Progress Towards the Implementation of Management Plan for:

Wavyrayed Lampmussel (*Lampsilis fasciola*)

2025

Species at Risk Act

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Cover illustration: Courtesy of Environment and Climate Change Canada (male on left, female on right)

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Preface

The federal, provincial, and territorial government signatories under the Accord for the Protection of Species at Risk (1996) agreed to establish complementary legislation and programs that provide for the protection of species at risk throughout Canada. Section 72 of the *Species at Risk Act* (S.C. 2002, c.29) (SARA) requires the competent minister to report on the implementation of the management plan for a species at risk, and on the progress towards meeting its objectives within 5 years of the date when the management plan was placed on the Species at Risk Public Registry and in every subsequent 5-year period, until its goal and objectives have been achieved or the species becomes threatened or endangered under SARA, at which point a recovery strategy would be required.

Reporting on the progress of management plan implementation requires reporting on the collective efforts of the competent minister(s), provincial and territorial governments, and all other parties involved in conducting actions that contribute towards the conservation of the species. Management plans identify broad strategies and management objectives that will provide the best chance of conserving species at risk. Some of the identified strategies and measures are sequential to the progress or completion of others, and not all may be undertaken or show significant progress towards implementation during the time frame of a report on the progress of the management plan (progress report).

The Minister of Fisheries is the competent minister under SARA for the Wavyrayed Lampmussel and has prepared this progress report.

As stated in the preamble to SARA, success in the conservation of species at risk depends on the commitment and cooperation of many different groups that will be involved in implementing the directions set out in the management plan and will not be achieved by Fisheries and Oceans Canada (DFO) or any other jurisdiction, alone. The cost of conserving species at risk is shared amongst different groups. All Canadians are invited to join in supporting and implementing the “Management Plan for the Wavyrayed Lampmussel (*Lampsilis fasciola*) in Canada” for the benefit of the species and Canadian society as a whole.

Acknowledgments

This progress report was prepared by Josh Stacey, Colin Illes, and Jessica Epp-Martindale, Fisheries and Oceans Canada (DFO) – Ontario and Prairies Region. To the extent possible, this progress report has been prepared with input from DFO Science. DFO would like to express its appreciation to all individuals and organizations who have contributed to the conservation of the Wavyrayed Lampmussel.

Executive summary

Wavyrayed Lampmussel was listed as endangered under the SARA in 2003; however, the status was downlisted to special concern in 2013 following a reassessment by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2010. The “Management Plan for the Wavyrayed Lampmussel (*Lampsilis fasciola*) in Canada” was finalized and published on the Species at Risk Public Registry in April of 2018.

The main threats identified in the management plan for Wavyrayed Lampmussel include exposure to contaminants and toxic substances, nutrient loading, turbidity and sediment loading, altered flow regimes, and habitat removal and alterations. These threats are in addition to factors impacting the availability of host fishes, predation and harvesting, recreational activities, and the presence of aquatic invasive species, such as Zebra Mussels (*Dreissena polymorpha*) and Quagga Mussels (*Dreissena rostriformis bugensis*).

This report summarizes the progress that Fisheries and Oceans Canada (DFO), the province of Ontario, conservation authorities, and other stakeholders have made towards implementing the management plan to ensure the long-term persistence of this species throughout its current range in Canada. This report will highlight the actions between 2018 and 2023 that have contributed to the management objectives of Wavyrayed Lampmussel, including:

- Sampling conducted by DFO and partner agencies has continued to detect live Wavyrayed Lampmussel at historically known sites within the Ausable, Thames, and Grand river watersheds, as well as the St. Clair River delta. However, no live specimens have been detected at historically known sites in the Detroit and St. Clair rivers or Lake St. Clair. Extensive sampling efforts have also been carried out in the Grand River near Caledonia to support a large-scale mussel relocation program.

- DFO and partner agencies have conducted research investigating the potential impacts of invasive species, such as the Round Goby (*Neogobius melanostomus*), on freshwater mussels. Extensive studies have also examined the effects of contaminants and toxicants, including pesticides, urban pollutants (for example, wastewater from treatment plants, firefighting additives, sediment-associated substituted phenylamines, pharmaceutical pollutants, ammonia, chloride, copper, and potassium), and road salt on freshwater mussels, with a focus on the Wavyrayed Lampmussel in many cases. Additional research has explored the impacts of habitat alterations, such as suspended sediments, on the clearance rates of freshwater mussels. Efforts have also been directed towards developing expertise in the culture and rearing of Wavyrayed Lampmussels to support potential future stocking efforts.

- Progress has been made in stewardship and awareness through habitat improvement projects and outreach initiatives led by partner agencies, with support from the Habitat Stewardship Program. DFO has also contributed to outreach efforts by conducting annual events such as the Ontario Freshwater Mussel Identification Workshop and the Canadian Freshwater Mollusc Research Meeting.

Taken together, these actions highlight the progress that is being made towards the goal of conserving Wavyrayed Lampmussel populations in Canada; however, more research to assess the distribution and impact of in-stream barriers is needed, as well as an exploration into the feasibility of barrier removal where appropriate. Similarly, further coordination may be needed

with other jurisdictions to ensure that flow requirements of Wavyrayed Lampmussel are considered in management of flow regimes.

Table of contents

1. Introduction

This progress report summarizes the progress made towards meeting the management objectives listed in the "Management Plan for the Wavyrayed Lampmussel (*Lampsilis fasciola*) in Canada" (Fisheries and Oceans Canada [DFO] 2018) from April 2018 to March 2023[1]. This report is 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) assessment and status report (COSEWIC 2010) and the management plan.

Section 2 of the progress report provides an overview of key information on the main threats to the species, management objectives for conserving the species, and conservation approaches to achieve the objectives. For more details, readers should refer to the management plan. Section 3 reports on the progress made towards the actions identified in the management plan to support achieving the management objectives. Section 4 provides a concluding statement about the progress of actions taken and outcomes of these conservation efforts.

2. Background

2.1 COSEWIC assessment summary and threats to the Wavyrayed Lampmussel and its habitat

The listing of Wavyrayed Lampmussel as special concern under the *Species at Risk Act* (SARA) in 2013 led to the development and publication of the management plan for the Wavyrayed Lampmussel in 2018. The management plan is consistent with the information provided in the COSEWIC status report (COSEWIC 2010) and the COSEWIC summary information is included in section 1 of the management plan.

