Species at Risk Act
Management Plan Series

Management Plan for the Mapleleaf (*Quadrula quadrula*) Great Lakes – Upper St. Lawrence Population, and Rainbow (*Villosa iris*) in Canada

Mapleleaf

Rainbow

2023

Canada

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For copies of the Management Plan or for additional information on species at risk, including Committee on the Status of Endangered Wildlife in Canada (COSEWIC) Status Reports and other related recovery documents, please visit the SAR Public Registry.

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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 protection of species at risk throughout Canada. Under the *Species at Risk Act* (S.C. 2002, c.29) (SARA), the federal competent ministers are responsible for the preparation of a management plan for species listed as special concern and are required to report on progress 5 years after the publication of the final document on the Species at Risk Public Registry and every subsequent 5 years, until its objectives have been achieved.

The Minister of Fisheries and Oceans is the competent minister under SARA for the Mapleleaf (*Quadrula quadrula*) and Rainbow (*Villosa iris*) mussels and has prepared this management plan, as per section 65 of SARA. In preparing this management plan, the competent minister has considered, as per section 38 of SARA, the commitment of the Government of Canada to conserving biological diversity and to the principle that, if there are threats of serious or irreversible damage to the listed wildlife species, cost-effective measures to prevent the reduction or loss of the species should not be postponed for a lack of full scientific certainty. To the extent possible, this management plan has been prepared in cooperation with the Government of Ontario, Environment and Climate Change Canada, Central Michigan University, University of Guelph, Bishop Mills Natural History Centre, St. Clair Region Conservation Authority, Ausable-Bayfield Conservation Authority, Upper Thames River Conservation Authority, Lower Thames Valley Conservation Authority, and the Grand River Conservation Authority as per subsection 66(1) of SARA.

As stated in the preamble to SARA, success in the conservation of this species depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions and measures for the conservation of the species set out in this 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 constituencies. All Canadians are invited to join in supporting and implementing this management plan for the benefit of the Mapleleaf and Rainbow, and Canadian society as a whole.

A SARA management plan includes measures for the conservation of the species of special concern to prevent it from becoming threatened or endangered. The competent minister must prepare a management plan that includes measures for the conservation of the species that the minister considers appropriate. These measures for the conservation of the species set out to achieve the management objectives identified in the management plan. Implementation of this management plan is subject to appropriations, priorities, and budgetary constraints of the participating jurisdictions and organizations.

Acknowledgments

The Mapleleaf (Great Lakes – Upper St. Lawrence Population) and Rainbow management plan builds on separate, earlier recovery strategies and action plans for both species. Fisheries and Oceans Canada (DFO) acknowledges contributions to the original documents and the current combined management plan as follows: Dr. Daelyn Woolnough (DFO contractor), Pat Dimond (DFO contractor), Amy Boyko (DFO), Shawn Staton (DFO), Jessica Epp-Martindale (DFO), Dave Andrews (DFO), and Peter L. Jarvis (DFO contractor). DFO would also like to acknowledge the following organizations for their support in the development of the Mapleleaf and Rainbow management plan: Ontario Freshwater Mussel Recovery Team, Environment and Climate Change Canada, Ontario Ministry of Natural Resources and Forestry, University of Guelph, Central Michigan University, Ausable-Bayfield Conservation Authority, Grand River Conservation Authority, St. Clair Region Conservation Authority, Upper Thames River Conservation Authority, Lower Thames Valley Conservation Authority, Niagara Peninsula Conservation Authority, and the Bishop Mills Natural History Centre. Mapping was produced by Shady Abbas (DFO contractor) and Dave Andrews (DFO).

Executive summary

The Mapleleaf (*Quadrula quadrula*) and Rainbow (*Villosa iris*) are freshwater mussels of the family Unionidae that have similar needs and share similar geographic ranges in Canada. As these species frequently co-occur and share many common threats and limiting factors, they are being considered in a combined management plan. The Mapleleaf and Rainbow, along with other freshwater mussels (unionids), provide important ecosystem services such as biofiltration, nutrient recycling, and storage.

There are 2 designatable units (DUs) of Mapleleaf in Canada: the Great Lakes – Upper St. Lawrence DU in Ontario, and the Saskatchewan – Nelson Rivers DU in Manitoba. The Great Lakes – Upper St. Lawrence DU of Mapleleaf was listed as special concern under the *Species at Risk Act* (SARA) in 2019. This DU was originally listed as threatened under SARA, but was subsequently downlisted to special concern following the 2016 Committee on the Status of Endangered Wildlife in Canada (COSEWIC) reassessment, principally due to newly discovered populations. A separate combined recovery strategy and action plan is being developed for the Saskatchewan – Nelson Rivers DU as these populations have been assessed by COSEWIC, and listed under SARA, as threatened. The Rainbow was originally listed as endangered under SARA, but was subsequently listed at the lower risk level of special concern in 2019 following the 2015 COSEWIC reassessment, principally due to the discovery of large numbers of individuals in previously unknown localities (and evidence of recent recruitment in 6 of 7 subpopulations examined).

This management plan is considered one in a series of documents that are linked and should be taken into consideration together, including the COSEWIC status reports (2015 and 2016). In addition, the Mapleleaf and Rainbow were included in the recovery potential assessment (2011) of the Eastern Pondmussel, Fawnsfoot, Mapleleaf, and Rainbow and proposed recovery strategies were published in 2016 before the species were downlisted to special concern.

The Mapleleaf is a medium to large (up to 13.5 cm) freshwater mussel (DFO 2011). The shell is approximately square in outline, relatively thick and displays colour variations ranging from yellowish green to light brown in juveniles, and greenish brown to dark brown in older individuals. The global range of the Mapleleaf extends throughout the Ohio-Mississippi River drainages, as well as the Red River Drainage in Manitoba, North Dakota, and Minnesota. In Ontario, populations appear restricted to a few coastal areas and rivers draining into lakes St. Clair, Huron, Erie, and Ontario. The Rainbow is smaller than the Mapleleaf (with an average length of 5.5 cm); it has a narrow elliptical shape and typically a yellowish-green shell with numerous dark green rays. The global range of the Rainbow includes the Tennessee, Cumberland, and Ohio River basins, and the upper Mississippi River. In Canada, it is restricted to tributaries of lakes Ontario, Erie, St. Clair, and Huron, and includes a very small presence in the St. Clair River delta.

The main threats facing the Mapleleaf and Rainbow are described in section 5 and include: invasive species, turbidity and sediment loading, contaminants and toxic substances, nutrient loading, altered flow regimes, habitat removal and alterations, lack of access to host fish, and recreational activities. These threats include activities that degrade water quality and habitat, most prominently, run-off and discharge from agricultural, municipal and industrial activities, which often contain metals and nutrients and result in increased siltation rates. Dreissenid mussels were introduced in the mid-1980s and have resulted in profound changes in unionid

community structure and continue to be a major threat for existing populations, as they outcompete unionids for habitat and food resources.

The management objectives (section 6) for the Mapleleaf and Rainbow are:

- protect self-sustaining populations to prevent decline
- restore degraded populations to healthy self-sustaining levels by improving the extent and quality of habitat (where feasible)

A description of the broad strategies and measures for the conservation of the species that provide the best chance of achieving the management objectives are included in section 7. The following 4 broad strategies were identified to address threats to the species and meet the management objectives: 1) inventory and monitoring; 2) research; 3) management and coordination; and 4) stewardship and outreach. The conservation of the species is best accomplished through cooperation with existing single-species and ecosystem-based recovery programs for fish and mussel species at risk. Actions taken to conserve the species will prove beneficial to all aquatic species at risk and eliminate duplication of effort.

Table of contents

1. Introduction

This is a management plan for 2 freshwater mussel species at risk in Canada, the Mapleleaf (*Quadrula quadrula*) (Great Lakes – Upper St. Lawrence population) (Mapleleaf, from this point forward) and Rainbow (*Villosa iris*[1]). The Mapleleaf was initially listed under the *Species at Risk Act* (SARA) as threatened, based on an assessment by the Committee on the Status of Wildlife in Canada (COSEWIC) (COSEWIC 2006a); however, in 2019, the species was downlisted to special concern under SARA after the species was re-assessed by COSEWIC (COSEWIC 2016). The principal rationale for the change in status as given by COSEWIC relates to the discovery of new locations, and evidence for recent gene flow across Lake Erie. The Rainbow was initially listed under SARA as endangered, based on the COSEWIC assessment (COSEWIC 2006b); however, in 2019, the species was downlisted to special concern under SARA, based on an updated COSEWIC assessment (COSEWIC 2015). The principal rationale for the change in status as given by COSEWIC relates to the discovery of large numbers of individuals in previously unknown localities, especially at headwaters of larger rivers, and strong evidence of recent recruitment in 6 of the 7 subpopulations examined.

This management plan is considered one in a series of documents for these species that are linked and should be taken into consideration together, including COSEWIC status reports (COSEWIC 2015; 2016) a recovery potential assessment that included both species (Bouvier and Morris 2011; Fisheries and Oceans Canada [DFO] 2011), and combined proposed recovery strategy and action plan for both species that were published in 2016 before the species were downlisted to special concern (DFO 2016). The management plan includes measures for the conservation of the species to ensure that a species of special concern does not become threatened or endangered. It sets objectives and identifies measures for the conservation of the species to support achieving the management objectives.

2. COSEWIC species assessment information

Date of assessment: November 2016

Species' common name (population): Mapleleaf (Great Lakes – Upper St. Lawrence population)

Scientific name: *Quadrula quadrula*

Status: special concern

Reason(s) for designation: This heavy-shelled mussel, shaped like a maple leaf, has a limited distribution in southern Ontario. There is evidence of an ongoing, but slight, decline in the range over the last 3 generations. Low-impact threats, including those from Zebra and Quagga mussels, habitat alteration, and pollution continue. Despite these threats, this population is estimated to be large (millions of animals) and apparently stable at a number of locations in Lake St. Clair, Lake Erie, and western Lake Ontario watersheds. The change in

[1] The scientific name has recently changed to *Cambarunio iris* but *Villosa iris* will be used throughout this document to be consistent with the legal listing name under SARA.

status since the original report is a result of increased sampling effort across the region, newly discovered

locations, and evidence for recent gene flow across Lake Erie, which suggests the potential for rescue.

Canadian occurrence: Ontario

Status history: Designated threatened in April 2006. Status re-examined and designated special concern in November 2016.

Date of assessment: November 2015

Species' common name: Rainbow

Scientific name: *Villosa iris*

Status: special concern

Reason(s) for designation: This small mussel is widely distributed in southern Ontario. Surveys since the previous assessment in 2006 have found large numbers of individuals in previously unknown localities, especially at headwaters of larger rivers. There is strong evidence of recent recruitment in 6 of the 7 subpopulations examined. Although it has been lost from Lake Erie and the Detroit and Niagara Rivers, it was apparently never common in these waters. Low abundance and signs of continued decline are evident in 2 subpopulations (Ausable River and Lake St. Clair). Ongoing threats to some subpopulations include invasive species (dreissenid mussels and Round Goby) and pollution (household sewage and urban wastewater, as well as agricultural effluents). The species may become threatened if threats are not effectively managed or mitigated.

