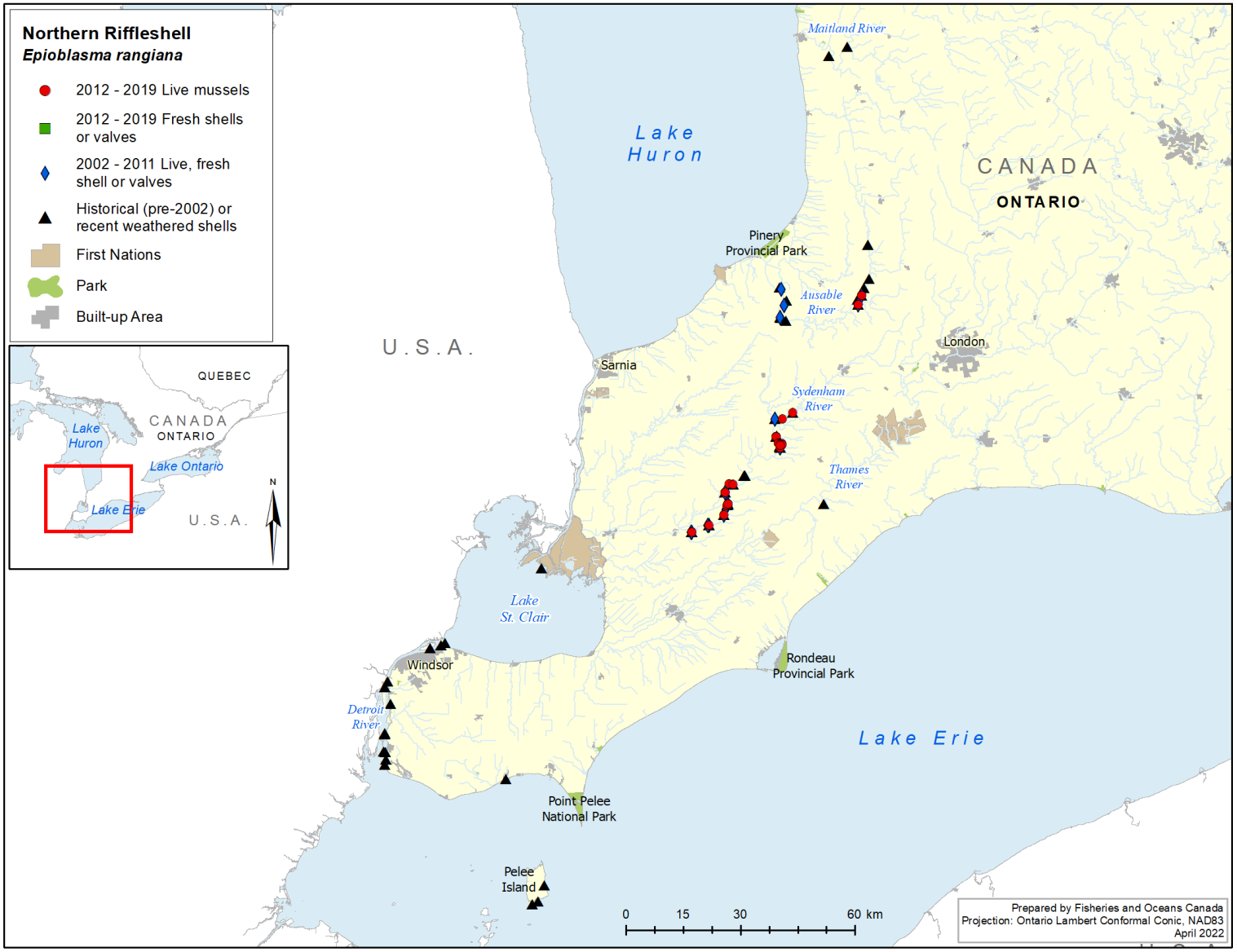

Figure 1. Historical distribution and recent detections of Northern Riffleshell in Canada.

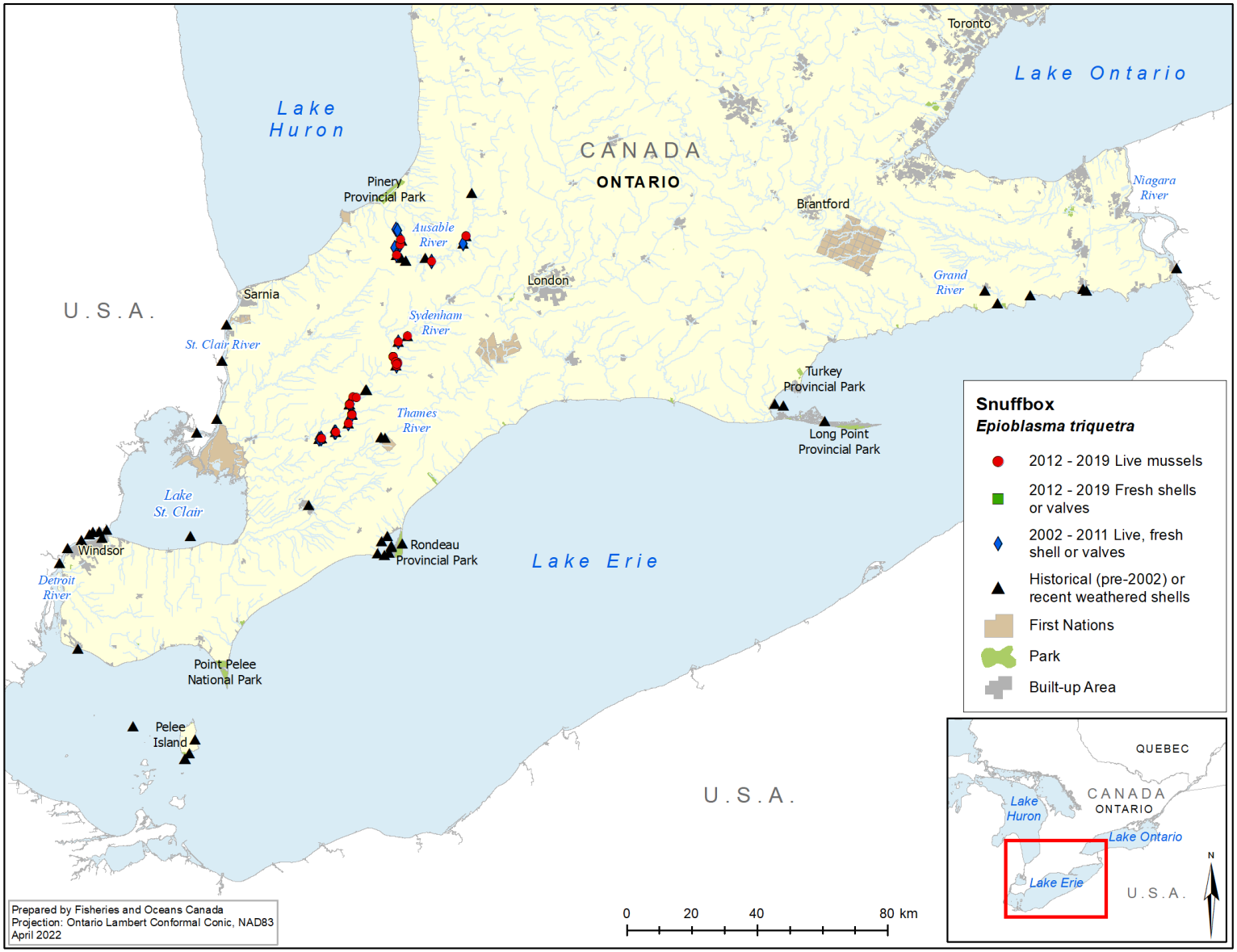

Figure 2. Historical distribution and recent detections of Snuffbox in Canada.

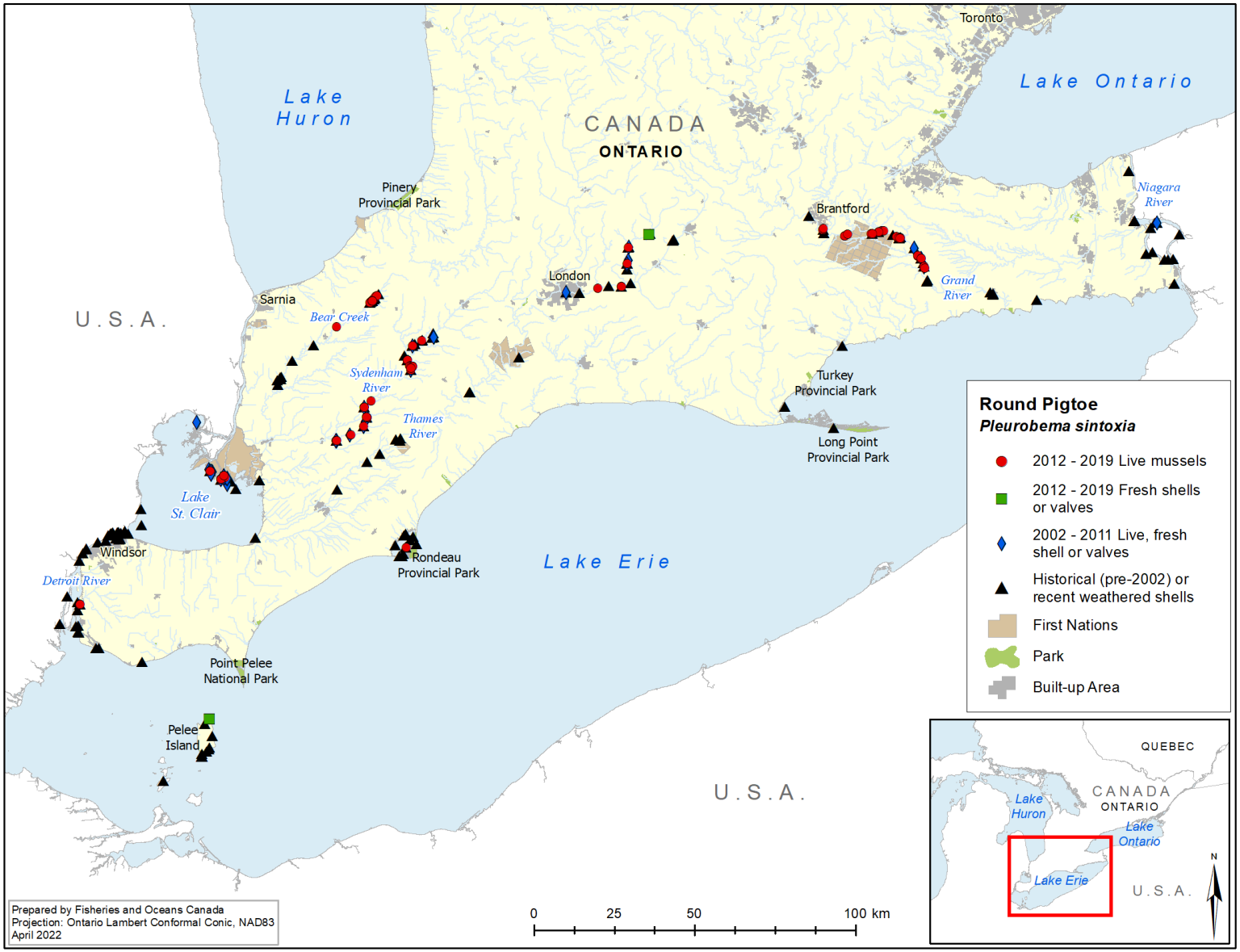

Figure 3. Historical distribution and recent detections of Round Pigtoe in Canada.