2.2 Distribution

Since the management plan was posted in April 2018, Wavyrayed Lampmussel has continued to be detected in a variety of waterbodies in Ontario, as seen in figure 1.

[1] The management plan was posted on the Species at Risk Public Registry on April 17, 2018; therefore, the progress reporting period begins in April and ends in April, 5 years later.

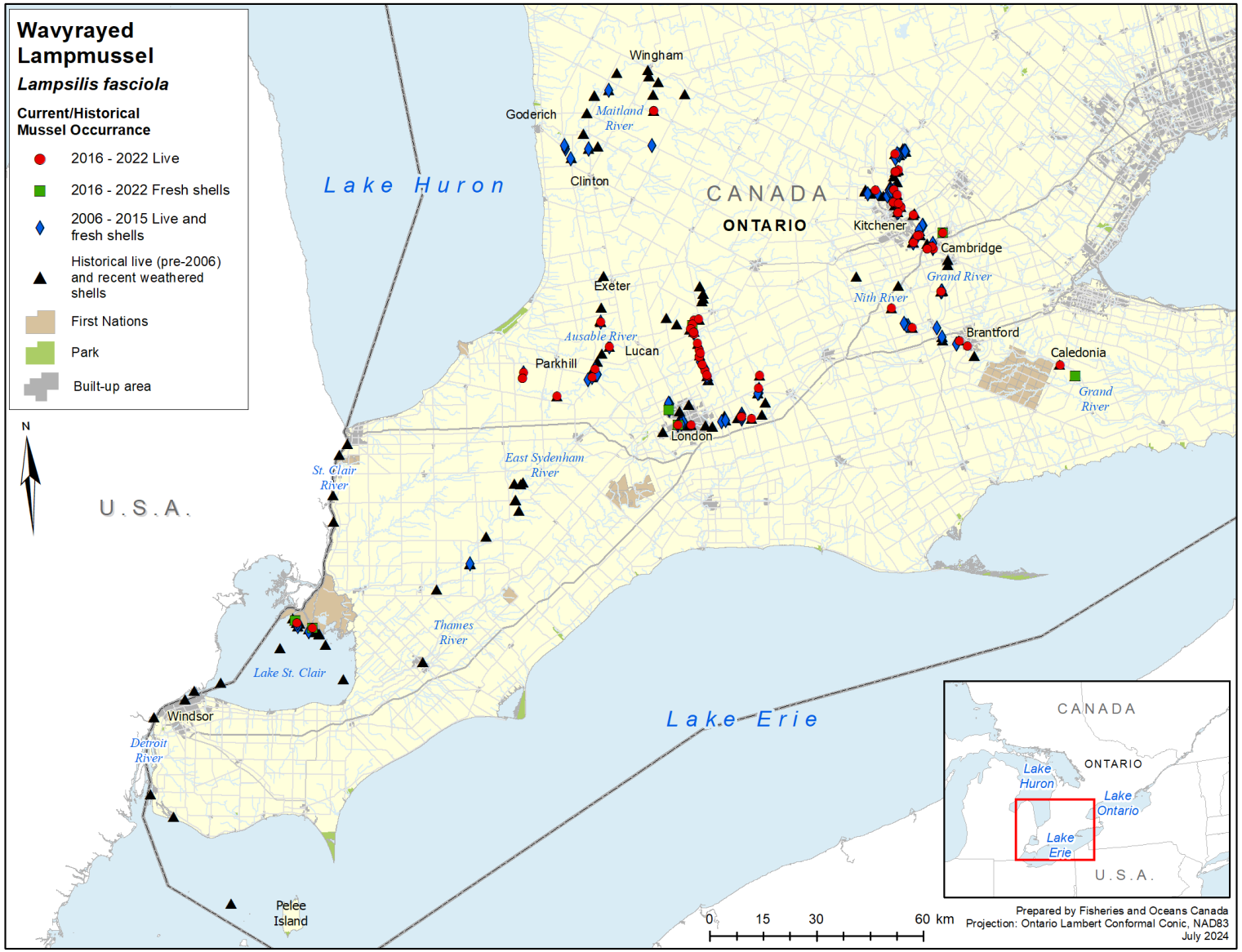

Figure 1. Historical and recent detections of Wavyrayed Lampmussel in Canada.

2.3 Management

This section summarizes the management objectives identified in the management plan (DFO 2018) as necessary for Wavyrayed Lampmussel conservation.

2.3.1 Goal

The goal of the management plan is to ensure the persistence of Wavyrayed Lampmussel throughout its current range by maintaining or enhancing self-sustaining populations, and restoring degraded populations through habitat improvement initiatives where feasible.

2.3.2 Objectives

The following short-term objectives (over the next 5 to 10 years) have been identified to assist in achieving the management goal:

- to refine extent, abundance, and population demographics of existing populations
- to confirm host fish(es) in the field
- to continue to monitor Wavyrayed Lampmussel habitat and the habitat of its host(s)
- to continue to evaluate threats impacting the Wavyrayed Lampmussel and its habitat and implement remedial actions to reduce their effects
- to continue to increase public awareness of the significance of the Wavyrayed Lampmussel and its status as a Canadian species at risk

3. Progress towards conservation

Section 72 of SARA requires the competent Minister(s) to report on the implementation of the management plan and the progress towards meeting its objectives, within 5 years after it is posted on the Species at Risk Public Registry and in every subsequent 5-year period, until its objectives have been achieved, or the species becomes threatened or endangered under SARA, at which point a recovery strategy would be required. In the interest of capturing the most recent progress on the conservation of Wavyrayed Lampmussel, this document includes actions completed by the end of April 2023.

The management plan for the Wavyrayed Lampmussel divides conservation efforts into 4 broad strategies required to protect, maintain, and improve Wavyrayed Lampmussel populations and habitat:

1. research and monitoring
2. management and coordination
3. stewardship
4. awareness

3.1 Actions supporting management objectives

Table 1 provides information on the implementation of actions undertaken to achieve the management objectives identified in the implementation schedule table of the management plan (DFO 2018). The table provides a list of relevant actions and publications between April 2018 and April 2023, as well as research and monitoring actions or publications conducted in 2016 and 2017 that were not captured in the management plan.