Canadian occurrence: Ontario

Status history: Designated endangered in April 2006. Status re-examined and designated special concern in November 2015.

3. Species status information

Table 1. Summary of existing protection or other status designations assigned to Mapleleaf (Great Lakes – Upper St. Lawrence populations).

Jurisdiction	Authority/organization	Year(s) assessed and/or listed	Status/description	Designation level
Ontario	*Endangered Species Act, 2007*	2018	Special concern	Species
Ontario	NatureServe	2013	Regional (ON): S2-imperilled	Population

Jurisdiction	Authority/organization	Year(s) assessed and/or listed	Status/description	Designation level
Ontario	Committee on the Status of Species at Risk in Ontario	2017	Special concern	Population
Canada	*Species at Risk Act*	2019	Special concern	Population
Canada	Committee on the Status of Endangered Wildlife in Canada	2016	Special concern	Population
International	NatureServe	2009	Global: G5-secure	Species

Table 2. Summary of existing protection or other status designations assigned to Rainbow.

Jurisdiction	Authority/organization	Year(s) assessed and/or listed	Status/description	Designation level
Ontario	*Endangered Species Act, 2007*	2017	Special concern	Population
Ontario	Committee on the Status of Species at Risk in Ontario	2016	Special concern	Population
Canada	*Species at Risk Act*	2019	Special concern	Population
Canada	Committee on the Status of Endangered Wildlife in Canada	2015	Special concern	Population
Canada	NatureServe	2013	N1 – Critically imperilled	Population
International	NatureServe	2009	Global: G5-secure	Species

4. Species information

4.1. Species description

Mapleleaf

The Mapleleaf is a medium-large (up to 13.5 cm) member of the freshwater mussel family Unionidae. The shell is approximately square in outline, relatively thick and displays colour variations ranging from yellowish green to light brown in juveniles and greenish brown to dark brown in older individuals. Typically, 2 rows of raised nodules extending in a V-shape from the point of shell union (umbo or beak) to shell edge (ventral margin) distinguish the outer shell surface of this bivalve species, while the interior (nacre) of the shell is white. Mapleleaf are not sexually dimorphic, based on external examination (Bouvier and Morris 2011). There are no other unionids in Canada with which Mapleleaf can be confused. More detailed information can be found in COSEWIC (2016).

Rainbow

The Rainbow is a small freshwater mussel (average length of about 5.5 cm for Canadian specimens) of the family Unionidae. There are 18 species in the genus *Villosa* in North America, but only the Rainbow and Rayed Bean (*V. fabalis*) have ranges that extend into Canada. The Rainbow has a narrow elliptical shape, while the beaks are low and compressed, and sculpture consists of 4 to 6 distinct bars. The shell is yellowish, yellowish-green or brown (in old specimens), with numerous wide or both narrow and wide broken, dark green rays that cover the whole surface of the shell, or are absent anteriorly. Rays may become obscure in old specimens. The Rainbow can be distinguished from all other species of unionids in Canada by its small size, narrow elliptical shape, and interrupted green rays. More detailed information can be found in COSEWIC (2015).

Ecological role of unionids: The impact of the loss of unionids from streams and rivers is difficult to predict, but these animals can be important components of food web dynamics, linking and influencing multiple trophic levels (Vaughn et al. 2004, Vaughn and Spooner 2006). Vaughn et al. (2008) catalogued some of the food web and trophic influences of unionid communities on other ecosystem components. Mussels can provide habitat for other organisms by creating physical structure, and dense mussel beds can stabilize streambed substrates during periods of high flow. Unionids influence food availability directly and indirectly through bio-deposition of organic matter and nutrient excretion. For example, the metabolic waste products of unionids can be assimilated by algae, while their pseudofeces (material that has been removed from the water column but not metabolized; Nalepa et al. 1991) are decomposed by benthic microorganism and consumed by portions of the benthic fauna.

Unionids are sensitive indicators of the health of freshwater ecosystems, including water and habitat quality, and especially the fish community on which they depend for successful reproduction. The Rainbow may be a particularly good indicator of ecosystem health because it is more sensitive to environmental contaminants than most other unionids tested to date (Mummert et al. 2003). Unionids can also be important prey for a few species, including the Muskrat (*Ondatra zibethicus*) (Neves and Odom 1989), which results in a transfer of energy from the aquatic to the terrestrial environment.

4.2. Population abundance and distribution

Mapleleaf

Global range: The global range of the Mapleleaf extends throughout the Ohio-Mississippi River drainages from Louisiana to Texas and up to the Red River drainage in Manitoba and the Great Lakes drainage in Ontario (figure 1). In the United States (U.S.), the distribution ranges from Texas in the southwest to Alabama in the southeast, while the northern distribution ranges from the Great Lakes drainage in Minnesota and Wisconsin to New York and extends into the Red River drainage in Minnesota and North Dakota (NatureServe 2020; figure 1). It has also been introduced into the Tongue River in Montana (NatureServe 2020).

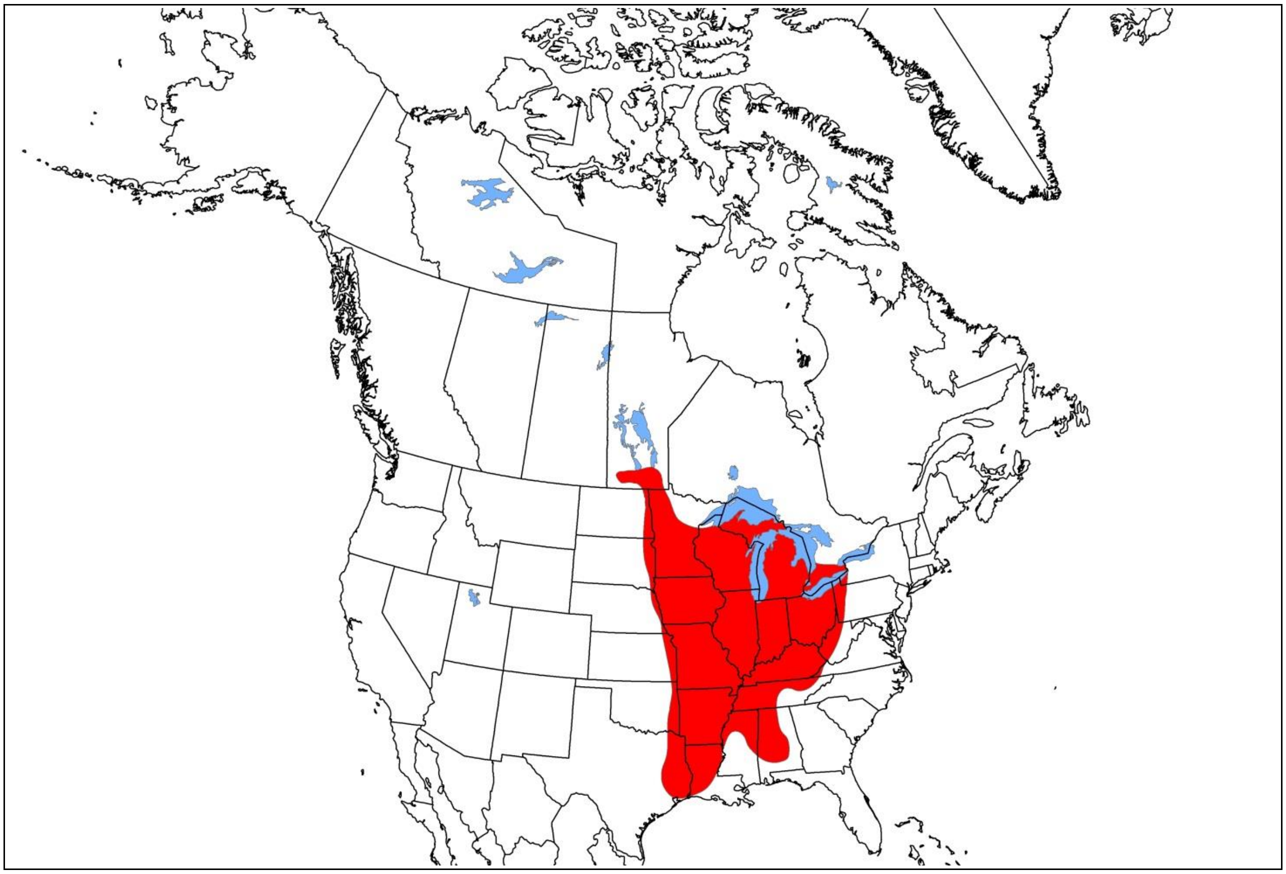

Figure 1. Global native distribution of the Mapleleaf (modified from Royal Ontario Museum).

Canadian range: The Canadian distribution of Mapleleaf has been separated into 2 designatable units (DUs). COSEWIC can identify DUs below the species level that merit distinction, based on discreteness and evolutionary significance. Great Lakes – Upper St. Lawrence populations (Ontario) (figure 2) and the Saskatchewan – Nelson Rivers population (Manitoba) are the 2 DUs as identified by COSEWIC in Canada. In Manitoba, populations occur in the Red River (and tributaries), the Assiniboine River, and Lake Winnipeg (and tributaries), while Ontario populations appear restricted to a few coastal areas and rivers draining into lakes Huron, St. Clair, Erie, and Ontario. In both provinces, an analysis of the historical records indicates an apparent reduction in distribution of the species (COSEWIC 2016).