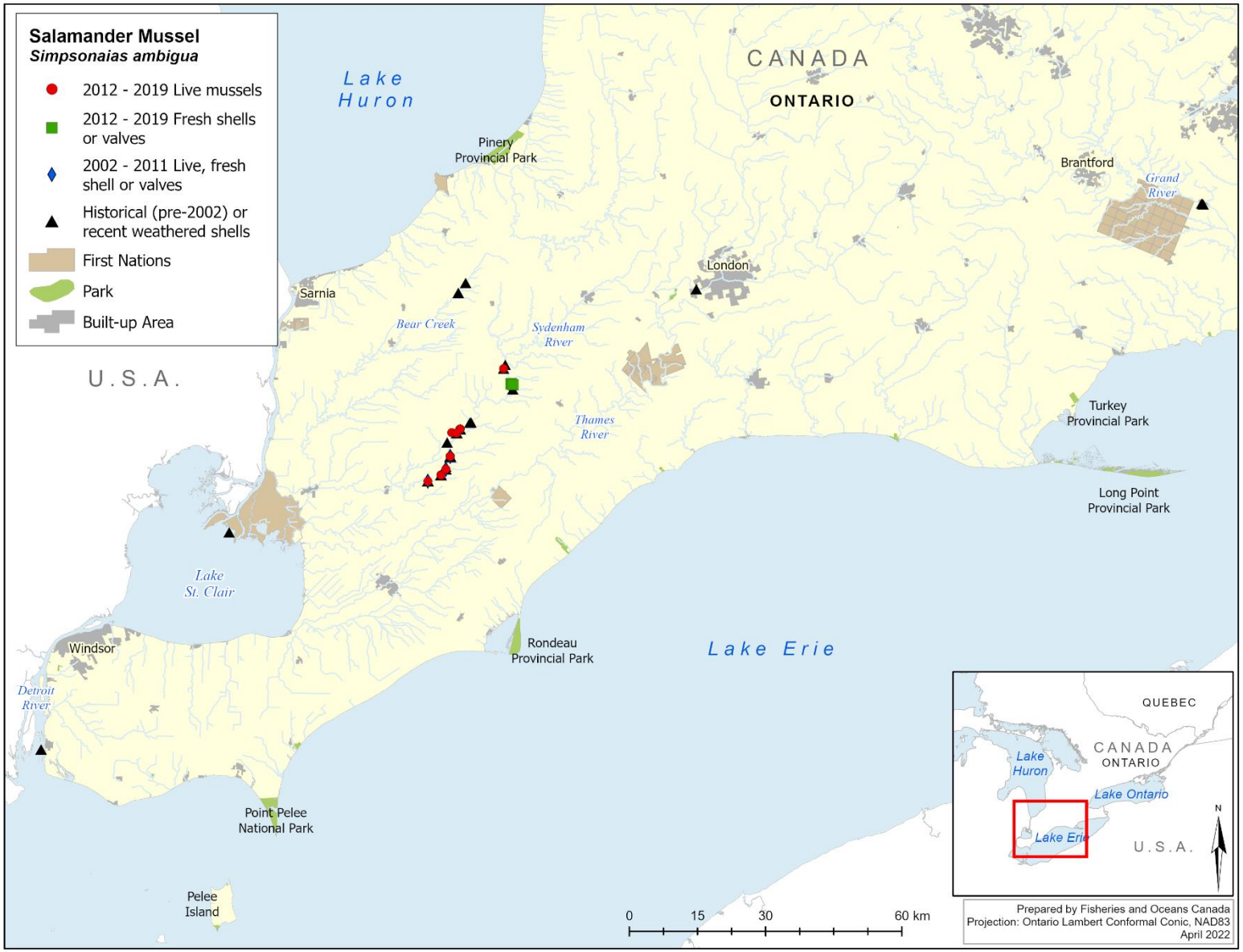

Figure 4. Historical distribution and recent detections of Salamander Mussel in Canada.

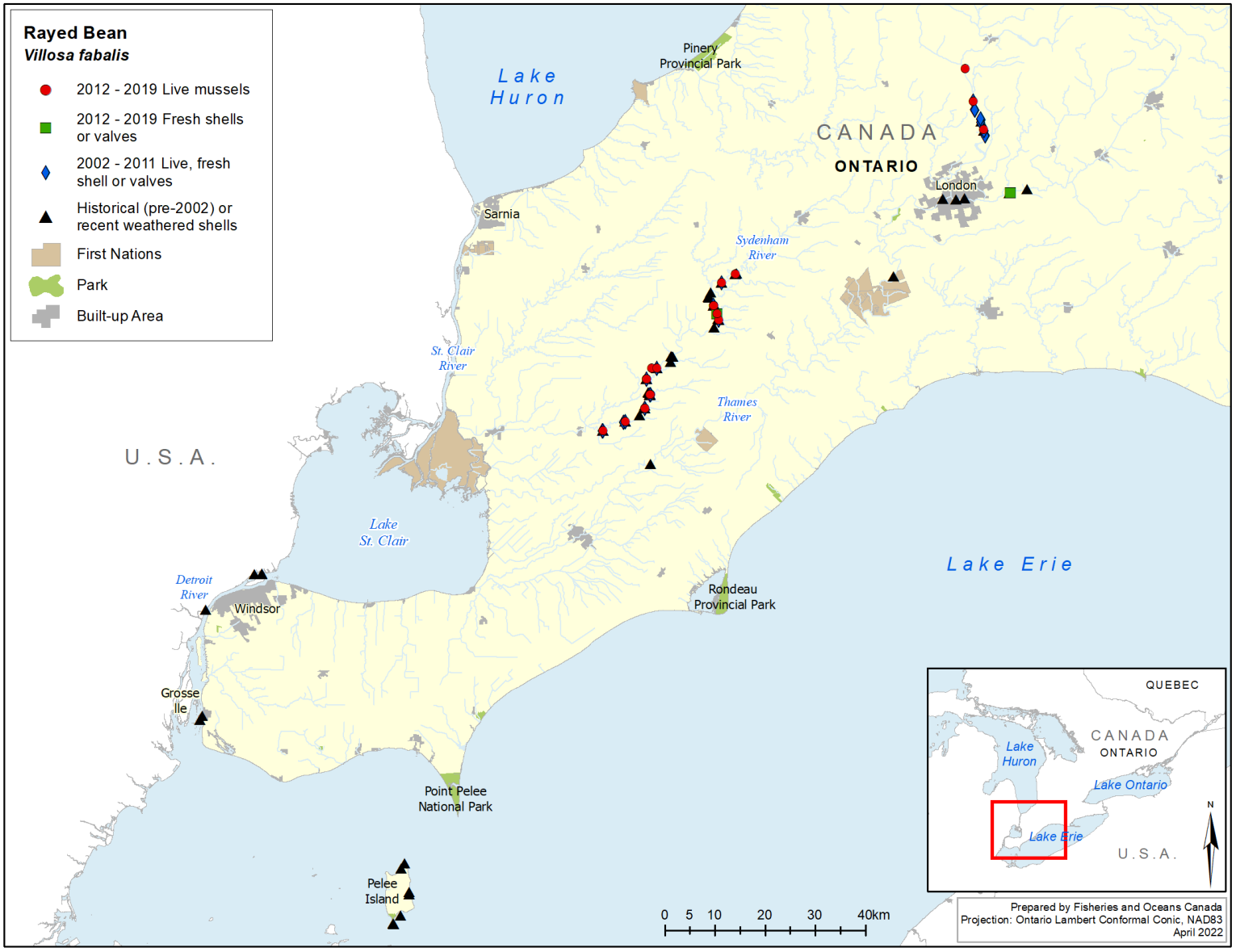

Figure 5. Historical distribution and recent detections of Rayed Bean in Canada.

2.3 Threats

This section summarizes the information found in the recovery strategy on threats to survival and recovery of Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean.

2.3.1 Threats to the species

Population-level threats (table 1) for Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean were identified in the recovery strategy (Morris and Burridge 2006). For more information on these threats, please refer to section I.6. of the recovery strategy.

Table 1. Threat classification table for Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean (adapted 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
Invasive species	Contributing	Widespread	Chronic	Probable

2.4 Recovery

This section summarizes the information found in the recovery strategy on the population and distribution objectives necessary for the recovery of Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean. This section also describes the performance measures that provide a way to define and measure progress toward achieving the population and distribution objectives.

2.4.1 Population and distribution objectives

Section II.1. of the recovery strategy identified the following long-term goals necessary for the recovery of the 5 mussels.

Recovery goals

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, 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 River delta

v. to return/maintain healthy self-sustaining populations of Salamander Mussel to the Sydenham and Thames rivers, and the St. Clair River delta
vi. to return/maintain healthy self-sustaining populations of Rayed Bean to the Sydenham and Thames rivers

2.4.2 Performance measures

The recovery strategy did not include performance indicators; however, short-term recovery objectives toward achieving the population and distribution objectives were included:

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 impacts, 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. Progress towards recovery

The recovery strategy for Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean divides the recovery approaches into broad categories: 1) research and monitoring, 2) management, 3) stewardship, and 4) awareness. Progress in carrying out these broad strategies is reported in section 3.1. Section 3.2 reports on the activities identified in the schedule of studies to identify critical habitat. Section 3.3 reports on the progress on meeting the recovery objectives and other commitments (for example, action plan and critical habitat identification) identified in the recovery strategy, and information obtained through its implementation.