Table 1. Details of the actions undertaken to achieve the management objectives identified in the management plan supporting the conservation of Wavyrayed Lampmussel from 2018 to 2023, as well as actions conducted in 2016 and 2017 that were not captured in the management plan.

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
Research: field confirmation of host fish(es).	Research and monitoring	No research has been conducted to confirm host fish(es) in the field. However, fish community monitoring by DFO has confirmed the presence of host fishes, Smallmouth Bass (SMB; *Micropterus dolomieu*) and Largemouth Bass (LMB; *Micropterus nigricans*), throughout the Canadian range of Wavyrayed Lampmussel (WRLM) between 2016 and 2023.	1-1	Host fish(es)	**DFO**

[2] Note that not all of the actions described in the description and results were conducted to specifically address measures prescribed in the management plan. There are many actions described that were conducted for other species and/or by other organizations. They were included in this report because they are relevant to the management objectives of Wavyrayed Lampmussel.
[3] Lead participant(s) is/are listed on top and in bold; other participants are listed alphabetically. Not all activities have specific participants identified.
[4] Participants full names: Academic Institutions (AI), Agriculture and Agri-Food Canada (AAFC), Ausable Bayfield Conservation Authority (ABCA), Conservation Authorities (CAs), Central Michigan University (CMU), Environment and Climate Change Canada (ECCC), Fisheries and Oceans Canada (DFO), Grand River Conservation Authority (GRCA), Lower Thames Valley Conservation Authority (LTVCA), Maitland Valley Conservation Authority (MVCA), Michigan Department of Natural Resources (MDNR), Ontario Ministry of Environment, Conservation and Parks (OMECP), Natural Resource Solution Inc. (NRSI), Ontario Ministry of Natural Resources (MNR), Ontario Soil and Crop Improvement Association (OSCIA), St. Clair Region Conservation Authority (SCRCA), Toronto Zoo (TZ), and Upper Thames River Conservation Authority (UTRCA).

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		Ausable River watershed: The host species were consistently captured by DFO throughout all areas where WRLM occurs in the Ausable River in 2017 and 2018 (Barnucz et al. 2020; McAllister et al. 2022). **Sydenham River watershed:** In 2022, DFO captured a LMB within the range of WRLM in the Sydenham River watershed. Both host species are known to occur throughout the entire range in the river, and were consistently captured downstream between 2016 and 2023, near the most downstream WRLM occurrence (DFO unpub. data). **Thames River watershed:** Between 2016 and 2023, sporadic monitoring efforts by DFO detected both host species up to the first physical barriers in London, Fanshawe Dam in the North Thames River and Hunt Dam in the South Thames River (Barnucz et al. 2022; Lamothe et al. 2020). Above these dams, SMB was recorded where WRLM occurred in 2018, as well as LMB in the South Thames River in 2017 (DFO unpub. data). **St. Clair River and Detroit River watersheds:** The host species were captured throughout the historical range of WRLM in the Detroit and St. Clair rivers between 2016 and 2023 (DFO unpub. data). **Grand River watershed:** Between 2016 and 2018, SMB was frequently captured by DFO throughout all			

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		areas where WRLM occurs in the Grand River, whereas LMB was only captured in a single reach of the river where WRLM occurs (DFO unpub. data). These data indicate that host fishes are present throughout the current and historical range of WRLM populations. Future research should focus on identifying unknown host species and investigating adaptations in host-defense capabilities, specifically for WRLM and host fish populations that are restricted by barriers.			
Monitoring populations: continue routine surveys to monitor changes in the distribution and abundance of all populations.	Research and monitoring	**Ausable River watershed:** WRLM was detected in the Ausable River in 2018, 2019 and 2022, where it is known to occur (Jean 2020; Jean 2023). **Sydenham River watershed**: Surveys focused on the Sydenham River watershed found no live WRLM at historically known sites between 2016 and 2022 (Febria 2021; MacLennan-Nobrega et al. 2023; McNichols-O'Rourke et al. 2023; Paterson 2021; Sheldon et al. 2018; Snetsinger 2021). **Thames River watershed:** Between 2016 and 2022, monitoring efforts by DFO and partners consistently detected WRLM in the North Thames River (Goguen et al. 2022; Sheldon et al. 2018; Sheldon et al. 2020b), with significant numbers recorded in 2022 (Gibson et al. 2023). Quantitative quadrat surveys conducted in the South Thames River in 2017 and 2018, and Middle Thames River in 2017, found 16 and 3 live WRLM, respectively (Sheldon et al. 2018). Surveys in the Lower Thames	1-2	All threats	**DFO, ECCC**, AI, ABCA, CMU, MDNR, NRSI, OMECP SCRCA

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		River and tributaries did not detect any WRLM throughout this time period (Gibson et al. 2023; Sheldon et al. 2016; Sheldon et al. 2020b). **St. Clair River and Detroit River watersheds:** WRLM was recorded in the St. Clair River delta in 2016 (Sheldon et al. 2016), whereas only shells were detected in Lake St. Clair, Detroit River, and St. Clair River in 2017, 2019, and 2021, respectively (Keretz et al. 2021; Sheldon et al 2018; Sheldon et al. 2020a). **Grand River watershed**: Periodic surveys conducted between 2016 and 2022 consistently found WRLM in the Upper Grand River and Middle Grand River sections, while surveys in tributaries and downstream areas often yielded no specimens (Gillis 2017; Gillis 2020; Goguen et al. 2022; LeBaron et al. 2023; Sheldon et al. 2018; Sheldon et al. 2020a; Sheldon et al. 2020b). In 2020, mussel relocation efforts in Caledonia successfully captured WRLM. A subset of these mussels was marked or PIT-tagged, and monitoring events conducted in 2020, 2021, and 2022 resulted in the majority of them being recaptured. These population monitoring actions provide essential data for the reassessment of WRLM by COSEWIC in 2024, such as changes in distribution and abundance. As well as continuing to develop and refine relocation and survey methods that are used for WRLM to better detect them in future			