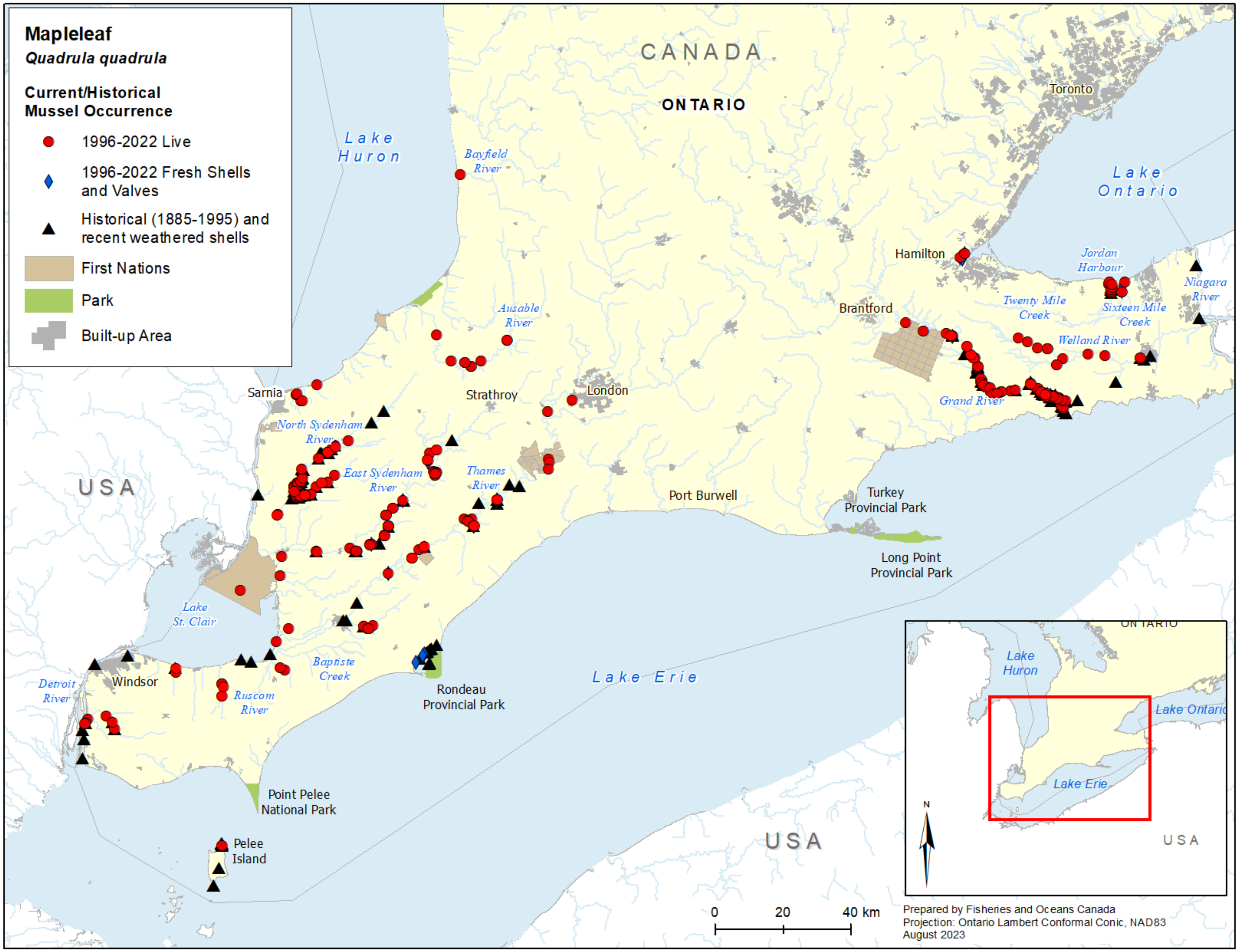

Figure 2. Current (1996 to 2022) and historical (1885 to 1995) occurrences of Mapleleaf, Great Lakes – Upper St. Lawrence population.

Ontario population size: The overall population size of Mapleleaf in Ontario appears to be stable (COSEWIC 2016). Canadian population estimates were developed by Bouvier and Morris (2011) and COSEWIC (2016), see table 3 for detailed information. The following descriptions of the known occurrence of Mapleleaf in Canada were adapted from Bouvier and Morris (2011), and COSEWIC (2016).

Great Lakes and connecting channels

Records exist for Mapleleaf within Lake Erie, Lake St. Clair, and Detroit and Niagara rivers. Until recently, the majority of these were historical records, such as the only 2 records that exist for Canadian waters of the Niagara River, from 1934. Likewise, there have been no recent observations of live Mapleleaf in Canadian waters of Lake St. Clair, with the exception of a live individual found in 2005. However, live specimens have recently been recorded in the Canard River and at Pelee Island. In the Canard River, 196 live specimens were observed from 6 sites, including 1 site at the confluence of the Detroit and Canard rivers in 2019 (DFO, unpubl. data). Furthermore, a recent study within U.S. waters of Lake Erie, Lake St. Clair, and the Niagara and Detroit rivers, identified 780 live Mapleleaf individuals at 141 sites, representing 27% of surveyed sites (Zanatta et al. 2015). This included 6 sites in western Lake Erie in 2011 and 2012 showing evidence of recent recruitment. According to Zanatta et al. (2015), this is evidence of a recent geographic expansion in Lake Erie.

Lake St. Clair drainage

St. Clair River delta: The St. Clair River delta has been surveyed extensively over the last twenty years, but Mapleleaf was not recorded until 2005, when a single live animal was documented from Chematogan Bay during a snorkelling survey (McGoldrick et al. 2009). No subsequent detection of live individuals has occurred.

Thames River: The Thames River has been sampled extensively since the mid-1990s and, although a few records of Mapleleaf exist in the upper Thames River, the species is predominantly present in the middle and lower portions of the river (including 2 tributaries, McGregor and Baptiste creeks). A large number of live Mapleleaf (for example, 225 from a single excavation) were detected during quadrat (1 m^2) excavations in 2010 (DFO, unpubl. data). There are no data available for determining if there have been changes in population size over time in the Thames River, although the recent data from the lower Thames suggest a healthy population, with 238 live individuals recorded at 1 quadrat site in 2016 (DFO, unpubl. data).

Puce River: Only 1 live specimen was recorded in 2016 (DFO, unpubl. data) from the Puce River, a tributary on the south shore of Lake St. Clair.

Jacks Creek Drain (Rivard Drain): In 2017, 34 live individuals were recorded in Jacks Creek Drain located northeast of the Lake St. Clair National Wildlife Area (DFO unpubl. data).

Ruscom River: In 1999, a unionid survey was conducted on the Ruscom River (a tributary on the south shore of Lake St. Clair), which yielded 9 live Mapleleaf. Additional surveys in 2010 found 26 Mapleleaf (present at 2 of 6 sites; McNichols-O'Rourke et al. 2012); as evidence of recruitment, multiple size classes were recorded.

Sydenham River (including Black Creek and Little Bear Creek): Mapleleaf was first recorded in the Sydenham River in 1963 and has been found regularly in subsequent surveys. An appraisal of Mapleleaf in the Sydenham River found that it was encountered more frequently and from more sites during surveys from 1999 to 2004 than in the pre-1991 surveys (Metcalfe-Smith et al. 2003). The species' range in this system occurs from Wallaceburg to just upstream of Alvinston in the East Sydenham River. In the North Sydenham River, Mapleleaf can be found in Bear Creek downstream of Petrolia and in Black Creek as far north as Plowing Match Road. Surveys in both Bear Creek and Black Creek have recently identified hundreds of individuals. In Bear Creek, 229 live individuals were recorded in 2016, 148 individuals in 2017, and 1,116 individuals in 2018. In Black Creek, 529 live individuals were identified in 2017, and 106 individuals in 2018. Many Mapleleaf locations have been sampled throughout the East Sydenham River from 1997 to 2019 and continue to yield live Mapleleaf (Metcalfe-Smith and Zanatta 2003, Bouvier and Morris 2011; T. Morris, DFO, unpubl. data). Size frequency distributions are indicative of recent recruitment of Mapleleaf within the Sydenham River system.

Little Bear Creek: Only 1 live individual was recorded at the mouth of Little Bear Creek in 2017 (DFO unpubl. data).

Lake Huron drainage

Ausable River: The first record of Mapleleaf in the Ausable River is from 2002 when 9 live specimens were captured. Subsequent sampling at additional sites in 2004 yielded another 9 specimens at 3 additional sites. In 2006, the 2002 site was revisited and 19 live Mapleleaf were observed (Ausable-Bayfield Conservation Authority [ABCA]), unpubl. data). Additional sampling from 2008 to 2013 confirmed that Mapleleaf occurs in low numbers in this system (ABCA, unpubl. data). More recent quadrat sampling by the ABCA in 2019 identified 31 individuals at 2 sites sampled using quadrats (ABCA, unpubl. data). Data are insufficient for determining if there have been changes in population size over time in the Ausable River but size frequency distributions are indicative of recent recruitment.

Bayfield River: The species was first detected in 2007 when a single Mapleleaf was identified (Morris et al. 2012a). Limited sampling for unionids has occurred in the Bayfield River, and therefore, at this time it is not known whether a reproducing Mapleleaf population is present.

Southern Lake Huron tributaries: In 2014, 24 live specimens were captured from 2 tributaries draining into Lake Huron (Cow Creek and Perch Creek/Telfer Diversion Channel) by the St. Clair Region Conservation Authority (SCRCA; E. Carroll, SCRCA, unpubl. data).

Lake Erie drainage

Lake Erie coastal embayments: In 2015, 2 live animals were collected from Lake Henry on Pelee Island by the Ontario Ministry of Natural Resources and Forestry (OMNRF; COSEWIC 2016). These were the first known live records of the species at this location. Further investigation in 2016 discovered 74 live individuals in Lake Henry (DFO, unpubl. data). Fresh shells have recently (2014 to 2015) been discovered in Rondeau Bay (Reid et al. 2016), suggesting the existence of a remnant population.

Grand River: Records of Mapleleaf in the Grand River date back to 1885, with all historical records occurring in the lower 65 km of the river, between Onondaga and Port Maitland. Mapleleaf was the most abundant species found in a 2011 survey (representing 55% of live unionids found); the size-frequency relationship suggests that the population is reproducing successfully, with multiple animals in nearly every size category (Minke-Martin et al. 2015).

Intensive sampling north of Caledonia failed to locate any individuals until 2019 when 3 live individuals were identified at 3 sites.

Lake Ontario drainage

Welland River: Only 2 historical records exist for Mapleleaf in the Welland River, neither of which represented a live individual. In 2008, unionid surveys were conducted and 25 live individuals were recorded at a site near Warner (approximately 50 km upstream of the historical location); no specimens were found at the historical location (Morris et al. 2012b). The same site was revisited in 2014 and 58 Mapleleaf were found (J.R Hoffman, Central Michigan University, unpubl. data). Additional surveys in 2015 yielded 69 live specimens from 7 sites on the Welland River, as well as 101 live specimens from 2 sites on Oswego Creek and Coyle Creek, which are both tributaries of the Welland River (DFO, unpubl. data). Most recently, 203 live specimens were sampled in 2016 and 216 in 2017 (DFO, unpubl. data) from the Welland River. Size frequency distributions are indicative of recent recruitment of Mapleleaf within the Welland River system.

Lake Ontario coastal embayments: Mapleleaf has been encountered in Jordan Harbour/Twenty Mile Creek, Sixteen Mile Creek, Fifteen Mile Creek/Pond, and Cootes Paradise/Spencer Creek (Hamilton Harbour) (Reid et al. 2014; DFO, unpubl. data; MNRF, unpubl. data).

Twenty Mile Creek/Jordan Harbour: The first recorded population of Mapleleaf within the Lake Ontario watershed was discovered in Jordan Harbour, where Twenty Mile Creek enters Lake Ontario. In 2010, 3 fresh valves and more than 100 weathered shells were observed on the northeast shore of Jordan Harbour (Theysmeyer pers. comm. 2010); however, no live specimens were observed. Further surveys (2011 to 2015) have consistently detected the species at multiple sites within the Twenty Mile Creek/Jordan Harbour system (Reid et al. 2014; DFO, unpubl. data, Reid et al. 2018). Little indication of recent recruitment is evident from size frequency distributions but this may be a reflection of sampling technique.