3.1 Activities supporting recovery

Table 2 provides information on the implementation of activities undertaken to address the broad strategies and recovery actions identified in the recovery strategy. Table 2 is not necessarily an exhaustive list of all relevant activities, but is meant to broadly represent work undertaken from 2012 to 2019.

Table 2. Details of activities supporting the recovery of Northern Riffleshell (NRS), Snuffbox (SB), Round Pigtoe (RP), Salamander Mussel (SM), and Rayed Bean (RB) from 2012 to 2019.

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3],[4]
Research host fishes: Continue host fish testing for the NRS, SB, RP, and RB.	Research and monitoring	Schwalb et al. (2013) demonstrated a strong correlation between mussel (including SB, NRS, RP and RB) and host fish distribution at the regional scale in southwestern Ontario rivers. Furthermore, mussel distribution appears more closely linked to host fish for high-dispersal mussel species, and that the absence of mussels does not necessarily indicate unsuitable environmental conditions, but may reflect dispersal limitation of the host fish (Schwalb et al. 2015). Barrett and Hayes (2017) investigated freshwater mussels and potential hosts in Muddy Creek (Pennsylvania). NRS was found to be positively associated with Grass Pickerel (*Esox americanus vermiculatus*), Bluntnose Minnow (*Pimephales notatus*), and Smallmouth Bass (*Micropterus dolomieu*); SB with Greenside Darter (*Etheostoma blennioides*), and Northern Hogsucker (*Hypentelium nigricans*); and, RB with Golden Redhorse (M*oxostoma erythrurum*). McNichols-O'Rourke et al. (2016 and 2017) investigated the reproductive timing windows (spawning, brooding, glochidial [parasitic	ii	**DFO**, **AI**

[3] Participant full names: Academic Institutions (AI), Conservation Authorities (CA) which include Grand River (GRCA), Niagara Peninsula (NPCA), LPRCA (Long Point Region), St. Clair Region (SCRCA), Ausable Bayfield (ABCA), Essex Region (ERCA), Lower Thames Valley (LTVCA), and Upper Thames Region (UTRCA) conservation authorities, Carolinian Canada Coalition (CCC), Fisheries and Oceans Canada (DFO), Environment and Climate Change Canada (ECCC), Environmental Non-Governmental Organizations (ENGO), International Union for Conservation of Nature (IUCN), Ministry of the Environment, Conservation and Parks (MECP), Ontario Ministry of Natural Resources and Forestry (OMNRF), Ontario Parks (OP), Ontario Soil and Crop Improvement Association (OSCIA), United States Fish and Wildlife Service (USFWS), United States Geological Survey (USGS), and Walpole Island First Nation (WIFN).
[4] Lead participant(s) is/are listed on top and in bold; other participants are listed alphabetically.

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		larval form] release and host infestation) for NRS, SB, and RP in the Sydenham River (DFO, unpublished data). Preliminary results suggest that spawning occurs in summer (late-June to late-August) for NRS, June to August for SB, and the potential for a prolonged spawning period between early-June to mid-October for RP. Gravid NRS and SB females were observed beginning in mid-August and continued until at least October. Only 3 gravid RP females were observed in late-May and late-June; further investigation is required to determine when RP spawn in Canada. Van Susteren et al. (2015) demonstrated that Logperch (*Percina caprodes*), from the St. Croix River, Minnesota is a natural host for SB, confirming laboratory studies. Caldwell et al. (2016) confirmed Blackside Darter (*P. maculata*) as a laboratory-successful host fish for SB, but found that Logperch was able to transform a greater proportion of glochidia to juveniles compared to the Blackside Darter. Tremblay et al. (2015) developed discriminant models to identify unionid glochidia of unknown species using their shell dimensions. All of the 5 mussels were included in their analysis; the overall success rate of the models varied between 71% and 78%.		
Surveys for host fishes: Determine the distribution and abundance of the host species.	Research and monitoring	Fish community assessments completed by government agencies and CAs are undertaken at mussel monitoring sites, which provide insight on the availability of host fishes throughout a significant portion of the 5 mussels' distribution. In addition, DFO and OMNRF fish sampling was conducted in a number of other areas within the range of the 5 mussels (for example, Detroit River, coastal Lake Erie) using a variety of gear types such as electrofishers, seine nets, and fyke nets.	ii	**DFO**, **CA**, **OMNRF**
Research critical habitat: Determine the habitat	Research and monitoring	Water quality parameters continue to be recorded during unionid surveys (for example, during the 2017 survey of the Sydenham River within the Sydenham River Nature Reserve). Ultimately, this	iii	**AI**, **DFO**

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
requirements for all life stages.		information may improve understanding of unionid environmental requirements, which may aid in refining critical habitat determination for the 5 mussels. Furthermore, research on contaminants and turbidity (see table 2, research threats) continues to shed light on unionid susceptibility to deleterious water quality conditions. French and Ackerman (2014) investigated responses of newly settled juvenile unionids (including SB) to bed shear stress[5]. Their laboratory experiments demonstrated that juvenile unionids cannot become established when bed shear stress exceeds a critical value. Both bed shear stress and behaviour were found to affect the establishment of juveniles on sediments, and hence their distribution and abundance. Therefore, settlement and recruitment of juveniles could be affected by any process that changes stream characteristics (for example, erosion of stream banks). In addition, a study is underway that aims to physically model juvenile mussels using microbeads for release within a DFO reference site where critical habitat has been identified (Farrow and Ackerman 2018). This research will provide a better understanding of the transport and settlement of juvenile mussels under varying flow conditions after they have released from their host fish. This will help to characterize the type of habitat features where juvenile mussels settle as a result of passive transport and consequently, where future sampling for juvenile mussels should be focused within a stream reach. Daniel et al. (2018) investigated habitat suitability for 11 unionids, including SB and RP. Unionid distribution was most strongly predicted by host fish richness (not for SB), stream discharge, urban land use (not for RP), and upstream dam density (not for RP). Of the 11 species under consideration, SB was the only one where anthropogenic factors contributed more than natural predictor variables to the observed distribution. SB was negatively associated		

[5] Bed shear stress is a measure of fluid force per unit of area on the stream bed.

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants[3,4]
		with upstream network dam density, and high intensity urban land use. Lum (2020) conducted research in the Sydenham River with the objective to further identify critical habitat for juvenile unionids by investigating the role of bed shear stress in the settlement of juvenile mussels. The author hypothesized that shear stress determines the settlement and re-suspension of juvenile mussels as well as the saltation[6] of sediment within lotic environments. The results found that shear stress best predicts juvenile presence with a non-linear relationship.		
Survey critical habitat: Prepare a distribution map of areas of suitable habitat.	Research and monitoring	Mapping of critical habitat was published for each of the 5 mussels in an amended recovery strategy on July 30, 2019 (DFO 2019).	iii	**DFO**
Research managed refuge sites: Investigate the feasibility of establishing actively managed refuge sites in the St. Clair River delta.	Research and monitoring	No actively managed refuge sites have been established at this stage within the St. Clair River delta. The delta as a whole was considered by organizations, including DFO and WIFN, to be a refuge for freshwater mussels since 2003. However, subsequent sampling conducted in 2011 and 2016 found that unionids have become more patchy, with an overall reduction in the number of unionids found (Morris et al. 2017).	vi	**DFO**, **WIFN**
Population augmentation: Examine the feasibility of translocations and re-introductions.	Research and monitoring	Mair (2013) experimented with the culture of juvenile NRS, examining algal diet and concentration and 3 types of recirculating aquaculture systems in relation to growth and survival. The findings indicated that low, continuous algal concentrations in the bucket culture systems resulted in higher growth and survival of juveniles (Mair 2013). McMurray and Roe (2017) highlighted important considerations that need addressing before initiating the controlled propagation,	vi	**DFO**, **OMNRF**, AI, CA

[6] In this instance saltation refers to the transport of particles from the streambed to a downstream location.

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		augmentation, and reintroduction of unionids. Although the paper focuses on United States (U.S.) scenarios, it also contains information relevant to Canadian projects. Additionally, Donaldson et al. (2019) explored the effectiveness of captive breeding programs for freshwater mussels and fishes using systematic map criteria. Beginning in 2010, NRS was translocated to multiple sites within the Vermilion River basin (Illinois, U.S.). To gauge success, many NRS were PIT (passive integrated transponder) tagged to allow for long-term monitoring (for example Tiemann et al. 2019). Stodola et al. (2017) investigated the survival of translocated individuals and found relatively low annual survival for NRS (0.30), and as of yet, no documented recruitment. Recommendations offered by the authors include spreading reintroduction efforts over several geographically separate river systems, translocating individuals over a period of several years to lessen risk of failure due to isolated events (for example, floods), and stocking greater numbers of individuals in multiple translocations to maximize chances for natural recruitment. Caldwell et al. (2016) suggested that when available, larger Logperch (for example, >100 mm) should be used for propagation of SB, because larger fish produce the highest transformation rates. Additionally, results of their study suggest that broodstock mussels coming from streams with better water quality and fewer threats may produce more viable glochidia and juveniles. The OMNRF's Fish Culture Section (White Lake OMNRF Fish Culture Station) is continuing to develop expertise in the culture of at risk unionids (including the SB and NRS), and investigating the feasibility of establishing broodstocks and/or ark populations. The program has also been beneficial in supplying captive reared unionids for research (for example Salerno et al. 2018), which may reduce the need to utilize wild caught individuals. Research conducted through this program has assessed the infestation rates and cumulative survival of		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		juvenile SB and NRS using the primary hosts (Logperch – SB, Iowa Darter – NRS) (Loftus and Wilson 2018). Furthermore, a protocol is being finalized for mussel propagation and rearing techniques. The findings of this research will be beneficial if federal or provincial jurisdictions decide to undertake repatriation programs. Galbraith et al. (2015) investigated patterns of genetic structure and diversity in 6 unionid species collected from Ontario rivers. As genetic structure was largely detected at the watershed scale, translocation within rivers is likely to minimize genetic risks to recipient sites. Beaver et al. (2019) assessed the genetic diversity and structure among populations of SB in the Great Lakes drainage. Their findings suggest that SB genetic profiles should be put into historical context when considering translocations or hatchery propagation of juveniles. A systematic review of published information that investigated the efficacy of captive breeding programs for imperilled freshwater fishes and mussels in terms of their achievement of conservation of recovery objectives in the wild was completed (Donaldson et al. 2019). A systematic map was developed that highlights the lack of studies on the effectiveness of captive breeding for at risk freshwater mussels, and the need for further systematic evaluation to determine the effectiveness of captive breeding and release programs.		
Monitoring mussel and host fish populations: Establish a network of permanent monitoring stations throughout historic and present ranges.	Research and monitoring	**Current locations:** **Rondeau Bay** Reid et al. (2016) surveyed Rondeau Bay for unionids in 2014 and 2015. SB and RP were known historically from Rondeau Bay. The results indicate a substantial decline in unionid diversity since the dreissenid (Zebra Mussel [*Dreissena polymorpha*] and Quagga Mussel [*D. bugensis*]) invasion of Lake Erie, and that Giant Floater (*Pyganodon grandis*) is the only remaining viable population. Only a single live RP was encountered during the surveys.	i, ii, iv	**DFO**, **CA**, **OMNRF**, AI, ECCC, ENGO, WIFN