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		monitoring, these data may also be helpful in identifying locations for brood stock collections and stocking.			
Monitoring habitat: use existing monitoring stations to track changes in WRLM habitat.	Research and monitoring	Quantitative mussel sampling conducted within the Maitland, Ausable, East Sydenham, Thames, and Grand rivers, and the St. Clair River delta is paired with assessments of habitat conditions. Quadrat sampling, which is conducted within riverine habitats, includes observations of habitat parameters, including water velocity; depth; degree of siltation; aquatic macrophyte presence/absence; algal growth; degree of shading; and streambed/substrate composition. The OMECP water quality monitoring stations exist within the distribution of WRLM that measure concentrations of dissolved nutrients, chlorophyll, phosphorus, metals, and sodium chloride from road salt run-off (PWQMN 2023). Provincial water quality monitoring network (PWQMN) stations that sampled between 2018 and 2023 are located in sections of the Maitland, Ausable, East Sydenham, Thames, and Grand rivers where WRLM currently occurs (for more information see the provincial [stream] water quality monitoring network map). The UTRCA conducts additional sampling to support the PWQMN including 3 additional locations in the Mud Creek, Fullarton Corridor, and Whirl Creek subwatersheds of the Thames River to fill gaps in the network; and increased frequency of sampling. In addition, the UTRCA collects water samples from 5	1-3	All threats	**DFO, OMECP**, AAFC, UTRCA

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		locations in the Thames River for Agriculture and Agri-Food Canada for the purpose of monitoring the presence of pesticides.			
Monitoring aquatic invasive species: continue to monitor reservoirs for establishment of Zebra Mussel, and track the upstream invasion of Round Goby (*Neogobius melanostomus*) in the Ausable, Sydenham, Thames, and Grand rivers	Research and monitoring	**Zebra Mussels:** DFO has not conducted any sampling to monitor the establishment of Zebra Mussels within reservoirs in watersheds where WRLM occurs. **Round Goby:** **Ausable River watershed:** DFO conducted sampling at 36 sites in the lower and middle sections of the Ausable River from August to September 2017, targeting Eastern Sand Darter (*Ammocrypta pellucida*) using Siamese trawls that captured Round Goby (McAllister et al. 2022). Similarly, DFO conducted sampling targeting Eastern Sand Darter at 9 additional sites in the upper section of the Ausable River in July of 2018 using a bag seine; however, Round Goby was not captured at these sites (Barnucz et al. 2020). Using data collected from these aforementioned surveys, McCallister et al. (2022) reported that Round Goby comprised 7.3% of the catch per unit of effort, (CPUE) in the lower Ausable River; however, CPUE declined sharply with distance from the river mouth, with no Round Goby detected at sites in the middle and upper portions of the river. **Sydenham River watershed:** DFO conducted targeted surveys for Northern Madtom (*Noturus stigmosus*) in the East Sydenham River between Dresden and Dawn Mills in 2019 and found that	1-4	Aquatic invasive species	**DFO**

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		Round Goby was the most frequently occurring species (97% of sites) and was among the most abundant species captured (Barnucz and Drake 2021). **Thames River watershed:** DFO conducted sampling targeting Eastern Sand Darter in August 2020 in the Big Bend area of the Thames River, which captured Round Goby (Barnucz et al. 2022). Lamothe et al. (2020) describe sampling of benthic fishes in the Lower Thames River in 2012, 2013, 2015, and 2016, using Missouri and Siamese trawls. Round Goby was detected at 35% of sites in the Thames River, with a probability of detection of 0.833 (Lamothe et al. 2020). **Grand River watershed:** Raab et al. (2018) used a mini-Missouri trawl to sample multiple sites within 3 river reaches of the lower Grand River in 2010, 2011, 2013, and 2014, including reach 3 between the Dunnville Dam and the Caledonia Dam (Round Goby present); reach 2 between the Caledonia Dam and the Wilkes Dam (Round Goby present); and reach 1 between the Wilkes Dam and the Paris Dam (Round Goby not known to occur). Through this sampling, they captured 1,605, 2,260, and 472 Round Goby in 2010, 2011, and 2013, respectively, within reach 3; and 2,062, 3,929, and 1,056 Round Goby in 2010, 2011, and 2013, respectively, within reach 2 (Raab et al. 2018). Round Goby was not captured at the most upstream reach (above the Wilkes Dam); however, a discriminant function			

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		analysis based on 4 environmental variables indicated that the impounded area immediately upstream of the Wilkes Dam may be at high risk of future Round Goby establishment due to the presence of wider channels, slow-moving deep water, and fine substrate (Raab et al. 2018). The results of Raab et al. (2018) suggest that although dams provide a barrier against the upstream migration of Round Goby, they also generate habitat conditions that are highly amenable to its establishment should it be transported upstream through human-mediated transfer, for example, bait-bucket introductions (Raab et al. 2018).			
Barrier analysis: assess the distribution of in-stream barriers in all basins. Determine their impact and the feasibility of barrier removal or mitigation where appropriate.	Research and monitoring	The UTRCA has continued to inventory the distribution of new or decommissioned dams and barriers in the Upper Thames River watershed. These data are compiled into a database that includes information collected from projects over the years. Barriers and dams are also reviewed through visual assessments using photo interpretation as new aerial imagery becomes available. The specific impacts of dams and barriers to WRLM populations and the feasibility of removals remain to be investigated.	1-5	Altered flow regimes	**UTRCA**
Continue to investigate/test mitigation techniques for non-point	Research and monitoring	**Mitigation techniques for non-point source pollution:** Dagnew et al. (2019) used a Soil and Water Assessment Tool model to assess nutrient load, concentration, yield, and distribution in the St. Clair-Detroit River system, including the Thames and	1-6	All threats	**AI**