Sixteen Mile Creek: The first recorded population of Mapleleaf within the lower Sixteen Mile Creek was reported in 2013 when 6 live animals were found at 2 sites (Reid pers. comm. 2014). Live animals were found upstream of coastal wetlands where no dreissenid mussels (Zebra Mussel [*Dreissena polymorpha*] and Quagga Mussel [*D. bugensis*]) were observed in the turbid waters.

Hamilton Harbour: In 2015, 2 live Mapleleaf were collected from Cootes Paradise in Hamilton Harbour (DFO, unpubl. data). These were the first records of the species from this location. In 2018, 2 live individuals were recorded at Carroll's Bay (DFO, unpubl. data).

Population status

Bouvier and Morris (2011) derived population estimates for the Ausable, Grand, Sydenham, and Thames rivers (table 3); the Sydenham River estimate was updated as per COSEWIC (2016). The populations presented in table 3 have all shown evidence of recruitment, as have Mapleleaf in the Welland and Ruscom rivers. Estimates of population sizes were confined to these systems as they were the only locations where quantitative surveys had occurred. As many of the estimates are based on limited sampling, they are only meant to be used in a relative sense; refer to Bouvier and Morris (2011) and COSEWIC (2016) for details on the methodology.

Table 3. Abundance estimates for Mapleleaf (Bouvier and Morris 2011, COSEWIC 2016).

Waterbody	Average density (individuals/m^2 ± SE)	Area of occupancy (km^2)	Population size
Ausable River	0.135 (± 0.121)	0.71	9,977 to 183,005
Grand River	0.030[2]	10.83	324,831
Sydenham River[3]	0.370 (± 0.092)	5.80	1,612,579 to 2,679,898
Thames River	0.508 (± 0.187)	11.73	3,765,144 to 8,144,262

Rainbow

Global range: The Rainbow was once widely distributed in eastern North America, from New York and Ontario west to Wisconsin and south to Oklahoma, Arkansas, and Alabama. In the U.S., it has been recorded from Alabama, Arkansas, Illinois, Indiana, Kentucky, Michigan, Missouri, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, Tennessee, Virginia, West Virginia, and Wisconsin (NatureServe 2020; figure 3). The current distribution of the Rainbow is similar to its historical distribution, but it has been declining in many places, particularly the Great Lakes (NatureServe 2020). In Canada, Rainbow occurs only in Ontario (figures 3 and 4; COSEWIC 2015).

[2] Density estimate is only available from a single site and, therefore, Standard Error (SE) is not available
[3] T. Morris, DFO, unpubl. data

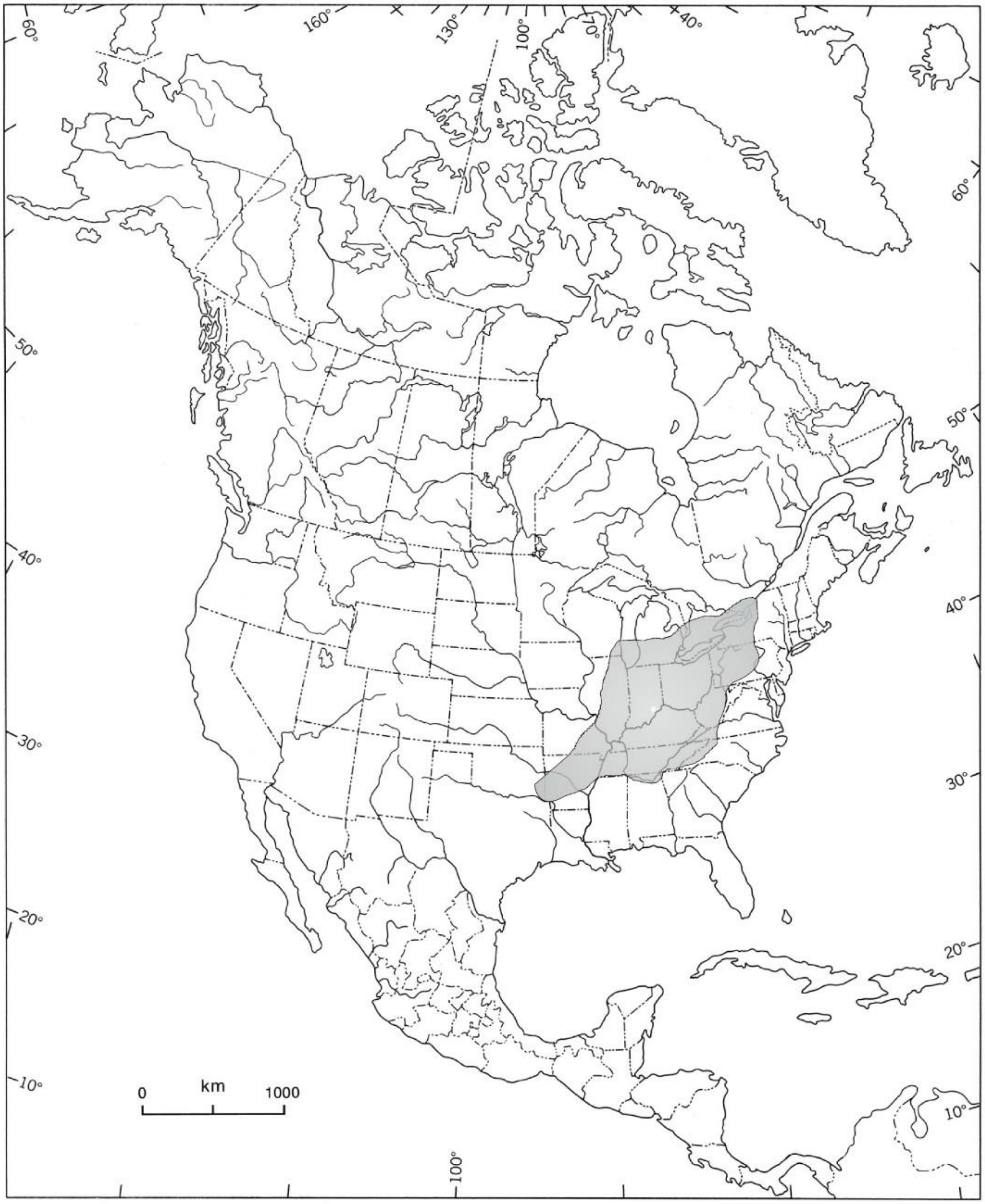

Figure 3. Global distribution of the Rainbow (from COSEWIC 2015).

Canadian range: In Canada, Rainbow is known only from southern Ontario. The current distribution of the species, collected between 1996 and 2022, is shown in figure 4. Live specimens have been found in the St. Clair River delta and in the Saugeen, Maitland, Bayfield, Ausable, Sydenham, Thames (North and Middle), Grand, lower Trent, Moira, and Salmon rivers. Rainbow appears to have been lost from the Detroit River, Lake Erie, lower Grand River, Niagara River, and Lake Ontario, areas that do not appear to have ever sustained large populations (COSEWIC 2015).

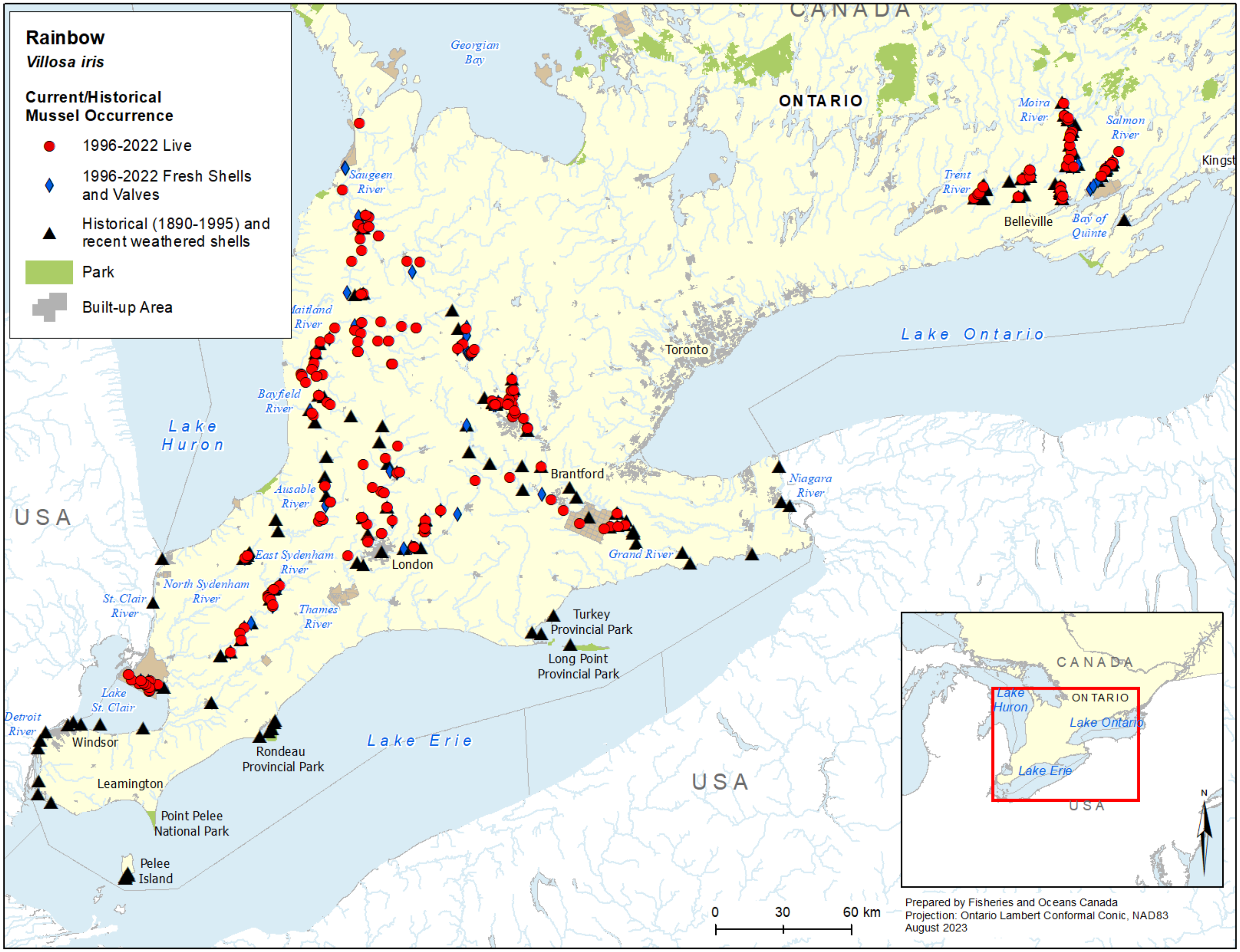

Figure 4. Current (1996 to 2022) and historical (1890 to 1995) occurrences of Rainbow in Canada.