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		Index stations Monitoring stations relevant to the 5 mussels have been established within Lake St. Clair (St. Clair River delta), and the Ausable, Grand, Sydenham, and Thames rivers. Sampling is conducted over time to track changes in the abundance of freshwater mussel species, measure environmental variables, and undertake fish community assessments that provide information regarding the availability of host fishes. **Ausable River** There are a total of 7 index monitoring stations in the Ausable River, which are sampled using quadrat surveys conducted by ABCA. In 2018, 4 of the 7 index stations were surveyed (weather related issues prevented a full survey) for unionids, and to assess habitat conditions. At 1 site, 1 NRS and 9 SB were found. The remaining 3 sites were surveyed in 2019, where 1 NRS and 7 SB (3 sites) were detected. Furthermore, projects that occur outside the purview of routine index station monitoring sometimes detect the 5 mussels. In 2013, ABCA conducted an intensive unionid and host fish inventory and detailed habitat sampling at 1 of the index stations and found 67 SB. In an unrelated behaviour study, DFO detected 1 NRS in 2012, and 1 SB and 2 NRS in 2013. **Grand River** The 7 Grand River index stations were surveyed (quadrats) by DFO over the 2017 to 2018 time period. In 2017, 4 of the index stations were sampled, none of the 5 mussels were detected. In 2018, the other 3 index stations were sampled, and 26 RP were detected at 1 station, while a single RP shell was found at another site.		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		Furthermore, projects that occur outside the purview of routine index station monitoring sometimes detect the 5 mussels. Timed-search surveys[7] were conducted by University of Guelph personnel in the lower Grand River and uncovered 9 RP in 2012, and 2 in 2013. DFO and OMNRF conducted timed-search surveys in the Grand River, uncovering 3 RP at 2 stations in 2015, while DFO also collected 2 from 1 other station in 2015. In 2017, ECCC found 10 RP at 3 sites in the lower Grand River in association with a study investigating the impact of wastewater effluent on unionids. In 2018, half hectare surveys were performed by DFO at 3 sites in the lower Grand River; only 1 RP valve was uncovered. In 2019, DFO conducted timed-search surveys at 10 sites in the Grand River watershed and found 2 RP at 1 site and 2 other sites that contained valves or shells. OMNRF conducted transect-based surveys using a mussel brail at 48 non-wadeable sites along the lower Grand River in 2019. Forty-two RP (and 4 shells) were collected from 9 sites distributed along 94 km of the river (LeBaron et al. 2023). **Lake St. Clair** A survey conducted by DFO at 8 index stations uncovered 13 RP in the St. Clair River delta during the 2016 field season. Live RP were detected at 4 of the 8 stations, while 3 shells wenre detected at 1 other station. In 2017, DFO in partnership with WIFN, undertook timed-search surveys at 4 previously unsearched sites, 3 sites in Johnston Bay and 1 site in the Chematogan Channel; none of the 5 mussels were encountered (Morris et al. 2017). **Sydenham River**		

[7] Following timed-search technique as described by Metcalfe-Smith et al. (2000).

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		Of the 15 Sydenham River index stations, 13 were surveyed (quadrats) by DFO over the 2012 to 2019 time period; sampling at the other 2 sites requires divers. Five of the sites were sampled in 2012, and detections included: 40 RP (5 sites), 5 SM (1 site), 115 SB (4 sites), 313 RB (4 sites), and 195 NRS (4 sites). A further 5 of the sites were sampled in 2013, and detections included: 133 NRS (4 sites), 123 RB (4 sites), 37 RP (5 sites), 6 SM (2 sites), and 52 SB (4 sites). The last 3 sites (excluding the deep-water sites) were sampled in 2015, and detections included: 166 SB (2 sites), 200 NRS (2 sites), 35 RP (2 sites), and 43 RB (2 sites), and 1 SM. Furthermore, projects that occur outside the purview of routine index station monitoring sometimes detect the 5 mussels. In 2013, DFO detected 89 SB, 18 RP, and 179 NRS, and in 2014 3 SB, 30 RP, and 12 NRS all from 1 location in the Sydenham River for a reproduction study. DFO sampled 1 of the index stations in the Sydenham River in 2015 with a timed-search survey and recorded 18 NRS, 17 SB, and 2 RB. In the course of operating DFO's unionid identification workshops, the 5 mussels are occasionally detected, for example: 9 RP, 42 SB, and 75 NRS in 2017; and, 8 SB, 4 NRS, and 7 RP in 2018. These detections originate from 2 Sydenham River index stations. Targeted timed-search surveys were completed by DFO in 2018 at 6 sites in the Sydenham River to investigate the distribution and abundance of SM. Of these 6 sites, 5 had been previously surveyed for unionids, and live SM had been observed at 4 of these sites. A total of 50 detections of live SM occurred during the surveys at 4 of the 6 sites, representing 35 unique individuals, as repeat sampling of distinct individuals occurred. Although within its known distribution, 1 of the sites where live SM were found represents the first record of the species at that specific location. In 2019, DFO conducted further targeted timed-search surveys for SM over a 75 km stretch of the Sydenham River, including previously unvisited sites. At 4 of the 12		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3,4]
		sites surveyed, 17 SM were detected. The extent of occurrence of SM in the Sydenham River has expanded upstream due to the detection of a live individual above Alvinston. Genetic and reproductive samples were also obtained to investigate genetic relationships, and to determine the reproductive timing of the species. Within the course of this work, 2 RB (2 sites) and 1 NRS were detected in 2018, while 2 NRS (2 sites), 1 SB, and 1 RB were detected in 2019. In cooperation with DFO, the OMNRF has been collecting unionids for the purpose of developing expertise in artificial mussel propagation. The following collections have occurred at index stations on the Sydenham River: 12 SB and 12 NRS were collected from 1 location in 2015; 15 SB and 15 NRS were collected from 2 locations in 2016; 19 SB were collected from 2 locations in 2017; and, 9 SB were collected from 1 location in 2018. In 2017, DFO and Ontario Nature completed an extensive unionid survey along a 2.5 km stretch of the Sydenham River, within the Sydenham River Nature Reserve (Goguen et al. 2022). Timed-search surveys of 5 sites were performed, and detections included: 36 NRS (5 sites), 20 RP (4 sites), and 6 SB (5 sites), 1 SM weathered valve, and 2 fresh shells of RB (1 site). Quadrat surveys were also performed at an additional 5 sites, and detections included: 33 NRS (5 sites), 5 RP (4 sites), 2 RB (1 site), 3 SB (2 sites), and 2 valves of SM (2 sites). Timed-search surveys have been conducted by the University of Guelph in the Sydenham River for a variety of research projects (for example, bed shear stress trials), and detections included: • 2012: 39 NRS, 43 SB, 7 RP, and 3 RB collected from 1 location • 2013: 19 NRS (2 sites), 10 RP (2 sites), 19 SB (2 sites), and 2 RB (1 site)		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		• 2014: 37 SB (3 sites), 10 RP (3 sites), 17 RB (2 sites), and 45 NRS (3 sites) • 2015: 2 SB and 1 NRS from 1 location • 2016: 1 NRS • 2018: 3 NRS and 4 SB from 1 location • 2019: 14 NRS and 3 SB from 1 location. In 2017, SCRCA completed timed-search surveys at 30 sites in the north branch of the Sydenham River. Fifteen sites were surveyed on Bear Creek, 14 on Black Creek, and 1 site on Booth Creek. A total of 35 RP were found at 8 sites in Bear Creek, while a single valve of SM was discovered in Bear Creek. In 2018, a 7 km stretch on Bear Creek was surveyed (timed-search), in addition to road crossings on both Bear and Black creeks, to determine the extent and abundance of RP in this system. The surveys were conducted by SCRCA to fulfill recovery measures of the Sydenham River action plan; no RP were found. **Thames River** From 2012 to 2019, all 16 Thames River index stations were surveyed by DFO using the quadrats sampling method. Briefly, in 2015, sampling at 4 stations uncovered 1 RP in the south branch (1 RB valve), 25 RP in the middle branch, and 16 RB in the north branch. Of the 5 additional sites sampled in 2016, a single RP valve was encountered, while a further 3 sites surveyed in 2017 detected 1 RP. In 2018, an additional 4 stations were surveyed and 3 RP were uncovered from 1 site and 1 shell from another site, while 11 RB were detected from 1 of the 4 sites. The 4 sites surveyed in 2018 were all located in the upper Thames River subwatershed and included 1 in the north Thames River, 2 in the middle Thames River, and 1 in the south Thames River. These sites represent new index stations in conjunction with the original 12 index stations already established throughout the upper and lower Thames River.		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3,4]
		Furthermore, projects that occur outside the purview of routine index station monitoring sometimes detect the 5 mussels. As part of a relocation effort in the Thames River in 2013, 1 RB was excavated and moved. Also in 2018, DFO uncovered 1 RB valve during a timed-search survey at a site downstream of The Forks, the location at which all 3 upper Thames River branches connect (Sheldon et al. 2020). Since live RB are only known from the north Thames River above the Fanshawe Reservoir, it is possible the valve could have travelled from the north Thames River population upstream. **Historical locations:** In 2012, DFO conducted a preliminary search (visually, using the intensive timed-search technique) for NRS in the Maitland River (Epp et al. 2013); no live (or shells) NRS were found. Historically RP and SB were known from the Niagara River; however, recent surveys (2014 to 2016) of the Welland River (a tributary of the Niagara River) found no evidence of these species (Wright et al. 2017). The intensive timed-search technique was used, with the addition of mussel scoops for deeper areas, at 19 sites. Lake Henry on Pelee Island was surveyed for the first time using a semi-quantitative sampling technique in 2016. Only 1 RP shell was encountered at the 22 sites sampled. In 2019, Central Michigan University undertook a scuba diving survey at U.S. and Canadian sites in the Detroit River (Keretz et al. 2021). Canadian sites yielded three RP and shells of NRS. Additionally, reports have recently been published that characterize surveys that occurred in the time-period of the previous progress report (2006 to 2011). In 2008, Morris et al. (2012) surveyed 8 sites		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		(visually, using the intensive timed-search technique) within the Welland River watershed; no RP or SP were found. In 2011, DFO undertook freshwater mussel surveys in 2 Great Lakes drainages using the semi-quantitative half-hectare survey method (Minke-Martin et al. 2015). The survey included sites in the lower Grand River; no SB or RP were detected.		
Monitoring habitat: Establish permanent monitoring sites for tracking changes in habitat.	Research and monitoring	Habitat monitoring is performed in conjunction with routine index station monitoring within Lake St. Clair (St. Clair River delta), and the Ausable, Grand, Sydenham, and Thames rivers. Quantitative mussel sampling conducted at these locations is paired with assessments of habitat conditions. This included water velocity, depth, degree of siltation, aquatic macrophyte presence/absence, algal growth, degree of shading, and streambed/substrate composition. The Provincial Water Quality Monitoring Network (PWQMN) measures water quality in rivers and streams across Ontario (PWQMN 2022). Parameters measured include: total and dissolved nutrients, metals, conductivity, turbidity, and chloride. Stations exist within the distribution of the 5 mussels in the Grand, Thames, Ausable, and Sydenham rivers.	iv	**DFO**, **CA**, MECP
Research threats: Identify and evaluate threats to all life stages.	Research and monitoring	No investigations into the status of the Mudpuppy (*Necturus maculosus*; the only known host for SM) in the Sydenham River have been undertaken to date. LTVCA is in the process of collecting threat data and initiating threat assessments to aquatic species at risk in LTVCA jurisdiction at a subwatershed level. **Invasive species**: Rowe and Zanatta (2015) investigated whether *Dreissena*-induced population declines might have impacted the genetic population structure of the Fatmucket (*Lampsilis siliquoidea*) in the St. Clair River delta. Genetic effects were found to be relatively minor on the	v	**DFO**, **AI**, **CA**, **ECCC,** OMNRF, USGS, USFWS