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
source pollution and increasing levels of sodium chloride.		Sydenham rivers. These authors found that agricultural non-point sources were major contributors of phosphorous within the Thames and Sydenham rivers. Specifically, they observed that sources of dissolved reactive phosphorous tended to be distributed fairly evenly throughout these watersheds, while total phosphorous levels tended to be higher in the upper sections of both watersheds. **Sodium chloride:** Gillis et al. 2021 investigated 3 potential alternatives to sodium chloride (road salt), which has been demonstrated to negatively impact freshwater mussels. These alternatives included salt brine, beet juice, and mix of brine and beet juice. They found that the beet juice and the brine-beet juice mix presented an increased risk to freshwater mussels of 19-fold and 13-fold compared to brine, and concluded that beet juice de-icing products are more of a hazard to early life-stages of freshwater mussels than traditional products.			
Investigate potential water quality issues resulting from stormwater management and wastewater treatment facilities and encourage municipalities to upgrade their	Research and monitoring	Gillis et al. (2017a) investigated differences in the abundance of freshwater mussels, including WRLM, at various sites in the Grand and Speed rivers. The study focused on the effects of urban impacts, particularly wastewater treatment plants (WWTPs) and impoundments. They found that catch per unit effort (CPUE) declined by more than 60% from upstream to downstream sites in the Grand River, correlating with increased exposure to WWTPs and impoundment effluent. In the Speed River, declines of up to 98% CPUE were observed downstream of WWTPs and impoundments.	1-7	Turbidity and sediment loading; contaminants and toxic substances; nutrient loading, altered flow regimes; and habitat	**AI**

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
infrastructure to reduce such threats.		To further examine the impact of WWTP effluent on freshwater mussels, including WRLM, in the Grand and Speed rivers, Gillis et al. (2017b) investigated the changes in mussel abundance before and after upgrades to the Kitchener WWTP. No live mussels were found for 7 km downstream of the Kitchener WWTP in 2012. After the upgrades in 2012, some recolonization was observed by 2014, but only small numbers of mussels were found at sites downstream of the WWTP. The Speed River may have served as a refuge for mussels, potentially aiding recolonization in the Grand River.		removal and alteration	
Identify contaminants and water quality parameters that could pose the greatest threat to the WRLM.	Research and monitoring	**Pesticides:** Salerno et al. (2018) investigated how pesticides affect 2 freshwater mussel species, Fatmucket (*Lampsilis siliquoidea*) and Rainbow (*Cambarunio iris*), at juvenile and adult life stages through lab experiments. Researchers tested several pesticides, including fungicides, neonicotinoids, carbamates, and a butenolide, all of which have been found in Ontario surface waters. The results showed that these pesticides pose minimal risk to freshwater mussels during short-term and moderate-length exposures, as the pesticide levels in Ontario streams are much lower than those used in the experiments. While the study did not specifically look at WRLM, the findings may help in understanding potential pesticide impacts on this species as well. **Urban polluants:** Graetz et al. (2020) conducted laboratory experiments to evaluate the effects of 6 fluorine-free firefighting water additives on various	1-8	Contaminants and toxic substances	**AI**

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		aquatic organisms, including WRLM. They found that 4 of the 6 additives tested were toxic to WRLM, particularly F-500, which had a significant impact on glochidia (mussel larvae) even at very low concentrations. To assess the toxicity of substituted phenylamines (SPAs) chemicals used in consumer products, such as polymers and lubricants, Prosser et al. (2017a) conducted laboratory experiments on different life stages of freshwater mussels, including WRLM. The study found that SPAs, particularly 4,4'-methylene-bis[N-sec-butylaniline], were toxic to WRLM glochidia. However, the likelihood of WRLM encountering harmful concentrations in natural waters was considered low. In a laboratory study, Salerno et al. (2020) investigated the effects of ammonia, chloride, copper, and potassium on juvenile WRLM and Rainbow. The study found that these common contaminants could harm mussel larvae and juveniles, potentially affecting their survival and recruitment in natural waters. The co-occurrence of these contaminants was also identified as an important consideration when assessing their risk to freshwater mussels. DFO evaluated the relative risk of granular Bayluscide, a chemical lampricide used to assess and suppress invasive Sea Lamprey (*Petromyzon marinus*), to WRLM (Andrews et al. 2021). Andrews			

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		et al. (2021) determined that granular Bayluscide is moderately toxic to WRLM; however, they assessed the risk as low because there is a low level of spatial overlap between the application sites and WRLM populations. **Road Salt:** To investigate the toxicity of winter road run-off, Prosser et al. (2017b) exposed road salt (sodium chloride) to different life stages of freshwater mussels, including WRLM glochidia. Prosser et al. (2017b) determined that winter road run-off is harmful to freshwater mussels, particularly due to the chloride content, as concentrations as low as 6% were toxic to the mussels. Gillis et al. (2022) further investigated the impact of chloride level in road run-off on WRLM glochidia and freshwater mussels, collected from bridges over tributaries of the Thames River. The study showed that chloride levels in road run-off varied significantly, and that higher levels were deadly to mussels. They also found that survival was better downstream, where chloride was more diluted. Bringolf et al. (2022) compared the toxicity of various chloride and sulfate salts on freshwater mussels to understand how water hardness affects this toxicity. Different salts have varying levels of toxicity to mussels, with potassium chloride being particularly harmful. Softer water increased the toxicity of these salts, making them more dangerous, especially to			

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		species like WRLM. The study also highlighted that toxicity decreases as water hardness increases. **Suspended Sediment:** Tuttle-Raycraft et al. (2017) investigated how increased total suspended sediment (TSS) affects the clearance rates of juvenile and adult mussels from 4 species, including the WRLM. Higher TSS levels significantly decreased the clearance rates of both juvenile and adult mussels, with juveniles being 5 times more affected. A TSS concentration threshold of 8 mg/L was identified, beyond which the clearance rates dropped notably, especially for WRLM. In a subsequent study, Tuttle-Raycraft and Ackerman (2018) examined the impact of different types of suspended sediments, such as clay, coarse silt, and fine silt, on the clearance rates of 4 mussel species, including WRLM. Clearance rates were reduced in clay, coarse silt, and mixed sediment treatments, but remained similar to control levels in fine silt treatments. Tuttle-Raycraft and Ackerman (2018) also found that the quality of particles, such as those with more algae, protein, and lipid content, have a greater effect on mussel clearance rates than particle size. Hansen et al. (2016) used a model to explore how suspended sediment, in combination with other factors like streamflow and mussel abundance, affects freshwater mussel populations. The study highlighted how land-use changes affecting water			