Canadian population size: To date, it appears that there are 11 remaining systems containing Rainbow in Ontario. Canadian population estimates were developed by Bouvier and Morris (2011) and COSEWIC (2015) (see table 4 for detailed information). The following descriptions of the known occurrence of Rainbow in Canada were adapted from Bouvier and Morris (2011) and COSEWIC (2015).

Great Lakes and connecting channels

Historical Rainbow records exist for the nearshore area of Lake Erie (Long Point Bay, Rondeau Bay), Lake Ontario, and Lake St. Clair (south shore), as well as the Niagara and Detroit rivers and a single location in the St. Clair River. The last Rainbow record from any of these waterbodies was from 1994, when 2 individuals were found in the Detroit River. Surveys have occurred post-dreissenid mussel invasion at all historical Rainbow locations and no live individuals have been found. As is the case with most other unionids, it is believed that this species is now extirpated from the Great Lakes and its major connecting channels, due principally to the impacts of dreissenids.

Lake St. Clair drainage

St. Clair River delta*:* It is possible that small isolated populations of Rainbow inhabit the St. Clair River delta, as live animals have been observed sporadically in low numbers since 1999. Zanatta et al. (2002) found Rainbow at 14 of 53 sites located off the St. Clair River delta and along the eastern shore of Lake St. Clair. Based on sampling conducted by Metcalfe-Smith (2004), it appears that the species is far more common in the nearshore waters of the U.S. than in Canada. Surveys in 2004 to 2006 and 2011 detected Rainbow at 3 of 17 sites. Surveys conducted in 2016 in the Squirrel Island/Bass Bay area, resulted in the collection of 3 live individuals from 1 site. Additionally, the 2016 surveys found 3 live individuals from 2 sites in the area of Pocket Bay and Bassett Island, while 1 site produced 3 live individuals in this area in 2017 (DFO unpubl. data).

Sydenham River: Rainbow was first observed in the Sydenham River in 1963 and, over subsequent years, the species has been observed infrequently in spite of the Sydenham River being one of the most well-studied river systems in Ontario. It can be found in both the North Sydenham (Bear Creek) and East Sydenham rivers, albeit in low numbers. Quantitative surveys conducted at 15 monitoring sites during 1999 to 2003 by Metcalfe-Smith et al. (2007b) resulted in the capture of only 5 live specimens. Of these 15 sites, 10 were resampled in 2012 to 2013 and 4 contained Rainbow but, once again, in low numbers (more common in the east Sydenham River). Rainbow is believed to be a rare species throughout the Sydenham River and likely never occurred in significant numbers.

Thames River (including Otter, Fish, Medway, Stoney, Black, Dingman, North Branch, and Oxbow creeks): Rainbow is currently restricted to the North Thames River and several of its tributaries, a small reach of the Middle Thames River, and 2 sites on the South Thames River near Innerkip and Dorchester (Mackie 2011; DFO unpubl. data). Timed-search surveys were conducted in 2004 to 2005 at 37 sites throughout the upper and lower reaches of the watershed. Live individuals were only found in tributaries of the upper watershed, with more than 90 live specimens located (Morris and Edwards 2007). Sites with the highest numbers of Rainbow were located in Otter, Fish, and North Branch creeks. However, in 2018 a site in the Middle Thames near Thamesford was found to have 73 live individuals. It appears that Rainbow occurs infrequently in the Thames River, but is occasionally abundant in the mid to upstream reaches of the river.

Lake Huron drainage

Ausable River: Few records of Rainbow were known until 2002, when timed-search and quadrat sampling yielded 54 live individuals. Recent detections (since 2006) are all within the upper reaches spanning just north of Brinsley to Nairn, as well as 2 tributaries: Nairn Creek and the Little Ausable River (DFO, unpubl. data). In total, there are 5 sites where Rainbow currently resides and 8 additional sites with records of weathered and fresh shells. Most recently, there were 43 live individuals from 3 sites in 2018 and 11 live individuals from 1 site in 2019 (DFO, unpubl. data).

Saugeen River (including Teeswater River): Rainbow was first observed in the Saugeen River in 1993 when a single live specimen was captured. Since 1998, subsequent sampling has occurred at 22 new sites, with Rainbow detected in the Teeswater, North Saugeen, South Saugeen, and Beatty Saugeen rivers; the greatest concentration was in the Teeswater River. Morris (2007) found that Rainbow is widely distributed in the Saugeen River watershed, but numerically rare. Live Rainbow were found at half of the sites surveyed in 2011 (6 of 12); their measured size distribution is indicative of ongoing reproduction and recruitment (McNichols-O'Rourke et al. 2012).

Maitland River: Rainbow was first recorded from the Maitland River in the 1930s and was not recorded again until 1998. Recent sampling (33 sites surveyed between 1998 to 2012) in the Maitland watershed detected Rainbow in high densities at over half of the surveyed sites, 10 of which are on tributaries representing all branches of the river (Middle Maitland, South Maitland, and Little Maitland rivers). The Maitland River is believed to support the largest remaining population of Rainbow in Canada (table 4).

Bayfield River: A single fresh shell collected in 2005 represents the first record of Rainbow in the Bayfield River. In 2007 and 2011, intensive surveys of the Bayfield River were completed and Rainbow was detected at 9 of 18 sites: 2 from the Bannockburn River, 3 from the upstream reaches of the main channel (spanning Clinton to Vanastra), as well as 4 headwater sites with shells only (Morris et al. 2012a). No individuals or shells were found in the lower reaches of the river. A total of 19 live individuals were identified at 1 site in the town of Clinton in 2019 (DFO, unpubl. data).

Lake Erie drainage

Grand River (Mallet and Conestogo rivers): The overall abundance of Rainbow in the Grand River is low, although there are numerous historical records of the species. Only 1 record existed of Rainbow in the lower Grand River since the 1970s until 95 live individuals were found from 3 sites in Boston Creek in 2017 (DFO, unpubl. data). In the central Grand River, a few specimens were detected in 2012 and 2014 (Gillis et al. 2017a). More recently, surveys in the central portion of the river identified several live specimens at 1 site at Kiwanis Park in 2019 as well as at West Montrose in 2019 (DFO, unpubl. data). In the headwaters and tributaries of the Grand River, 40 live Rainbow have been found since the 1970s. Of the 34 specimens discovered in the last decade, 3 were from the Mallet River, 14 from the Conestogo River, and 17 in the upper portions of the main branch of the Grand River. The Mallet, Conestogo, and Nith rivers have numerous records of fresh and weathered shells, suggesting that this area sustains widespread Rainbow populations. As headwater systems have not been surveyed for Rainbow, the distribution of the species may extend further upstream in the watershed.

Lake Ontario drainage

Moira River: A total of 32 live individuals were collected from 3 of 6 sites in 1996. A survey conducted in 2014 found Rainbow widespread (at 14 of 17 surveyed sites), with a distribution from Tweed to just upstream of the mouth of the river in the most developed areas in Belleville (Reid and Morris 2017). Additionally, lower numbers were found at the 1 site surveyed on the Skootamatta River, a tributary to the Moira River (Reid and Morris 2017). In 2017, 56 live individuals were discovered at a site in Parks Creek, while 10 live individuals were found at 2 sites in the main stem of the Moira (DFO, unpubl. data).

Salmon River: In the Salmon River, more than 100 weathered and a few fresh shells were found during shoreline surveys between 2005 and 2010 (Schueler 2012), but it was not until 2011 that 4 live individuals were reported from 2 sites (S. Reid, OMNRF, unpubl. data). Targeted surveys conducted in 2014 detected the species at 5 of 7 sites (Kingsford to a site between Lonsdale and Milltown); no Rainbow were detected at the 2 upstream sites (just south of Tamworth) (Reid 2016). In 2017, 11 live individuals were identified at 2 sites (DFO, unpubl. data).

Trent River: Surveys conducted in 2013 within the Trent River system resulted in 195 live individuals (from 9 sites total), although most sites were located within small tributaries (Rawdon, Cold, Burnley, and Percy creeks). Few live animals were found at the 2 sites located in the main stem of the Trent River at Meyer’s Reach and Glen Ross, where Zebra Mussel was in high abundance (Epp-Martindale pers. comm. 2020). Weathered shells were found in Salt Creek, indicating that populations may have at one time resided in this tributary.

Population status

Rainbow in Lake St. Clair and the Sydenham and Ausable rivers may be declining, while evidence of recruitment is available for populations detected in the Thames, Saugeen, Bayfield, Moira, Salmon, and Trent rivers (COSEWIC 2015). COSEWIC (2015) derived Rainbow population abundance estimates and area of occupancy for most Canadian locations (table 4). Eastern locations (for example, Moira, Salmon, and Trent rivers) were excluded due to the lack of quantitative surveys, as were the Detroit River, Lake Erie, Niagara River, and Lake Ontario, from which Rainbow appears to be extirpated. These estimates replace earlier ones found in Bouvier and Morris (2011), as they contain information gained from recent quantitative surveys. As many of the estimates are based on limited quantitative sampling, they are only meant to be used in a relative sense; refer to COSEWIC (2015) for further details on the methodology and rationale.

Table 4. Abundance estimates for Canadian Rainbow populations (COSEWIC 2015).

Waterbody	Average density (individuals/m^2 ± SE)	Area of occupancy (km^2)	Population size
Ausable River	0.07 ± 0.03	0.18	5,900 to 18,000
Bayfield River	0.28[4]	0.26	74,000
Grand River	0.01 ± 0.01	3.89	4,700 to 45,000
Lake St. Clair	0.0002[4]	6.82	1,500
Maitland River	0.74 ± 0.40	5.69	2,000,000 to 6,500,000
Saugeen River	0.31 ± 0.08	2.28	520,000 to 880,000
Sydenham River	0.01 ± 0.00	1.24	17,000 to 18,000
Thames River	0.06 ± 0.02	1.27	48,000 to 94,000

4.3. Needs of the species

Habitat and biological needs

Mapleleaf

Spawning to encysted glochidia stage: The reproductive biology of the Mapleleaf is similar to that of most unionids (adapted from Clarke 1981, Kat 1984). During spawning, males release sperm into the water and females living downstream filter the sperm out of the water with their gills. Once the ova are fertilized, they are held until they reach a larval stage called the glochidium. The length of the brooding season for the Mapleleaf has been reported to vary with location, ranging from late spring to early summer in Canada (Clarke 1981). In the Sydenham River, gravid Mapleleaf have been found between mid-July and mid-August (T. Morris, DFO, unpubl. data). The Mapleleaf is considered a short-term brooder (tachytictic), brooding and releasing its glochidia in the same year (COSEWIC 2016). The released glochidia are obligate parasites that must attach to an appropriate host. Many species of freshwater mussels have evolved complex host attraction strategies to increase the probability of encountering a suitable host (Zanatta and Murphy 2006).