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		Fatmucket, the most common unionid remaining in the delta. Genetic effects on the 5 mussels still found in the delta remains to be explored, and the authors caution against assuming that other unionids would necessarily display similar levels of genetic diversity and patterns of gene flow. Tremblay et al. (2016) investigated whether the invasive Round Goby (*Neogobius melanostomus*) facilitates or inhibits unionid (including NRS and SB) recruitment. Their findings suggest that the Round Goby serves more as a glochidia sink than host, thereby limiting unionid recruitment success. Furthermore, the consumption of unionids by Round Goby was documented in the French Creek watershed, Pennsylvania (Bradshaw-Wilson et al. 2019). The risk to freshwater unionids stemming from a potential invasion of Black Carp (*Mylopharyngodon piceus*) is currently being assessed (T. Morris, DFO pers. comm 2018). Black Carp, a large molluscivore originating from eastern Asia, is likely to prey upon freshwater mussel species within the Great Lakes watersheds should it become established. This study examines the potential risk to native freshwater mussel species, including those that are federally and provincially listed, by examining the relationship between the gape limitation of Black Carp and the size distribution and growth patterns exhibited by mussels (Morris et al. 2016). **Habitat alteration (siltation and turbidity, nutrient loads, thermal effects)**: A meta-analysis of the literature was performed to investigate relationships between habitat condition and mortality in freshwater mussels. The studies included in this meta-analysis contain a variety of habitat variables such as substrate composition, nutrient levels within the water, water depth, water temperature, pH, dissolved oxygen, sedimentation, flow, presence of host fishes, and others. The		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		results of this research provide insight towards species-specific threat evaluation and help to prioritize avenues of threat mitigation research (Braoudakis et al. 2017). Cao et al. (2013) examined how unionid species richness and abundance were related to land use at different spatial scales, and to fish species richness and abundance (in east central Illinois, U.S.). They found that RP abundance decreased with higher water depth and % cobble, and increased with higher sinuosity and % wetlands. Additionally, Hornbach et al. (2019) observed decreased unionid diversity and abundance with increased agricultural land use. Ries et al. (2016) investigated the annual variation in unionid recruitment and its relationship to river discharge (West Newton Chute a side channel in the Upper Mississippi River, Minnesota). Unionid recruitment (RP is part of the mussel assemblage) appeared to be significantly related to components of spring and summer discharge, suggesting that it may be possible to manage river discharge to benefit mussel recruitment. Mistry and Ackerman (2016) have examined the clearance rates (CR)[8] of the recently metamorphosed juveniles of other mussel species (which can be used as surrogates for species at risk) under ecologically relevant conditions of algal flux[9]. These surrogate species include: Fatmucket (*Lampsilis siliquoidea*), Wavyrayed Lampmussel (*Lampsilis fasciola*), Rainbow (*Villosa iris*), and Eastern Pondmussel (*Ligumia nasuta*). The results of this study showed that the CR of the juvenile mussels increased with algal flux as well as in relation to the mussel size (shell length). These findings demonstrate that changes in pore water velocity and/or algae concentration (algal		

[8] The rate at which mussels feed on suspended particles.
[9] Refers to a value that represents the combined interactive effects of water velocity and algal concentration.

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3,4]
		flux), which can result from sediment loading and habitat alteration, can impact the growth and survival of juvenile mussels. In addition, research conducted by Mistry and Ackerman (2018) examined the CR of adult mussels of the aforementioned species under varying levels of algal flux and demonstrated their ability to discriminate and select preferred algae species is diminished when exposed to higher rates of flux. These findings suggest that increased flows resulting from hydro facilities, climate change, and land-use practices could limit the ability of mussels to select algae species of higher nutritional value, consequently impacting their growth and survival. Although the 5 mussels have not been specifically evaluated, evidence suggests that elevated total suspended solids (TSS) concentrations are detrimental to unionids. Tuttle-Raycraft et al. (2017) examined the effect of TSS concentration on the CR of newly transformed juvenile and adult unionids. CRs were found to decrease as TSS increased, and the decrease in feeding was 5 times greater in juveniles compared to adults. Therefore, elevated turbidity levels may have detrimental effects on unionid recruitment. Evidence suggests that increases in TSS may interfere with sperm uptake, thus impacting reproduction (Gascho Landis et al. 2013; Gascho Landis and Stoeckel 2015). Tuttle-Raycraft and Ackerman (2018) suggest that the modulation of CRs, in the face of elevated TSS, may be more dependant on particle quality rather than the size of particles present. Experiments on the combined effect of water temperature, turbidity, and flow on the CR, oxygen consumption, and resultant scope for growth of adult Fatmucket were conducted (Luck 2020; Luck and Ackerman 2022). The results of this study showed the primary factor affecting CR and oxygen consumption varied with acclimation temperature, with strong declines in CR when exposed to warmer temperature and high TSS. These findings determined a worst case		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		scenario (that is, higher oxygen consumption, lower CR and scope for growth) would occur during a summer with above average temperatures and TSS, and below or above average water velocities, resulting from increased frequency of drought and storm events. **Toxic compounds**: Boogaard et al. (2015) investigated the toxicity of lampricide (TFM [3-trifluoromethyl-4'-nitrophenol]) on SB (and a surrogate), and a common host fish (Logperch). Low SB mortality was observed at TFM concentrations above typical levels applied in the field, and no significant effect on the number of glochidia that metamorphosed on adult Logperch was observed. However, substantial mortality of Logperch was observed at TFM concentrations typically applied to streams, raising concerns that SB reproduction could be adversely affected from Sea Lamprey (*Petromyzon marinus*) control operations. Mitigation of impacts may be possible by reducing treatment concentrations or deferring treatments until later in the season after juvenile mussels have detached from host fish. Newton et al. (2017) estimated the risk of mortality and sub-lethal effects (that is, siphoning activity, gaped valves, production of mucus, rigid foot extension) on unionids (including RP) exposed to lampricide (Bayluscide) in a laboratory setting. Exposure to Bayluscide was associated with mortality and sub-lethal effects in most unionid species tested. Statistically significant duration effects on sub-lethal responses were recorded for RP adults. Patnode et al. (2015) recorded impaired survival of juvenile NRS that were deployed in cages downstream of a municipal wastewater treatment plant (Allegheny River, Pennsylvania). Although the 5 mussels have not been specifically evaluated, recent evidence suggests that chemical contaminants (derived from		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3,4]
		agricultural and road runoff, municipal wastewater, and industrial effluents) are negatively affecting unionid mussels (Gillis 2012; Hazelton et al. 2013; Gillis et al. 2014a, 2014b; Gilroy et al. 2014; Leonard et al. 2014; Machado et al. 2014; Jasinska et al. 2015; de Solla et al. 2016; Prosser et al. 2016; Gillis et al. 2017a, 2017b; Gilroy et al. 2017; Leonard et al. 2017; Jorge et al. 2018; Haag et al. 2019).The implications of road salt applications in Ontario has been a particular focus due to unionids sensitivity to chloride (Pandolfo et al. 2012; Blakeslee et al. 2013; Beggel and Geist 2015; Nogueira et al. 2015; Prosser et al. 2017; Wang et al. 2018a, 2018b). On the other hand, pesticides may pose a minimal risk to unionid viability and survival (Salerno et al. 2018). Kilgour et al. (2013) highlighted the ecological benefits (including to unionids) of implementing mitigations contained within Environment and Climate Change Canada's Code of Practice for the Environmental Management of Road Salts. However, they cautioned that the net ecological benefit of implementing best practice guidelines may be undermined as chloride loadings and concentrations are generally increasing in association with increasing urbanization.		
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	Research and monitoring	Galbraith et al. (2015) investigated patterns of genetic structure and diversity in 6 unionid species (including SB) collected from Ontario rivers. Genetic divergence among rivers (Ausable and Sydenham rivers) was most pronounced in SB compared to other species evaluated, which may reflect limited dispersal capabilities of host fishes. To a lesser degree, genetic structuring was also observed among populations of SB within the 2 rivers. Beaver et al. (2019) assessed the genetic diversity and structure among populations of SB in the Great Lakes drainage, including U.S. and Canadian locations. Genetic structure followed the geographic distribution of the sampling locations in the major drainages sampled; none of the 12 sampling locations showed evidence of significant	vi	**AI**, DFO, OMNRF, USFWS, USGS