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		quality can negatively impact mussel populations, finding that long-term sedimentation significantly reduced mussel density.			
Promote and enhance expertise in freshwater mussel identification/ biology and provide for the transfer of knowledge.	Management and coordination	DFO, in partnership with SCRCA, has continued to conduct a hands-on freshwater mussel identification course that is offered to government, non-government organizations, Indigenous peoples, and the general public. Similarly, the LTVCA has coordinated freshwater mussel identification workshops designed to encourage the participation of Indigenous communities. In 2020, unionid identification training was provided to DFO's Conservation and Protection fishery officers. Additionally, the Clam Counter app (Toronto Zoo) continues to be promoted and refined. The OMNR's Fish Culture Section (White Lake OMNR Fish Culture Station) has developed expertise in the culture of 4 at-risk mussel species, including WRLM, to be ready to support the culture and stocking of these species, should doing so be required as part of future recovery efforts (Wilson pers. comm. 2018). Research conducted through this program has assessed the infestation rates and cumulative survival of juvenile WRLM using SMB (Loftus and Wilson 2018). Furthermore, a protocol is being finalized for mussel propagation, rearing techniques, and broodstock development (Wilson pers. comm. 2023). The findings of this research will	2-1	All threats	**DFO, CAs**, OMNR, TZ

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		be beneficial if federal or provincial jurisdictions decide to undertake repatriation programs. Similarly, captive rearing may be useful to provide specimens for research needs, considering wild-caught individuals of listed species such as WRLM are of special concern.			
Collaborate among existing ecosystem recovery teams to implement conservation measures.	Management and coordination	DFO continues to partner with CAs and stewardship councils, principally through the Habitat Stewardship Program (HSP). The “Action Plan for the Ausable River in Canada: an ecosystem approach” (DFO 2020) contains measures to support the conservation of WRLM. To oversee the implementation of these action plans, the Ausable River Recovery Team was formed with participants from DFO, CAs, provincial departments, and academic partners.	2-2	All threats	**DFO**, **CAs**, AI, ECCC, OMECP, OMNR
Ensure that flow requirements of the WRLM are considered in management of flow regimes.	Management and coordination	No progress has been made on this objective.	2-3	Altered flow regimes	
Work with drainage supervisors, engineers, and contractors to limit the effects of drainage activities on WRLM habitat.	Management and coordination	DFO has delivered presentations and Species at Risk (SAR)-specific guidance to drainage supervisors and engineers that identify issues and threats to SAR, including WRLM, that may arise during 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	2-4	Turbidity and sediment loading	**DFO**

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		Ontario" has been published (Kavanagh et al. 2017). The document provides a detailed description of BMPs that should be used to reduce harmful impacts to fishes and freshwater mussels, including those that are at risk.			
Ongoing implementation of agricultural best management practices and other habitat enhancement projects in the Ausable, Sydenham, Thames, and Grand rivers.	Stewardship	The use of BMPs and mitigation approaches is encouraged when projects are reviewed by DFO and CAs on rural properties. These BMPs include livestock restrictions (exclusion fencing), milkhouse wash-water system installations, riparian buffers, streambank stabilization, wetland creation or enhancement, well decommissioning, septic upgrades, and sediment control/trapping to prevent run-off and improve water quality. BMPs, such as the aforementioned habitat improvement projects, have been implemented by CAs through funding from the Government of Canada's Habitat Stewardship Program (HSP) and through the Government of Ontario's Species at Risk Stewardship Program. For example, the GRCA provided landowners with technical assistance to help them improve manure storage and nutrient planning on their farms, constructed exclusionary cattle fencing, and installed 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. Furthermore, the Species at Risk Farm Incentive Program, through the OSCIA,	3-1	Turbidity and sediment loading, contaminants and toxic substances	**DFO, CAs, ECCC,** OMECP, OSCIA

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		includes information on what BMP farm activities can help SAR, including information on cost-share opportunities. Examples of completed projects include shoreline improvements, installation of exclusionary fencing, and improvement to stream crossings. Furthermore, UTRCA has conducted projects that included tree planting, enhancing buffer strips, and erosion control, and has provided technical aid and financial incentives to agricultural landowners to improve and protect water quality through its Clean Water Program.			
Establish riparian buffer zones in areas of high erosion potential by encouraging naturalization or planting of native species.	Stewardship	Actions related to riparian restoration, riparian buffer zones, and vegetation planting have been carried out between 2018 and 2023 by CAs with funding from HSP and OMECP's Species at Risk Stewardship Program. Examples of these actions are described below for watersheds where WRLM occurs. **Ausable River watershed:** In 2018, the ABCA undertook 8.3 ha of vegetation planting (including native trees and shrubs in areas listed as high or medium priority to benefit critical habitat for other SAR in the Ausable River Action Plan [2015]) spread across 11 sites in the Ausable River. In addition, it conducted 2.5 ha of riparian restoration spread across 5 sites in the Ausable River, which should benefit WRLM by reducing overland run-off. In 2019, ABCA established 7.45 ha of riparian buffer spread across 6 sites in sections in the Ausable River watershed that are within 15 km of WRLM records. Furthermore, they restored 0.3 ha of wetland habitat	3-2	Turbidity and sediment loading; contaminants and toxic substances; and nutrient loading	**ABCA, DFO, ECCC, GRCA, LTVCA, OMECP**

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		at 1 site that is in relevant proximity upstream of WRLM records. **Thames River watershed:** Between 2018 and 2023, the UTRCA has undertaken block plantings to buffer riparian areas as part of fragile land retirement, which included 3 locations in Fish Creek, 1 location in Medway Creek, and 1 location in the Dorchester Corridor, all of which are subwatersheds of the Thames River where WRLM has been detected. **Grand River watershed:** In 2019, GRCA undertook 0.4 ha of vegetation planting in a tributary in the Glen Morris area that flows into a section of the Grand River where WRLM has been recently found. A further 0.2 ha of vegetation was planted at 1 location in the Nith River subwatershed that is significantly higher in the watershed than any WRLM records. In 2020, GRCA planted trees to create buffers for adjacent watercourses. Two projects were conducted within 15 km for WRLM records, including 0.4 ha along Mud Creek, a drain which flows into the Nith River, 0.08 ha along the Nith River itself, and 0.42 ha along Little Creek, a tributary which flows into the Grand River upstream of Caledonia. Other similar projects led to a total of 5.36 ha of treed buffer created among 8 locations that were further upstream of WRLM records in subwatersheds, including the Nith and Conestogo rivers, and Canagagigue, Spring, and McKenzie creeks. In 2021, GRCA planted trees creating riparian buffers			