Unionids cannot complete their life cycle without access to the appropriate glochidial host. If host populations disappear or decline in abundance to levels below that which can sustain a mussel population, recruitment will no longer occur and the mussel species may become functionally extinct (Bogan 1993). Most common hosts appear to be fish species, but little

[4] Standard Error (SE) is not available

information on the specificity of host requirements for the Mapleleaf exists. The Channel Catfish (*Ictalurus punctatus*) has been implicated as a host fish (Schwebach et al. 2002) for Canadian populations, and its distribution overlaps populations of Mapleleaf (Bouvier and Morris 2011). The Brown Bullhead (*Ameiurus nebulosus*) is another potential host fish for the Mapleleaf in Canada (COSEWIC 2016). Glochidia will remain encysted until they metamorphose into juveniles. Attachment times for the Mapleleaf have been noted from 51 to 68 days, with temperature being a key factor in development time (Schwebach et al. 2002).

Juvenile: After metamorphosis, juveniles release themselves from the host and fall to the substrate to begin life as free-living mussels. Unionid juvenile stages generally reside buried within sediment substrates for a number of years, a behaviour that most likely applies to the Mapleleaf. A study of juvenile unionids in Virginia found them buried in substrate up to 8 cm deep, with the majority of individuals found in the surface layer (Neves and Widlak 1987). Juveniles residing within the sediment likely consume interstitial organic material, such as bacteria and algae (for example, Yeager et al. 1994). They remain buried until they are sexually mature, at which point they move to the surface for the dispersal/intake of gametes (Watters et al. 2001). Impacts of substrate type on Mapleleaf juvenile survival are unknown.

Adult: In Canada, Mapleleaf is most commonly encountered in shallow lakes, deep river impoundments, and medium to large rivers and embayments with slow to moderate flow characteristics (Clarke 1981, Parmalee and Bogan 1988, Watson 2000, Baitz et al. 2008). Flow does not seem to be a limiting characteristic, as Mapleleaf has been found in both slow- and fast-flowing water (Bouvier and Morris 2011). Surveys in the Grand River found Mapleleaf in locations with boulders, cobble, gravel, and all sites had a degree of mud (Mackie 2012). Dominant substrate used by Mapleleaf is variable, but recent studies have found them at sites dominated by muck/mud/silt/detritus, gravel, clay, and rubble (Wright et al. 2017, Reid et al. 2018, Morris et al. 2020, Wright et al. 2020). In the Ausable River, Mapleleaf was found exclusively at the survey station with the slowest flow characteristics (Baitz et al. 2008). Temperature tolerance is unknown; however, the temperature ranges recorded in occupied Canadian rivers range from near freezing to approximately 27°C.

Adult unionids have very limited dispersal abilities. Although adult movement can be directed upstream or downstream, a net downstream movement through time has been recorded (Balfour and Smock 1995). Nutritional requirements of unionids are poorly understood and species-specific studies on the Mapleleaf are unavailable. Extrapolation from feeding studies of other unionids suggest that the Mapleleaf is likely to ingest both suspended (Nichols and Garling 2000) and deposited (Raikow and Hamilton 2001) particulate organic matter, with possible selection of phytoplankton and bacteria.

Limiting factors: Factors involving reproduction and dispersal may be the most significant limiting factors for the Mapleleaf. Availability of host fish suitable for glochidial attachment may inhibit unionid population growth and dispersal, and the time frame for glochidia attachment to the host fish may be very limited. The primary means for large-scale dispersal, upstream movement, and the invasion of new habitat or survival of deteriorating habitat is limited to the encysted glochidial stage on the host fish. If host fish populations disappear or decline in abundance to levels below that which can sustain a mussel population, recruitment will no longer occur and the mussel species may become functionally extinct (Bogan 1993). The availability and health of the host species may therefore pose a limitation to the species. Unionids are known to be food sources for a variety of mammal, bird, and fish species (Fuller 1974). Predation by terrestrial predators, such as Muskrat, has been shown to be an important limiting factor for some populations (Neves and Odom 1989). Muskrat have been known to prey upon Mapleleaf (Nakato et al. 2007), while consumption of Rainbow has not been reported. In Ontario, Raccoons (*Procyon lotor*) have been reported to prey on unionids (COSEWIC 2015), but it is unknown if they target Mapleleaf or Rainbow. There is little information on the direct impact of predation on Canadian unionids; however, it is thought that the impact would be quite low (Bouvier and Morris 2011).

Rainbow

Spawning to encysted glochidia stage: The reproductive biology of Rainbow follows the general reproductive biology of most Unionids (refer to the information presented above for Mapleleaf). Unlike the short-term brooding Mapleleaf, the Rainbow is bradytictic (long-term brooder); it spawns in late summer, broods the glochidia over the winter and subsequently releases the glochidia in early spring (Watters et al. 2009). Upon release, the glochidia must attach to an appropriate host, which appears confined to fish species for Rainbow. Female Rainbow use a visual display to attract their host fish and, thus, water clarity may be important for successful reproduction. They have a modified mantle flap that mimics a crayfish in shape and movement; when a fish approaches or strikes at the lure, the female mussel expels her glochidia, which facilitates the attachment of the glochidia to the gills of the fish. The glochidia become encysted on the host and develop for 21–69 days (depending on temperature) until they metamorphose into juveniles (Woolnough et al. 2007). Known host fish, as determined in laboratory transformations for the Rainbow include: Green Sunfish (*Lepomis cyanellus*), Greenside Darter (*Etheostoma blennioides*), Mottled Sculpin (*Cottus bairdii*), Rainbow Darter (*E. caeruleum*), Smallmouth Bass (*Micropterus dolomieu*), Striped Shiner (*Luxilus chrysocephalus*), and Yellow Perch (*Perca flavescens*). Many of these species commonly occur throughout the mussel's range in Canada (Watters and O'Dee 1997, Scott and Crossman 1998, Watters et al. 2005); the Green Sunfish, Greenside Darter, and Striped Shiner do not occur within the more easterly portions of Rainbow's range. To date, 4 hosts for Rainbow have been identified in Ontario through laboratory studies: Largemouth Bass (*M. salmoides*), Mottled Sculpin, Yellow Perch, and Rock Bass (*Ambloplites rupestris*) (Woolnough et al. 2007, McNichols et al. 2008). Glochidia will remain encysted until they metamorphose into juveniles.

Juvenile: For juvenile habitat and biological needs, refer to the information presented above for Mapleleaf. It has been posited that juvenile Rainbow survival may be significantly impacted by substrate type (Hua et al. 2013). A study of juvenile unionids in Virginia found individuals of several species buried in substrate up to 8 cm deep (Neves and Widlak 1987). However, in a laboratory setting juvenile Rainbow were found to burrow less than 1 cm into the sediment (Yeager et al. 1994).

Adult: The Rainbow, like all unionids, is a sedentary animal that buries itself partially or completely in the substrates of rivers or lakes. It is most abundant in small- to medium-sized rivers (Van der Schalie 1938, Strayer 1983, Parmalee and Bogan 1988), but can also be found in inland lakes, and once occurred throughout the shallow nearshore areas of the lower Great Lakes and connecting channels in firm sand or gravel substrates (Clarke 1981, Strayer and Jirka 1997, Zanatta et al. 2002). In rivers, the Rainbow is usually found in, or near, riffles and along the edges of emergent vegetation in moderate to strong current (Metcalfe-Smith et al. 2005, COSEWIC 2015), where the species occupies substrate mixtures of cobble, gravel, sand, and occasionally mud or boulder (COSEWIC 2015). The Rainbow is most numerous in clean, well-oxygenated reaches at depths of less than 1 m (Van der Schalie 1938, Parmalee and Bogan 1988, Gordon and Layzer 1989).

Adult Rainbow have very limited dispersal abilities, as is the case with unionids in general. Their specific nutritional requirements are unknown.

Limiting factors: As with the Mapleleaf above.

5. Threats

5.1. Threat assessment

An assessment and prioritization of threats to Mapleleaf and Rainbow were informed by COSEWIC status reports (COSEWIC 2015, 2016), the recovery potential assessment that included both species (Bouvier and Morris 2011, DFO 2011), and the proposed recovery strategies that were published in 2016 (DFO 2016a, b). The current threat assessment and prioritization rely most significantly on the recovery potential assessment (Bouvier and Morris 2011, DFO 2011). For more details on the threat assessment process, refer to the Guidance on Assessing Threats, Ecological Risk and Ecological Impacts for Species at Risk (DFO 2014). The specific assessment categories and associated rankings are presented in tables 5(a, b) and 6(a, b). The threat level represents a combination of the current threat impact (that is, not potential impact) and threat likelihood at a location. It does not reflect the potential impact a threat might have on a unionid population if it were allowed to occur in the future (see Bouvier and Morris 2011 for further details).

Table 5. Population-level threat assessment for the Mapleleaf in Ontario. The number in brackets refers to the level of certainty associated with the threat impact and has been classified as: 1=causative studies; 2=correlative studies; and 3=expert opinion. Table modified from Bouvier and Morris (2011).

Threat	Detroit River/ Canard River	Ruscom River/ Puce River	Jacks Creek Drain (Rivard Drain)	St. Clair River delta	Little Bear Creek	Sydenham River	Lower Thames River
Invasive species	High	High (2)	Medium	High (2)	Medium	Medium (2)	High (2)
Turbidity and sediment loading	Medium	Medium (3)	Medium	Low (3)	Medium	Medium (3)	Medium (3)
Contaminants and toxic substances	High	High (3)	High	High (3)	High	High (3)	High (3)
Nutrient loading	Medium	Medium (3)	Medium	Low (3)	Medium	Medium (3)	Medium (3)
Altered flow regimes	NA[5]	Medium (3)	Low	NA[5]	Low	Medium (3)	Medium (3)
Habitat removal and alterations	High	High (3)	High	Medium (3)	High	High (3)	High (3)
Lack of access to host fish	Medium	Medium (3)	Medium	Medium (3)	Medium	Medium (3)	Medium (3)
Recreational activities	Low	Unknown (3)	Low	Low (3)	Low	Low (3)	Low (3)

[5] NA means not applicable

Table 5 (cont'd). Population-level threat assessment for the Mapleleaf in Ontario. The number in brackets refers to the level of certainty associated with the threat impact and has been classified as: 1=causative studies; 2=correlative studies; and 3=expert opinion. Table modified from Bouvier and Morris (2011).