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
in Canadian and U.S. waterways.		inbreeding. Some substructure was noted for SB in rivers that drain into the Huron-St Clair-Erie corridor (that is, Clinton, Ausable, and Sydenham rivers). Julian et al. (2014) identified and characterized microsatellite loci[10] in RB collected from 2 locations in the Allegheny River (Pennsylvania, U.S.). These markers may be useful for RB population analyses and recovery.		
Capacity building: Promote and enhance expertise in freshwater mussel identification/biology and provide for the transfer of knowledge.	Management	DFO, in partnership with SCRCA, have continued to conduct a hands-on freshwater mussel identification course that is offered to government, non-government organizations, Indigenous groups, and the general public. Similarly, LTVCA have coordinated (DFO provided the training) freshwater mussel identification workshops, which have been directed at Indigenous groups. DFO has worked with the Toronto Zoo to develop the Clam Counter app, for unionid identification and reporting. The Clam Counter was launched in 2017, and is available for Android and iOS devices.	vii	**DFO**, **CA**, Toronto Zoo
Cooperation ecosystem recovery strategies: Work with existing ecosystem recovery teams to implement recovery actions.	Management	The “Action Plan for the Sydenham River in Canada: An Ecosystem Approach” (DFO 2018b) contains measures to support the recovery of the 5 mussels, while the “Action Plan for the Ausable River in Canada: An Ecosystem Approach” (DFO 2018a) has a focus on NRS and SB recovery. To oversee the implementation of these action plans, the Sydenham River and Ausable River recovery teams were formed. These teams are made up of DFO, conservation authorities (CAs), provincial departments, and academic partners. A multi-stakeholder partnership led by the IUCN, which included DFO, resulted in the development of a report that identifies freshwater Key Biodiversity Areas (KBAs) in Canada (Tognelli et al. 2017). The report identifies eastern Lake St. Clair, and the Ausable and Sydenham rivers as freshwater KBAs in Canada. The NRS, SB, SM, and RB were key species considered in the identification of KBAs.	v, vii	**DFO**, **CA**, AI, IUCN, MECP, OMNRF, OP

[10] Short segments of repeated DNA.

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants[3,4]
		The information and data in this report should help guide conservation actions and management, development of policies, and aid in decision making regarding development activities within the KBAs.		
Municipal planning: Encourage municipal planning authorities to consider recovery goals in official plans.	Management	Municipal public works and planning departments have been included in aquatic species at risk outreach activities conducted by DFO. For example, DFO has provided a review of new species at risk Critical Habitat Orders, and a refresher on DFO's integrated project review process. Additionally, DFO has developed and distributed aquatic species at risk official plan guidance for municipalities (that is, Regional Planning Commissioners of Ontario) to incorporate into municipal official plan updates.	v, vii	**DFO**
Drainage: Work with drainage superintendents, engineers and contractors to limit the effects of drainage activities on mussel habitat.	Management	DFO provides species at risk-specific guidance regarding proposed drainage activities, on an ongoing basis. Furthermore, DFO has delivered presentations to drainage supervisors and engineers that identify issues and threats to species at risk, including the 5 mussels, which may arise as a result of drainage activities such as cleanouts. Mitigation measures and Best Management Practices (BMPs) are communicated through these presentations. Lastly, a DFO document titled "Guidance for Maintaining and Repairing Municipal Drains in Ontario" (Kavanagh et al. 2017) has been published. The document provides a more detailed description of BMPs that should be employed to reduce harmful impacts to fishes and freshwater mussel species.	v, vii	**DFO**
Fish management plans: Encourage the development of management plans for non-SAR fish species within watersheds inhabited by the NRB, SB, RP, and RB.	Management	No progress has been made regarding this measure.	v, vii	

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
Baitfish: Work with the baitfish industry to reduce the impacts of commercial baitfishing on host species.	Management	The province of Ontario is drafting a new baitfish strategy[11], which will describe a new approach to managing baitfish and leeches, with the aim of reducing the ecological risks associated with the use and movement of bait in Ontario. Commercial bait harvesters and dealers will be required to take a standardized training course designed to increase harvester and dealer awareness of non-target species, including invasive species and species at risk, and identify actions to prevent their spread. DFO updated the baitfish primer to include links to the national aquatic species at risk maps for areas to avoid during baitfish collection. In addition, an application called Baitfish Primer was created and is available for free download from the Apple App Store and the Google Play Store.	v, vii	**OMNRF, DFO**
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	Management	No progress has been made regarding this measure.	v, vii	

[11] Ontario's Sustainable Bait Management Strategy was published in 2020 and came into effect on January 1, 2022.

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
development where possible.				
Enforcement: Assist federal and provincial enforcement officers in obtaining the necessary information and/or resources required to protect these species and their habitats.	Management	Federal Fisheries Officers are provided copies of all the *Species at Risk Act* (SARA) permits that are issued, which helps to guide monitoring and compliance efforts. Training on SARA is part of the requirements of the Fisheries Officer Career Progression Program and provides Fisheries Officers with the knowledge and resources for SARA enforcement. Species at risk mapping is available to all federal Fisheries Officers, along with A Guide to Interpreting Fish and Mussel Species at Risk Maps in Ontario. Federal Fisheries Officers attended the freshwater mussel identification workshop, which is held yearly, where they were trained in mussel identification and provided with resources to identify mussels (for example, the "Photo Field Guide to the Freshwater Mussels of Ontario").	v, vii	**DFO**
Riparian buffers: Establish riparian buffer zones in areas of high erosion potential by encouraging naturalization or planting of native species.	Stewardship	Federal funding is available annually through the Aboriginal Funds for Species at Risk (AFSAR) and the Habitat Stewardship Program (HSP). HSP funding was provided by DFO through ECCC[12] to CAs and environmental non-government organizations to support local stewardship initiatives led primarily by environmental non-government organizations, while AFSAR funding supports the development of Indigenous capacity to participate actively in the implementation of SARA. Starting in 2018, the Canada Nature Fund for Aquatic Species at Risk (CNFASAR) was initiated with the aim of supporting the recovery and protection of aquatic species at risk. Collectively, funded activities facilitate the implementation of conservation measures, such as BMPs associated with water quality improvements, and reduction of sediment loading (for example, planting of riparian buffers). Similarly, the OMNRF administers the Species at Risk Stewardship Fund (SARSF)[13], which provides money for stewardship activities similar to what is described for HSP funded projects. Some of the	v	**DFO**, **CA**, **OMNRF**, ENGO

[12] HSP funding for aquatic species at risk has been funded solely through DFO since 2019.
[13] Note that it is currently called the Species at Risk Stewardship Program (SARSP) and administered by MECP.

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		projects funded through SARSF have been conducted in areas where the 5 mussels occur. With the aid of HSP funding, GRCA works with rural residents to implement projects that will improve water quality, which benefits species at risk like the RP. These projects have contributed towards the planting of native trees and shrubs, including: riparian buffers along the edge of watercourses and wetlands, and on retired pasture land. Similarly, SCRCA has undertaken habitat stewardship projects with local landowners, with the aid of HSP and SARSF funding. The planting of trees and shrubs has occurred within the Sydenham River watershed with the aim of reducing sediment and nutrient loading. ABCA has utilized SARSF, HSP, and CNFASAR funding to implement stewardship and habitat improvement approaches to recovery from the “Recovery Strategy for Species at Risk in the Ausable River: An Ecosystem Approach” (Ausable River Recovery Team 2005). Habitat improvement projects were completed in partnership with landowners that included the planting of streamside and wetland buffers of native trees and shrubs to reduce the impacts of erosion and improve water quality, the planting of cover crops, retiring floodplains from agriculture, and the re-establishment of wetlands to help reduce sediment and nutrient inputs. LTVCA have also started a HSP funded project to restore riparian buffers within the Thames River watershed. Although not targeting any of the 5 mussels directly, additional HSP funded projects may aid in their recovery or improve conditions in historical locations (which may allow for future reintroductions if deemed feasible). Through the Thames River Aquatic Ecosystem Stewardship Initiative, UTRCA has worked directly with landowners to implement soil and water conservation practices to reduce nutrient and sediment loads to Fish Creek (a Thames River tributary). Stewardship projects included the establishment of tree buffers,		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		retirement of highly erodible lands, livestock watercourse access restriction, and the diversion of clean water away from potentially contaminated areas. Although the focus is on fish species at risk, ERCA has partnered with private landowners in order to achieve the planting of native tree and shrub species in riparian areas and on erodible lands. They also completed wetland excavation and streambank bioengineering projects to enhance water quality conditions. These projects were completed within priority watersheds of the Essex-Erie study area, and include tributaries to the Detroit River and Lake St. Clair (historical locations of the 5 mussels). LPRCA has improved water quality and habitat along watercourses in watersheds that encompass Big Creek, Turkey Point, and Long Point marshes (historical locations of the SB and RP). Projects included the creation of sediment basins and wetlands, tree planting and native ground cover establishment, and the creation of floodplain swamps and oxbow scars.		
Tile drainage: Work with landowners to mitigate the effects of tile drainage. **Herd management**: Encourage the active exclusion of livestock from the watercourse. **Livestock waste management**: Assist with establishing adequate manure collection and storage systems to avoid accidental spills, and	Stewardship	The use of BMPs is encouraged through project reviews and recommended mitigation approaches on rural properties, including: livestock restrictions (exclusion fencing), milkhouse washwater system installations, riparian buffers, streambank stabilization, wetland creation or enhancement, well decommissioning, septic upgrades, and sediment control/trapping to prevent runoff and improve water quality. Many HSP funded habitat improvement projects have occurred on agricultural land. For example, GRCA has provided landowners with technical assistance to help them improve manure storage and nutrient planning on their farms. This was achieved by constructing exclusionary cattle fencing, and installing water and sediment control berms. ABCA has undertaken stewardship projects with landowners, including the construction of exclusionary cattle fencing to keep cattle out of the watercourse, which should help reduce erosion and nutrient loading, and eliminate harm or death to mussels.	v, vii	**CA**, **OSCIA**, CCC, DFO