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		at 8 sites within 15 km of areas occupied by WRLM, including 1 site on Boomer Creek (4.05 ha), 2 sites on Canagagigue Creek (1.87 ha), 1 site on Fishes Creek (3.31 ha), 3 sites on the Nith River (0.45 ha), and 1 site on Washington Creek (0.14 ha). A total of 1.81 ha of riparian buffer was planted at additional sites that were further upstream from WRLM records, including the Nith River (2 sites), Conestogo River (1 site), and Fairchild Creek (1 site).			
Limit livestock access to rivers.	Stewardship	**Grand River watershed:** In 2021, GRCA installed 228 m of fence on a site within the Nith River watershed that is within 15 km of WRLM records, excluding approximately 50 cattle from the watercourse.	3-3	Turbidity and sediment loading; contaminants and toxic substances; and nutrient loading	**DFO, GRCA**
Encourage soil testing to determine fertilizer application rates.	Stewardship	There is currently no progress to report for this objective.	3-4	Contaminants and toxic substances and nutrient loading	
Conduct outreach through the various organizations in the Ausable River, Sydenham	Awareness	**Maitland River watershed:** In 2019, MVCA conducted a community tree planting event creating a riparian buffer adjacent to the Maitland River, to demonstrate stewardship approaches that can improve habitat for SAR mussels. **Ausable River watershed:** In 2018, ABCA conducted various outreach actions, including flyers	4-1	All threats	**ABCA, DFO, GRCA, LTVCA MVCA, OMECP,** TZ

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
River, Thames River, and Grand River watersheds.		and a media release that were distributed to inform landowners that funding is available for stewardship actions that would benefit aquatic SAR; conducting an in-field class where students planted trees and shrubs to create riparian buffers for the benefit of SAR; visiting schools and hosting events at conservation areas to generate awareness of SAR and stewardship actions that would improve their habitat; and holding information sessions for community members to describe the SAR in the Ausable River watershed and their habitat needs, in order to identify landowners interested in conservation and stewardship opportunities. In 2019, ABCA continued its outreach through the delivery of presentations, as well as information booths at public events, to make residents living within the Ausable River watershed aware of SAR and related stewardship actions for which funding was available; delivery of presentations within school classrooms to inform students of SAR found within the watershed and their habitat needs; and via a newspaper article to advertise funding available for actions that benefit SAR. **Thames River watershed:** In 2018, LTVCA conducted outreach through weekly Facebook posts that provided information on SAR fishes and mussels, the distribution of materials provided by the Ontario Ministry of Agriculture, Food, and Agribusiness, and by facilitating a freshwater mussel identification workshop with Indigenous partners in Moraviantown. In 2019, LTVCA conducted further			

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		outreach, including the distribution of 1,621 Save the Thames River flyers that provided information regarding SAR in the Lower Thames River and BMPs and stewardship approaches that should be adopted by landowners; continuation of Facebook posts to raise public awareness of the impacts of road salt to SAR mussels; and through participation in outreach events such as meetings, training events, tours, breakfasts, and BBQ's where awareness of SAR and related stewardship programs was promoted. Lastly, in 2020, LTVCA continued to conduct outreach via webinars and presentations at meetings; further social media posts providing information on SAR and related stewardship on Facebook, Twitter, and Instagram; and through the distribution of flyers promoting the recovery of SAR in the Thames River, and approaches to combat erosion. **Grand River watershed:** In 2019, GRCA conducted 3 workshops in Cayuga, Elora, and Cambridge that promoted actions contributing to the recovery of SAR mussels. In addition, they conducted 7 community planting events to create riparian buffers where they generated awareness of SAR mussels and the importance of stewardship actions to their recovery. In 2020, GRCA conducted further outreach through webinars focusing on the Private Land Tree Planting Program and Tree Care and presentations on SAR mussels in Grand River watershed, the role of landowner stewardship action, and available grants for stewardship projects. In 2021, GRCA delivered			

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		further webinars focused on SAR in the Grand River watershed and examples of stewardship projects that had been funded through HSP. **Other organizations:** In 2020 and 2021, the Toronto Zoo, through its Great Lakes Program, provided 316 classes (ranging from kindergarten to Grade 12) to 149 schools that included information about SAR mussels. Furthermore, they delivered 9 presentations to Girl Guide groups to generate awareness of aquatic SAR and their habitat needs.			
DFO staff to continue to deliver presentations at conferences and to different naturalist groups and schools.	Awareness	DFO staff has delivered presentations that highlight ways to reduce threats to aquatic SAR, including WRLM. Presentations have been given to a variety of audiences in multiple settings between 2018 and 2022. Some examples are provided for each year below: **2018** • Ministry of Transportation Ontario consultants: Training on SARA was provided, including the SARA, SAR, project review, and recovery planning. • DFO's online presentation for partners: The presentation included a review of listed SAR and their habitats, and a refresher on DFO's integrated project review process. • DFO's open house at the Canadian Centre for Inland Waters: The public and schools were provided guided tours that included a variety of displays highlighting aquatic SAR,	4-2	All threats	**DFO**, **OMNR**, AI, CAs

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		water research, and numerous other program and science activities. • A mussel identification course was delivered by DFO staff to members of the Chippewas of the Thames First Nation, Munsee-Delaware First Nation, Delaware, and Moraviantown First Nation. • A presentation was delivered to Fleming College Heavy Equipment Operators Course students that described aquatic SAR distribution, habitat, threats, legislation, and mitigation. • DFO hosted the Species at Risk Network conference that included presentations describing research undertaken to address knowledge gaps pertaining to SAR. **2019** • Canadian Centre for Inland Waters open house: The public were invited and interested schools were provided guided tours, which included a variety of displays highlighting aquatic SAR, water research, and numerous other program and science activities. • A presentation was delivered to members of the Drains Action Working Group (DAWG) that described listed SAR, including freshwater mussels. DAWG is a committee that brings together drainage supervisors, DFO, CAs, and the Ministry of Agriculture, Food and Agribusiness to collaborate on streamlining processes and approvals for works governed by the *Drainage Act*.			