Threat	Ausable River	Bayfield River	Southern Lake Huron tributaries	Pelee Island	Grand River	Hamilton Harbour	Jordan Harbour	Welland River	Sixteen Mile Creek
Invasive species	Medium (2)	Medium (2)	Medium	High	High (2)	High	High (2)	Medium (2)	High
Turbidity and sediment loading	Medium (3)	Medium (3)	Medium	Medium	Medium (2)	Medium	Medium (3)	Medium (3)	Medium
Contaminants and toxic substances	High (3)	High (3)	High	Unknown	High (2)	High	High (3)	High (3)	High
Nutrient loading	Medium (3)	Medium (3)	Medium	Low	Medium (2)	High	Medium (3)	Medium (3)	High
Altered flow regimes	Medium (3)	High (3)	Low	NA[5]	Medium (2)	NA[5]	NA[5]	Low (3)	High
Habitat removal and alterations	Medium (3)	Medium (3)	Medium	Low	High (2)	Medium	Medium (3)	Medium (3)	Medium
Lack of access to host fish	Medium (2)	Medium (3)	Medium	Medium	High (3)	Medium	Medium (3)	Medium (3)	Medium
Recreational activities	Low (3)	Low (3)	Low	Low	Low (3)	Low	Low (3)	Low (3)	Low

Table 6. Summary of threats to Rainbow in Canada. The number in brackets refers to the level of certainty associated with the threat impact and has been classified as: 1=causative studies; 2=correlative studies; and 3=expert opinion (table modified from Bouvier and Morris 2011).

Threat	St. Clair River delta	Saugeen River	Maitland River	Ausable River	Bayfield River
Invasive species	High (2)	Medium (2)	Medium (2)	Medium (2)	Medium (2)
Turbidity and sediment loading	Medium (3)	High (3)	High (3)	High (3)	High (3)
Contaminants and toxic substances	High (3)	High (3)	High (3)	High (3)	High (3)
Nutrient loading	Medium (3)	High (3)	High (3)	High (3)	High (3)
Altered flow regimes	NA[5]	Medium (3)	Medium (3)	Medium (3)	High (3)
Habitat removal and alterations	Medium (3)	High (3)	Medium (3)	Medium (3)	Medium (3)
Lack of access to host fish	High (3)	High (3)	Medium (3)	Medium (2)	Medium (3)
Recreational activities	Low (3)	Low (3)	Low (3)	Low (3)	Low (3)

Table 6 (cont'd). Summary of threats to Rainbow in Canada. The number in brackets refers to the level of certainty associated with the threat impact and has been classified as: 1=causative studies; 2=correlative studies; and 3=expert opinion (table modified from Bouvier and Morris 2011).

Threat	Sydenham River	Upper Thames River	Grand River	Trent River	Moira River	Salmon River
Invasive species	Medium (2)	High (2)	High (2)	High (2)	High (2)	High (2)
Turbidity and sediment loading	High (3)	High (3)	High (2)	Medium (3)	Medium (3)	Medium (3)
Contaminants and toxic substances	High (3)	High (3)	High (2)	High (3)	High (3)	Medium (3)
Nutrient loading	High (3)	High (3)	High (2)	Medium (3)	Medium (3)	Medium (3)
Altered flow regimes	Medium (3)	High (3)	Medium (2)	High (3)	Medium (3)	Medium (3)
Habitat removal and alterations	High (3)	High (3)	High (2)	High (3)	Medium (3)	Medium (3)
Lack of access to host fish	High (3)	High (3)	High (3)	High (3)	Medium (3)	Medium (3)
Recreational activities	Low (3)	Low (3)	Low (3)	Low (3)	Low (3)	Low (3)

5.2. Description of threats

Mapleleaf and Rainbow

The following brief descriptions emphasize the principal threats currently acting on Mapleleaf and Rainbow populations in Canada. Much of the information has been summarized from (Bouvier and Morris 2011) and (COSEWIC 2015, 2016).

Invasive species: Invasive dreissenids have had a profound impact on unionid communities in Canada (Ricciardi et al. 1998). Direct attachment by dreissenids on unionids can lead to interference of feeding, locomotion, respiration, and excretion (Haag et al. 1993, Schloesser et al. 1996). Dreissenids rely on passive dispersal of their larvae, and are therefore generally unable to move upstream, unlike unionids that employ host fish to facilitate upstream dispersal (Mackie 1991). For this reason, dreissenids pose an important threat to the lacustrine habitat of unionids. The apparent loss of Mapleleaf and Rainbow from the lower Great Lakes and connecting channels is believed to be directly related to the invasion of dreissenids within these systems, starting in the mid to late 1980s (Schloesser and Nalepa 1994, Nalepa et al. 1996). Dreissenids also threaten and limit the distribution of unionids in the St. Clair River delta (Metcalfe-Smith et al. 2007a, Metcalfe-Smith et al. 2007b).

Dreissenids could also pose a threat to riverine unionid populations, if they were to become established in reservoirs (Bouvier and Morris 2011). Dreissenids have been reported in 2 reservoirs on the Thames River (UTRCA 2003), and throughout the lower Thames River from Fanshawe Reservoir to the mouth of the river (Morris and Edwards 2007). Unionids in the Grand River are highly susceptible to dreissenids, as it is heavily impounded. Infestation by dreissenids of the Luther, Belwood, Guelph, or Conestogo reservoirs could have a significant impact on the unionid populations (Metcalfe-Smith et al. 2000). Fortunately, in some cases, Mapleleaf and Rainbow have the capacity to co-exist with dreissenids in areas where dreissenid densities are relatively low. For example, Mapleleaf in the lower Grand River (near Port Maitland) appear to survive dreissenid infestation, as demonstrated by the presence of live individuals covered in byssal threads (a sign that they had been infested; Staton pers. comm. 2016), and Rainbow downstream of reservoirs in the upper reaches of the Thames River system have co-existed with dreissenids for over 15 years. Should dreissenids become established in the Wildwood or Pittock reservoirs in the upper reaches of the Thames River watershed, it would pose a major threat to the Rainbow population in the river. Dreissenids are abundant throughout the Trent River, including sites where Rainbow was collected in 2013, and at many sites within the Moira River, and are also present in the Salmon River watershed (for example, Beaver Lake) (Reid and Hogg pers. comm. 2014).

Other invasive species may indirectly affect Mapleleaf and Rainbow by disrupting host-fish relationships. For example, Mottled Sculpin has shown recruitment failure and steep declines in abundance in the Great Lakes basin since the introduction of the Round Goby (*Neogobius melanostomus*) (Dubs and Corkum 1996, Janssen and Jude 2001). Poos et al. (2010) documented the upstream invasion of Round Goby into the lower portions of several rivers, including the Ausable, Sydenham, Thames, and Grand. Round Goby is abundant and widespread along the Trent River and at sites where Rainbow was collected in 2013 (Reid and Hogg pers. comm. 2014). The Round Goby may act as a reproductive sink, as it has been observed to be infested with Rainbow glochidia with low numbers of these glochidia successfully achieving metamorphosis (Tremblay et al. 2016).

Turbidity and sediment loading: High silt inputs can affect unionids by disrupting reproductive functions (decreasing the likelihood of attracting a suitable host fish through their visual display), clogging gill structures and inhibiting oxygen intake, and clogging siphons (Tuttle-Raycraft et al. 2017); susceptibility to siltation varies from species to species. Erosion due to poor agricultural practices can result in siltation and shifting substrates that can smother unionids. Agricultural practices that may result in increased siltation rates include allowing livestock access to streams, which can result in streambank instability; installation of tile drainage systems; and clearing of riparian vegetation.

The primary land use in the Ausable and Sydenham river basins is agricultural. The Ausable River watershed has been drastically altered (Bouvier and Morris 2011); it is estimated that by 1983, 85% of the land in this watershed had been converted from forest and wetland to agricultural land and that 70% of the land is now in tile drainage (Nelson et al. 2003). Over 85% of the Sydenham River watershed is agricultural land, with large areas of the river having little or no riparian vegetation (Dextrase et al. 2003). Suspended solids have been reported as high as 900 mg/L (Dextrase et al. 2003), a level that would negatively impact unionid populations (Bouvier and Morris 2011). In the Grand River, increased agricultural pressure has affected water quality, resulting in increased turbidity and sediment loads; however, species found in the lower Grand River (for example, Mapleleaf) are mainly affected (Bouvier and Morris 2011, COSEWIC 2016). It is estimated that over 75% of the land in the upper Thames River, where Rainbow is found, is used for agricultural purposes (UTRCA 2012). The upper Thames River is considered to be moderately turbid (COSEWIC 2015), with large areas of the river having little or no riparian vegetation (Taylor et al. 2004). The presence of a low head dam near the mouth of the river at Dunnville is also known to contribute to degraded (for example, high nutrient levels and low oxygen), highly turbid conditions within the lower 30 km reach of the Grand River where the Mapleleaf is found (MacDougall and Ryan 2012). The St. Clair River delta is considered to be less affected by this threat, as it is afforded protections by the Walpole Island First Nation Territory (Bouvier and Morris 2011).

Contaminants and toxic substances: Contaminants can enter Mapleleaf and Rainbow habitat in a variety of ways, such as agricultural and road run-off, and industrial and storm sewer discharges. Potential contaminants include pesticides, road salts, hydrocarbons, and heavy metals. Recent studies on the impacts of pesticides on early life stages indicate that unionids are relatively sensitive to pesticides (Bringolf et al. 2007), heavy metals (Keller and Zam 1990, Jacobson et al. 1997), acidity (Huebner and Pynnonen 1992), and salinity (Gillis 2011). As benthic filter-feeders, unionids can be exposed to contaminants in both the dissolved phase (that is, in the water column) and those associated with the sediment (both suspended and settled). Juvenile unionids remain buried in the sediment for the first few years of life, where they feed exclusively on particles in the interstitial water. Such behaviour may increase their exposure to sediment-bound contaminants during this sensitive early life stage (Yeager et al. 1994), which could have implications for the survival of species that are especially sensitive to toxic chemicals. The vast majority of unionids remain untested for most contaminants; consequently, it is often necessary to extrapolate chemical sensitivities when they are known for closely related species (Raimondo et al. 2016).

Toxicity of road salt to unionid glochidia has been demonstrated (Gillis 2011, Pandolfo et al. 2012). Prosser et al. (2017) conducted a probabilistic risk assessment of chloride to unionid glochidia, which revealed that chronic exposure to elevated chloride levels could pose a risk to unionids. Todd and Kaltenecker (2012) suggested that long-term road salt use is contributing to increases in baseline chloride concentrations in at-risk unionid habitats in southern Ontario, which may affect recruitment of at-risk unionid populations; Mapleleaf and Rainbow are found in many of these habitats. Although federal water quality guidelines for the protection of aquatic life have been set at 120 mg/L for chronic exposure to chloride, this guideline may not be sufficiently protective of glochidia of some species at-risk unionids in southern Ontario (CCME 2011).