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3,4]
winter-spreading of manure. **Farm planning**: Encourage the development and implementation of Environmental Farm Plans and Nutrient Management Plans. **Soil testing**: Encourage soil testing to determine fertilizer application rates.		CCC, with the aid of HSP funding, has encouraged the following: establishment of riparian buffer zones, the active exclusion of livestock from watercourses, the development and implementation of Environmental Farm Plans and Nutrient Management Plans, and soil testing to determine appropriate fertilizer application rates. The Species at Risk Farm Incentive Program (SARFIP), through the OSCIA, includes information on what BMP farm activities can help species at risk and on cost-share opportunities. Examples of completed projects include shoreline improvements, installation of exclusionary fencing, and improvement to stream crossings. The Great Lakes Agricultural Stewardship Initiative, targeted to the Lake Erie basin and the southeast shores of Lake Huron, aided farmers in adopting BMPs regarding soil erosion control structures, cover crops, residue management, and buffer and shelter strips.		
Sewage treatment: Work with landowners to improve faulty septic systems.	Stewardship	No progress has been made regarding this measure.	v, vii	
Agency interaction: Cooperating and coordinating efforts with stewardship councils and CAs.	Stewardship	DFO continues to partner with CAs and stewardship councils, principally through the HSP. Additionally, species at risk screening maps have been provided annually to CAs (through Conservation Ontario) that indicate where critical habitat of the 5 mussels is located within a given jurisdiction or municipality to inform planning and permitting decisions.	v, vii	**DFO**, **CA**
Awareness stewardship actions: Increase public knowledge of stewardship options and financial	Awareness	The HSP and AFSAR programs are key sources of funding that DFO makes available for stewardship projects targeting species at risk, including the 5 mussels (see table 2, riparian buffers). Annually, DFO promotes these funding opportunities to applicable CAs, Indigenous groups, and other key stakeholders. Through partnerships with watershed-based conservation organizations (for example, CAs),	vii	**DFO**, **CA**, CCC

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
assistance available to participate in activities.		DFO has promoted the implementation of BMPs via presentations, project reviews, and site meetings with the agricultural community, drainage engineers, and the Ontario Drainage Superintendents Association. With the aid of HSP funding, CCC has increased public knowledge of stewardship options and financial assistance available to participate in stewardship activities. CCC has created and promoted community-based conservation action plans (CAPs) for species at risk and ecosystem recovery in the Carolinian life zone. The CAP process engages multiple stakeholders and community organizations to identify and address the highest priority recovery needs of species at risk, and engages the business and agricultural communities in targeted recovery actions. BMP fact sheets were produced for species at risk identified in CAPs, and distributed to landowners, farmers, land managers, foresters, planners, conservation practitioners, and the general public. Similarly, ABCA, GRCA, LTVCA, and SCRCA have provided landowners with information on species at risk funding programs that focuses on stewardship projects designed to benefit species at risk. With the aid of HSP funded education and outreach programs, SCRCA has noted an increase in the number of word-of-mouth inquiries from landowners interested in implementing stewardship projects on their property.		
Invasive species: Increase public awareness of the potential impacts of transporting/releasing invasive species.	Awareness	Aquatic invasive species information has been disseminated through the Watercraft Inspection Program, and educational outreach material distributed by DFO (public postings and direct engagement). Furthermore, licensed commercial baitfish harvesters in Ontario have completed Hazard Analysis and Critical Control Point training, which focuses on impacts and prevention of the spread of aquatic invasive species. Research funded by DFO (Drake and Mandrak 2014b, 2014b) has quantified the risk of invasive fish species introductions throughout the province as a result of the bait industry. Through HSP funded projects, CAs and CCC continue to focus outreach activities on public education and awareness of aquatic invasive species. An	vii	**DFO**, **CA**, **OMNRF**, CCC, Toronto Zoo

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		example is ABCA's production of the Old Ausable channel fish community card, which provides information on the threat of invasive species to species at risk. Additionally, through their Great Lakes Program (GLP), the Toronto Zoo developed and delivered invasive species outreach presentations at the request of teachers, and opened an exhibit at the Toronto Zoo on Asian Carp. And finally, LTVCA has utilized social media posts to increase public awareness of aquatic invasive species. *Aquatic Invasive Species Regulations* were enacted under the *Fisheries Act* in 2015. The regulations provide a national regulatory framework to help prevent intentional and unintentional introductions of aquatic invasive species in Canada from other countries, across provincial and territorial borders, and between ecosystems within a region. They also provide measures to facilitate response and control activities related to invasive species. The government of Ontario has legislated the *Invasive Species Act* (2015), which seeks to prevent new invasions, slow and/or reverse the spread of existing invasive species, and reduce the harmful impacts of existing invasive species.		
Outreach: Encourage public support and participation by developing awareness materials and programs.	Awareness	Ongoing DFO outreach to Indigenous groups, key stakeholders, and the Canadian public, includes information on aquatic species at risk (including the 5 mussels), helping raise awareness of their status and need for conservation. DFO has delivered presentations that highlight threats, critical habitat and ways to reduce anthropogenic threats to aquatic species at risk through green infrastructure, mitigation, and recovery actions. Presentations have been given to: environmental students at Fleming College, the Ontario Aboriginal Lands Association (OALA) and the Ontario First Nations Economic Development Association (OFNEDA), the Latornell Conservation Symposium, partner agencies, and members of the Ontario Land Trust Alliance.	vii	**DFO**, **CA**, CCC, OMNRF, OSCIA, Toronto Zoo

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3, 4]
		Awareness of species at risk and the threats they are facing has been communicated to the general public and school children by DFO at the Canadian Centre for Inland Waters open house events, and outreach material was provided by DFO at the Day on the Grand Brantford Arts and Music Festival. Due to concern about the impact of increased recreational use of the Grand River on aquatic species at risk, municipal representatives, the general public, and other stakeholders (for example, outfitters) have been targeted with outreach sessions that review SARA, critical habitat, and BMPs to reduce potential impacts of outfitter activities. DFO staff have targeted outreach to youth groups (for example, Boy Scouts of Woodstock) with information sessions that include displays of freshwater mussel shells, fact sheets, and guide books. DFO, in conjunction with CAs, have reached representatives from municipalities, consultants, and contractors with presentations on SARA, aquatic species at risk listing changes, funding opportunities, and highlighted CA stewardship successes. With the aid of funding from HSP, numerous CAs have conducted their own outreach activities. Examples include ABCA conducting community information sessions and student programs to educate, and increase the profile of species at risk in the Ausable River watershed. Additionally, the community joined ABCA staff to evaluate the habitat in the Old Ausable Channel, while LTVCA has promoted awareness of unionids through social media postings. GRCA, with the aid of HSP funding, has been involved in outreach activities that have raised the profile of species at risk. Examples include, holding stewardship workshops for rural non-farm and horse owners, and the production of media releases highlighting projects undertaken to improve and protect habitat for aquatic species at risk. GRCA has also involved the public in stewardship projects by having volunteers assist in the planting of riparian buffers.		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants[3,4]
		SCRCA undertook a variety of education and outreach projects to assist with the recovery of a broad range of aquatic species at risk in the Sydenham River, through school programs, landowner contact, and direct promotion. It conducted a species at risk education program for elementary students through in-school and field visits. SCRCA continues to produce and distribute an annual species at risk newsletter, utilize social media, organize workshops and outreach events, all to generate awareness regarding the Sydenham River and it's aquatic species at risk. The Toronto Zoo, through its GLP with the aid of HSP and SARSF funding, has provided classroom outreach presentations on freshwater mussel biology and conservation, which demonstrates the interconnected relationships of species at risk to the health of the Great Lakes watershed. Outreach was targeted to schools in watersheds of HSP priority regions (Ausable, Grand, Thames, and Sydenham rivers). The program promotes BMPs to aid in minimizing impacts on species at risk and their habitats, while increasing public knowledge and awareness of species at risk. Freshwater mussels are key species at risk in the revised GLP brochure that were distributed to all program participants. Further activities included attending cottager association meetings, and developing a new interactive digital education module based on the life history and habitat requirements of target aquatic species at risk. With the aid of HSP funding, CCC has undertaken a variety of outreach activities. Briefly, species at risk outreach has occurred through press releases and newsletter articles highlighting species at risk recovery actions, presentations and talks, monthly Eco-News news briefs, events such as the Go Wild Grow Wild Expo and Ecosystem Recovery Forum, to a variety of stakeholders (for example, practitioners, landowners, Indigenous groups, and youth).		

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants [3,4]
		Through the SARFIP, several communications and outreach projects were developed with the aim of raising the profile of species at risk on farms, and to educate farmers about stewardship activities designed to enhance biodiversity.		
Refine and investigate the efficacy of monitoring protocols (not prescribed in recovery strategy).	Research and monitoring	Continued development and refinement of unionid survey protocols is important to the recovery of the 5 mussels. Reid (2016) investigated the relationship between species detection and search effort of timed-search methods undertaken in lotic environments. Although species detection was found to be imperfect, detection probabilities were high (>0.69) for most species. Ultimately, it was determined that 2 repeat 4.5 h surveys were required to confidently evaluate whether most mussel species were present at a site. Research has been conducted that explores the efficacy of a quadrat-based sampling protocol to detect mussel species at risk, estimate their abundance and detect changes in their density (Reid and Morris 2017). The results demonstrate that the protocol can detect the majority of species present at a site and provide accurate total mussel density estimates. For small individuals, excavation was essential for reliable detection, and to accurately estimate abundance. However, the usefulness of the protocol was limited for reliable detection of most species at risk, and imprecise density estimates precluded detection of all but the most extreme changes in density of most individual species. Hence, the authors conclude that either a substantially greater sampling effort under the current protocol, or a fundamental revision of the sampling approach may be necessary to meet monitoring objectives. Reid et al. (2018) used a simulation-based approach to evaluate whether adaptive cluster sampling could improve unionid monitoring versus the quadrat-based protocol. Adaptive sampling was found to be less accurate and efficient than alternatives, and hence, improvements to the existing quadrat-based monitoring program will only be achieved by increasing its spatial coverage. Additionally, the province of Ontario published a survey	iv	**OMNRF, DFO**

Activity	Broad strategy	Descriptions and results	Recovery objectives	Participants[3,4]
		protocol for sampling unionids in Ontario wetlands using visual, tactile, and/or scooping techniques (OMNRF 2018).		
Research the applicability of eDNA sampling for detecting freshwater mussels (not prescribed in recovery strategy)	Research and monitoring	Cho et al. (2016) investigated the possibility of developing species-specific environmental DNA (eDNA) markers for at-risk unionids. They determined that it should be possible to develop species-specific eDNA markers, which would allow for screening of water samples for unionid habitat occupancy. A sampling protocol specific to the Salamander Mussel is under development by DFO, which involves the use of eDNA. In addition to eDNA sampling that focuses on individual species (for example Currier et al. 2018), community eDNA assays are being developed that have the potential to characterize local species assemblages simultaneously (Coghlan et al. 2019). Morphometric analyses and DNA barcoding are being applied for the purpose of distinguishing between the frequently misidentified Wabash Pigtoe (*Fusconaia flava*) and RP (Willsie et al. 2020).	iv	**AI, DFO**

3.2 Activities supporting the identification of critical habitat

Table 3 provides information on the implementation of the studies outlined in the schedule of studies to identify critical habitat from the recovery strategy. Although critical habitat was identified in the amended recovery strategy published in 2019, studies are still needed to refine critical habitat identification. Each study has been assigned 1 of 4 statuses:

1. completed: the study has been carried out and concluded
2. in progress: the study is underway and has not concluded
3. not started: the study has been planned but has yet to start
4. cancelled: the study will not be started or completed

Table 3. Status and details of the implementation of the schedule of studies for the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean outlined in the recovery strategy (Morris and Burridge 2006) during the period of 2012 to 2019.