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		• Latornell Conservation Symposium, Nottawasaga Inn: A SAR program exhibit was open for 3 days and freshwater mussel posters were distributed and the Clam Counter application (an identification tool for freshwater mussels) was highlighted. Latornell is a premier conservation connection and networking symposium in Ontario, providing an opportunity to engage with potential partners for collaboration on stewardship efforts to protect SAR. Participants typically include consultants, the public, Indigenous peoples, and organizations with a role or interest in conservation. • SCRCA Soil Health Day, Alvinston: A presentation was delivered to CA staff and members of the general public that provided information on SAR found in the Sydenham River watershed. • DFO hosted the Species at Risk Network conference that included presentations describing research undertaken to address knowledge gaps pertaining to SAR. **2020** • SCRCA and Essex Region Conservation Authority staff, municipalities, consultants, and contractors: Presentation was delivered on the SARA, listed aquatic SAR, *Fisheries Act* review, and SAR funding.			

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		• MVCA and ABCA staff, municipalities, consultants, and contractors: Presentation was delivered on the SARA, listed aquatic SAR, *Fisheries Act* review, and SAR funding. **2021** • LTVCA and UTRCA staff, municipalities, consultants, and contractors: Presentation was delivered on the SARA, listed aquatic SAR, *Fisheries Act* review, and SAR funding. • GRCA staff, municipalities, consultants, and contractors: Presentation was delivered on the SARA, listed aquatic SAR, *Fisheries Act* review, and SAR funding. **2022** • Latornell Conservation Symposium: Encouraged participants to use DFO's aquatic SAR interactive map and provided links to the Fish and Fish Habitat Protection Program's Projects Near Water website resources, and provided freshwater SAR mussel hands-on display. • Members of Métis Nation of Ontario (Regions 1, 2, and 3): Presented information on the implementation of the SARA, and provided overview of the national SAR mapping tool. • Members of Métis Nation of Ontario (Regions 4, 5, and 7): Presented information on the implementation of the SARA, and provided overview of the national SAR mapping tool.			

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
		In addition, DFO and the OMNR have organized and hosted the Canadian Freshwater Mollusc Research Meeting in 2019 (Morris et al. 2020) and 2021 (Morris et al. 2022), which included presentations of research projects that are advancing knowledge of freshwater mussels (including SAR), their life histories, and the threats that are impacting them.			
Increase public awareness of the potential impacts of transporting/ releasing aquatic invasive species.	Awareness	DFO continues to disseminate educational materials focused on aquatic invasive species (AIS). Similarly, the Government of Ontario has developed invasive species action plans, including a boater's action plan designed to help stop the spread of invasive species in Ontario, and best management practices for watercraft users. Outreach has been conducted by CAs through funding from HSP that provides awareness of aquatic invasive species. Some examples include: • ABCA's production of the Old Ausable Channel fish community card, which provides information on the threat of invasive species to SAR • The Toronto Zoo's Great Lakes Program: staff deliver invasive species outreach presentations to schools and opened an exhibit at the Toronto Zoo on Asian Carp • LTVCA's use of social media posts to increase public awareness of AIS	4-3	All threats	**DFO**

Activity	Broad Strategy	Descriptions and results[2]	Management objectives	Threat(s) or concern(s) addressed	Participants[3] [4]
Increase awareness within the angling community about the role of the SMB as a host for the WRLM.	Awareness	There is currently no progress to report for this objective.	4-4	Host fish(es) (disruption); recreational activities	
Continue to promote mussel identification and recognition through annual workshops and the use of the mobile mussel identification guide app for cellular phones.	Awareness	Please refer to management objective 2-1 “Promote and enhance expertise in freshwater mussel identification/biology and provide for the transfer of knowledge”.	4-5	All threats	

4. Concluding statement

Overall, the management objectives actioned from 2018 to 2023 have improved DFO's understanding of the distribution and abundance of Wavyrayed Lampmussel, with substantial monitoring surveys conducted in areas of known occupancy, as well as areas where the species historically occurred such as the St. Clair, East Sydenham, and Detroit rivers. Extensive research projects have been undertaken, including investigations of the efficacy of potential new sampling approaches; and evaluations of potential threats to freshwater mussels overall; and, in some cases, Wavyrayed Lampmussel specifically (for example, invasive species, pesticides, urban pollutants, and suspended sediments).

Stewardship actions, such as the planting of riparian buffers and livestock restrictions from watercourses, have continued to improve habitat within watersheds where Wavyrayed Lampmussel currently or historically occurs, with conservation authorities playing an important role in the implementation of these actions. The creation and restoration of wetlands and riparian zones are expected to be significant contributors to the long-term welfare of Wavyrayed Lampmussel. Furthermore, outreach actions continue to be an important method to engage stakeholders and the general public in the plight of species at risk, and to publicize programs designed to mitigate threats and promote restoration actions.

These ongoing actions illustrate the progress that has been made towards the management objectives for Wavyrayed Lampmussel populations in Canada. Twenty-one actions for the Wavyrayed Lampmussel management plan are reported in table 1. Eighteen of these actions (86%) are in progress, including all 8 research and monitoring actions. Three of these actions (14%) have not been started due to no longer being priorities and will be removed during the next update of the management plan. More conclusive research is needed to assess the impact of dams on Wavyrayed Lampmussel, evaluate the feasibility of dam removals, and identify potential mitigation measures to reduce their effects.

Furthermore, additional research examining the habitat needs of each life stage and further threat assessments, including the continued monitoring of the range expansion of aquatic invasive species relative to Wavyrayed Lampmussel are required to allow DFO to meet the management objectives of the species. More specifically, a better understanding of threats impacting Wavyrayed Lampmussel may help to explain why detections of the species are rare in the East Sydenham River, while the species is frequently detected in the Thames and Grand rivers. The feasibility of the management goal and objectives may be reassessed in the future using updated distribution and abundance information, as well as threat information gathered since the publication of the management plan.

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