Study	Timeline	Status	Descriptions and results	Participants[14]
Conduct mussel population surveys	2012 to 2024	In progress	Monitoring surveys have been conducted within occupied/recently occupied locations including the Maitland, Ausable, Sydenham, Thames, Detroit, Grand, and Welland rivers, Lake St. Clair, Pelee Island, Rondeau Bay, and Long Point region. Some of the surveys employed quantitative survey methods that allow for inferences of species abundance, which in turn may ultimately inform an understanding of population trajectories.	DFO, CA, OMNRF
Assess habitat conditions in occupied areas (for example, flow, substrate, water clarity and quality)	2012 to 2024	In progress	Habitat conditions have been evaluated as a component of the quadrat surveys, which were conducted at index monitoring stations where populations of the 5 mussels occur. As surveys at index monitoring stations are repeated on a multi-year time frame, habitat conditions will continue to be evaluated.	DFO, CA
Determine any life stage differences in habitat use	2019 to 2024	Not started	Research regarding the life-stage specific habitat use has not been undertaken at this stage for any of the 5 mussels.	DFO
Survey and map areas of suitable but unused habitat within historical range	2012 to 2024	In progress	Habitat characteristics continue to be quantified in historically occupied 5 mussel locales. These data are collected as part of other unionid and fish surveys.	DFO, CA, OMNRF
Assess genetic structure of populations	2012 to 2024	In progress	Patterns of genetic structure and diversity have been investigated for the Snuffbox.	DFO, AI

[14] Participant full names: Academic Institutions (AI), Conservation Authorities (CA), which includes Grand River (GRCA), Niagara Peninsula (NPCA), Long Point Region (LPRCA), St. Clair Region (SCRCA), Ausable Bayfield (ABCA), Essex Region (ERCA), Lower Thames Valley (LTVCA), and Upper Thames Region (UTRCA) conservation authorities, Fisheries and Oceans Canada (DFO), and Ontario Ministry of Natural Resources and Forestry (OMNRF).

Study	Timeline	Status	Descriptions and results	Participants[14]
			Investigations into the genetic structure of the Salamander Mussel are in progress, while the other 3 species remain to be investigated for Canadian populations.	
Complete host fish studies	2012 to 2024	In progress	Investigations are continuing to strengthen understanding of host fish specificity and dynamics. Additionally, a model has been developed to aid in identifying unionid glochidia of unknown species using their shell dimensions, which may aid in determining the full suite of potential host fish species.	DFO, AI
Conduct host fish population surveys	2012 to 2024	In progress	Fish surveys continue to be performed in conjunction with unionid monitoring at index stations. Host fish population dynamics will be better understood from the data derived from these surveys, and from fish population surveys that are conducted for other purposes.	DFO, CA, OMNRF
Assess habitat use by host species	2012 to 2024	In progress	Fish community assessments have been conducted at index monitoring stations to assess the presence, and habitat use of host species. In addition, fish sampling has been undertaken by DFO and OMNRF in a number of projects unrelated to mussel research, within sites that are relevant to the 5 mussels.	DFO, CA, OMNRF
Determine areas of overlap between mussel and host habitat	2012 to 2024	In progress	See above	DFO

3.3 Summary of progress towards recovery

3.3.1 Status of progress

Highlights of progress toward reaching the recovery objectives include:

Determine extent, abundance and population demographics of existing populations

- Quantitative surveys were performed at all unionid index monitoring stations relevant to the 5 mussels (that is, Ausable, Sydenham, Thames, and Grand rivers, and St. Clair River delta)
- The Salamander Mussel was detected at a new site in the Sydenham River within its known distribution, and at a site upstream of its previously known distribution
- Lake Henry on Pelee Island was surveyed for the first time; only 1 Round Pigtoe shell was encountered
- A survey at Rondeau Bay uncovered a single Round Pigtoe; no Snuffbox were detected

Determine host fishes and their distributions and abundances

- Knowledge of host fish associations with Northern Riffleshell and Snuffbox were strengthened
- Logperch was confirmed as a natural host of Snuffbox, while the Blackside Darter was confirmed in the laboratory
- Improvements were made in identifying glochidia of unknown species based on shell dimensions

Define key habitat requirements to identify critical habitat

- Acquired a greater understanding of bed shear stress on the establishment of newly settled juvenile unionids

Establish a long-term monitoring program for all species, their hosts and the habitats of both

- Index monitoring stations relevant to the 5 mussels exist within Lake St. Clair (St. Clair River delta), and the Ausable, Sydenham, Thames, and Grand rivers. In the Thames River, 4 new stations were added; the initial survey of these stations was performed in 2018
- Monitoring of habitat and fishes continues to occur at index stations. These monitoring programs include provisions for the assessment of host fish populations, as well as mussel and host fish habitat monitoring

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

- The understanding of the role that the invasive Round Goby (*Neogobius melanostomus*) plays in unionid life history has been improved as has the impact of elevated turbidity on unionids
- An increasing body of work is helping to determine the susceptibility of unionids to a variety of chemical contaminants, in both laboratory and field settings

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

- In cooperation with the OMNRF, unionid culture techniques continue to advance (including Snuffbox and Northern Riffleshell)

- Continuing United States efforts on Northern Riffleshell translocations and monitoring are helping to reveal the viability of unionid reintroductions and methodological requirements

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

- The Clam Counter app was launched
- Unionid identification and survey workshops continue to be completed, and are helping to build knowledge for a wide variety of stakeholders and Indigenous groups
- Outreach activities are continuing to reach a multitude of stakeholders (for example, conservation authorities, drainage supervisors, municipal planners, general public), which is raising the profile of aquatic species at risk and their threats

3.3.2 Completion of action plans

Single species action plans have yet to be completed, but ecosystem-based action plans for the Sydenham and Ausable rivers were published in 2018 (DFO 2018a, 2018b), and include recovery activities that will benefit the 5 mussels (for example, stewardship actions that are informed by agricultural Best Management Practices [BMPs]).

3.3.3 Critical habitat identification and protection

Critical habitat was not identified in the original recovery strategy (Morris and Burridge 2006). Since the publication of the original recovery strategy, some investigations outlined in the schedule of studies have been completed, resulting in the identification of critical habitat. An amended recovery strategy identifying critical habitat was posted in July 2019, and critical habitat orders for each of the 5-mussel species came into effect on October 2, 2019.

3.3.4 Recovery feasibility

At the moment, there is no need to review the recovery feasibility for this species as the current information suggests that the 5 mussels still meet the feasibility criteria laid out in the recovery strategy. For example, reproducing populations still exist as potential sources to support recovery, and threats to the species can be addressed through restoration efforts and the promotion of BMPs, public awareness and education

4. Concluding statement

The 5 mussels continue to be detected during routine index station monitoring in the St. Clair River delta, and the Ausable, Sydenham, Thames, and Grand rivers. Additionally, several historical locations were recently surveyed. Although 1 Round Pigtoe was detected during a survey of Rondeau Bay, a location where the Snuffbox was also known historically, a substantial decline in unionid diversity has occurred since the dreissenid (Zebra Mussel [*Dreissena polymorpha*] and Quagga Mussel [*D. bugensis*]) invasion. Giant Floater (*Pyganodon grandis*) may be the only remaining viable unionid population in Rondeau Bay. A survey at Pelee Island failed to detect any of the 5 mussels, while the Round Pigtoe was only found at 1 site within the Detroit River. Surveys of the Welland River found no evidence of Round Pigtoe or Snuffbox, species known historically from the Niagara River system. A search for the Northern Riffleshell in the Maitland River was performed in 2012 to search for live specimens, as valves were collected in 2011; no Northern Riffleshell were encountered during the survey.

Overall, recovery activities conducted since 2011 have helped provide a better understanding of threats to the recovery of the 5 mussels, their current distribution, habitat requirements, and translocation and reintroduction potential. Ascertaining the magnitude of threats is difficult, but insights have been gained on the effects of the invasive Round Goby, as well as the impact of contaminants and turbidity on unionids. Multi-year sampling at index stations has resulted in the continued acquisition of distribution, abundance, and population demographic knowledge of the 5 mussels and their hosts. Ultimately, index station sampling should provide insights regarding the population dynamics of the 5 mussels in multiple watersheds. Furthermore, habitat monitoring performed in conjunction with unionid surveys may allow for the refinement of critical habitat identification in future recovery documents. Gaining a more extensive understanding of genetics, threats and habitat requirements of the 5 mussels is also necessary if future translocations or reintroductions are to be attempted.

Future recovery efforts for the 5 mussels should focus on the research, monitoring, and management measures that have not been adequately addressed. Specifically, research regarding life-stage specific habitat use has not been undertaken. While the understanding of threats and mechanisms of decline has improved, further research is required. A multitude of stewardship activities have occurred in watersheds occupied by the 5 mussels. Although it is difficult to quantify the effect on unionids, it is expected that the combined impact of these projects will improve recovery potential of the 5 mussels. Funding programs (Habitat Stewardship Program, Aboriginal Fund for Species at Risk, Canada Nature Fund for Aquatic Species at Risk, Species at Risk Stewardship Fund) have continued to be important components of stewardship and outreach, which are the principal modes of increasing public education on species at risk, and public participation in enacting recovery measures. Conservation authorities continue to play a key role in fostering public participation, particularly in stewardship projects that include important restoration activities designed to improve water quality and unionid habitat. Awareness activities, such as public campaigns and boat inspections (Watercraft Inspection Program), have helped to reduce or prevent the spread of aquatic invasive species that are a threat to the 5 mussels and other species at risk.

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