Many forms of pollution resulting from human encroachment, such as residential and urban development, may be present in Mapleleaf and Rainbow habitat (for example, run-off of lawn fertilizers and pesticides, road salts, and heavy metals from industrial sources). Exposure to municipal wastewater effluent can negatively affect unionid health (Gagné et al. 2004, Gagnon et al. 2006). Pharmaceuticals enter streams, rivers and lakes, largely via effluent from sewage treatment plants. There is an increasing concern of possible endocrine and reproductive effects from these chemicals on aquatic biota; related work with unionids is in its infancy (de Solla et al. 2016, Gilroy et al. 2017), but there is reason for concern as significant effects on freshwater fish communities have been demonstrated (Kidd et al. 2007). In the Grand River, recent work by Tetreault et al. (2011) has documented feminization of some fishes, including suspected host fish species. Although such impacts have not been documented for unionids within rivers of southern Ontario, in Quebec, Gagné et al. (2011) determined that Eastern Elliptio (*Elliptio complanata*) showed a dramatic increase in the proportion of females, and that males showed a female-specific protein downstream of a municipal effluent outfall. This indicates that pollution is disrupting gonad physiology and reproduction of this species.

Mackie (1991) reported that anthropogenic stressors (for example, sewage pollution) occurring below urban centres were responsible for much of the harm to the unionid assemblages in the Grand River. A recent study that assessed the cumulative impacts of urban run-off and municipal wastewater effluent on unionids in the Grand River concluded that chronic exposure to multiple contaminants (for example, ammonia, chloride and metals, such as copper, lead, and zinc) contributed to the decline of unionid populations in this watershed (Gillis 2012); the author also confirmed this negative impact through a follow-up study that revealed the existence of a “dead zone” immediately downstream of one wastewater treatment plant outfall near Kitchener, where no live unionids were detected for several kilometres. Alterations in unionid community and population structure in relation to urbanization in both the Grand and Speed rivers have been reported (Gillis et al. 2017a, b).

Within the Grand River watershed, copper levels have exceeded federal guidelines in several sub-basins (Grand River Conservation Authority 2006). Copper levels exceed federal guidelines in the Middle Maitland River (Kenny pers. comm. 2003), and concentrations of copper exceed guidelines in several sub-basins of the Thames River watershed (Morris et al. 2008). In the Welland River watershed, recent research has indicated the presence of highly elevated levels of per- and poly-fluorinated compounds (for example, Perfluorooctanesulfonic acid [PFOS]) in biota within Lake Niapenco in the upper watershed, with the source of the contamination attributed to the upstream Hamilton airport (de Solla et al. 2012). Contamination by fluorinated compounds is of concern for Mapleleaf (as well as other unionids) found further downstream in the Welland River, as recent laboratory results have indicated that the brooding glochidia of some mussel species are highly sensitive to such contaminants and are among the most sensitive organisms tested to date (Hazelton et al. 2012).

The use of chemical lampricides are one of several tactics used to control for Sea Lamprey (*Petromyzon marinus*) in natal streams within the Great Lakes basin (DFO 2021). One such lampricide, granular Bayluscide, is an important component of binational control efforts of Sea Lamprey in the Great Lakes and is also a known molluscicide (Andrews et al. 2021). Until recently, very little had been published in regard to the effects of granular Bayluscide on aquatic species at risk in the Great Lakes. Andrews et al. (2021) found the risk of granular Bayluscide application to Mapleleaf and Rainbow was low relative to other mussel species at risk. Furthermore, the estimated median mortality from a granular Bayluscide application in the Sydenham River was zero for both species, while median mortality in the Thames River was close to zero for Mapleleaf (Smyth and Drake 2021). Although the risk is low, there is the potential for applications of this lampricide to kill tens to hundreds of individuals of these species based on the modelling exercise published by Smyth and Drake (2021). For example, approximately 5% of the time, a granular Bayluscide application cycle is expected to kill tens of individuals of both Mapleleaf and Rainbow in the Sydenham River and tens of Mapleleaf and hundreds of Rainbow in the Thames River (Smyth and Drake 2021).

Nutrient loading: The primary concern of nutrient loadings in Mapleleaf and Rainbow habitat relates to eutrophication effects, namely algal blooms that can result in oxygen depletion and algal toxins. For example, reduced mussel growth has been observed in unionids when cyanobacteria levels are elevated (Bartsch et al. 2017). A negative correlation was found between concentrations of phosphorus and nitrogen and Wavyrayed Lampmussel (*Lampsilis fasciola*) abundance in a variety of southwestern Ontario streams (Morris et al. 2008). Additionally, juvenile mussels may be particularly sensitive to ammonia (Goudreau et al. 1993, Mummert et al. 2003), which has been measured at concentrations exceeding federal guidelines within the range of Mapleleaf and Rainbow (Morris et al. 2008). Mummert et al. (2003) found that juvenile Rainbow were among the most sensitive aquatic organisms to un-ionized ammonia and that this contaminant may limit the distribution of Rainbow in some systems. Mapleleaf remain to be tested for ammonia sensitivity.

The potential for run-off of fertilizer must be considered where agriculture is present. Accidental spills that have the potential to reduce dissolved oxygen can negatively influence unionid populations (Tetzloff 2001). The Thames River exhibits some of the highest phosphorus and nitrogen loadings found in the Great Lakes basin (WQB 1989). In particular, the lower Thames River is heavily impacted by agricultural activities. Phosphorus levels exceeding the provincial water quality objectives are often found in the Sydenham River (Dextrase et al. 2003), while water quality in the Ausable River is generally considered poor, resulting from agricultural run-off and manure seepage (Nelson et al. 2003). Total phosphorus levels in the Ausable River are often above the provincial water quality objective and nitrate levels also exceed guidelines (Nelson et al. 2003, Brock and Veliz 2013). The Maitland River population of Rainbow faces threats from agricultural run-off with 75% of nitrate samples on the Middle Maitland exceeding the federal guidelines for negatively impacting aquatic health, while 56% of total phosphorus levels exceed those indicating a high likelihood of algal blooms (Kenny pers. comm. 2003).

Altered flow regimes: Reservoirs alter downstream flow patterns and disrupt the natural thermal profiles of the watercourse, while impoundments act as physical barriers, potentially separating unionids from their host fish. Evidence has linked extinction of unionids to construction and operation of dams in multiple rivers (Theler 1987, Layzer et al. 1993). Impoundments also act to increase water retention times, thereby making river systems more susceptible to colonization by invasive species, such as dreissenids, and to changes in species composition, based on habitat changes. High flow conditions may result in dislodgement of adults and disruption of larval forms, while low flow can lead to low dissolved oxygen, silt accumulation, elevated temperatures and, at the extreme, desiccation. Unionids are particularly vulnerable to reductions in water depth, as they are frequently found in very shallow water (10 to 20 cm; Metcalfe-Smith et al. 2007a). A significant negative correlation between mean annual stream flow and growth of a variety of mussel species has been demonstrated (Rypel et al.

2008), indicating the profound role impoundments and artificial flow manipulation may have on unionid assemblages.

There are many dams and other water control structures on the Trent, Saugeen, Ausable, Moira, Salmon, Bayfield, Grand, and Thames rivers, while fewer exist on the Maitland and Sydenham rivers. For example, in the Thames River watershed there are now an estimated 177 structures in the upper watershed and 65 in the lower watershed (COSEWIC 2016). Within the lower Grand River, the low head dam near the mouth of the river at Dunnville has a profound effect on flow and habitat conditions including sediment transport and connectivity to Lake Erie (MacDougall and Ryan 2012).

Habitat removal and alterations: Destruction of habitat through dredging, ditching, and other forms of channelization, including measures that result in flow reduction, may impact Mapleleaf and Rainbow. River channel modifications, such as dredging, can result in the direct destruction of unionid habitat and lead to siltation and sand accumulation of local and downstream mussel beds. The construction of impoundments can lead to the fragmentation of habitat, altered water levels, habitat conversion, and the clearing of riparian zones, resulting in the loss of cover, increased rates of siltation, and thermal shifts. In addition, practices that result in the diversion of cool or cold water into unionid habitat may impact Mapleleaf and Rainbow (for example, through interference with reproductive timing). These are all factors that can negatively impact the survival of unionids in areas under development.

Lack of access to host fish: Unionids cannot complete their life cycle without access to the appropriate glochidial host. If host fish populations disappear or decline in abundance to levels below that which can sustain a mussel population, recruitment will no longer occur and the mussel species may become functionally extinct (Bogan 1993). Therefore, knowledge of the distribution and status of host fish is required to determine if access to glochidial hosts is a threat for populations of Mapleleaf and Rainbow. In Canada, the likely host fish for Mapleleaf is the Channel Catfish, which is considered to be a common species in Ontario. Therefore, the fish-mussel host interaction is not thought to be limiting the presence of Mapleleaf throughout its range in Ontario (Bouvier and Morris 2011). Currently, host fish availability is not thought to be limiting Rainbow populations, as several known host fish species are common throughout the mussel species' range in Canada.

Harvesting: Poaching of unionids is suspected, but unknown in its intensity or occurrence. Harvesting unionids for human consumption could be a potential concern; however, to date there are no reports of Mapleleaf or Rainbow harvest for human consumption (Bouvier and Morris 2011). For these reasons, harvesting has been omitted from the threat tables.

Recreational activities: Increasing popularity of recreational activities such as canoeing may further increase stresses on unstable populations. Mehlhop and Vaughn (1994) found that "recreational activities" were contributing to the decline of many species of unionids. Recreational activities that may impact mussel beds include (Bouvier and Morris 2011):

- driving all-terrain vehicles (ATVs) through river beds, which has been identified as a threat in the Thames and Sydenham rivers. ATVs have also been observed driving through the mussel bed where live Rainbow were present in the Salmon River (Hogg pers. comm.)
- propellers on recreational boats and jet skis; propeller channels have been noted through the mussel beds in the St. Clair River delta

- paddling action disturbance (for example, kayaks and canoes) of the mussel bed; in the Grand River, Metcalfe-Smith et al. (2000) observed that paddlers in shallow water often disturbed the riverbed, creating the potential for dislodging unionids and promoting downstream transport

6. Management objectives

The management objectives establish, to the extent possible, the number of individuals and/or populations, and their geographic distribution, that are necessary to prevent the Mapleleaf and Rainbow from becoming endangered or threatened.

The management objectives for both Mapleleaf and Rainbow are to:

- protect self-sustaining populations at locations in table 7 to prevent decline; and
- restore degraded populations to healthy self-sustaining levels by improving the extent and quality of habitat (where feasible)

Table 7. Locations with self-sustaining populations of Mapleleaf and Rainbow, or where self-sustaining populations could be achieved.

Mapleleaf	Rainbow
Ausable River	St. Clair River delta[6]
Sydenham River (including the North Sydenham River, Bear Creek, and Black Creek)	Saugeen River (including Teeswater River)
Thames River (including McGregor and Baptiste creeks)	Maitland River
Grand River	Bayfield River
Welland River (including Oswego River and Coyle Creek)	Ausable River
Twenty Mile Creek/Jordan Harbour	East Sydenham River
Sixteen Mile Creek	Thames River (including North Thames River tributaries and the Middle Thames River)
Fifteen Mile Creek/Pond[6]	Grand River (including Mallet and Conestogo rivers)
Cootes Paradise/Spencer Creek[6]	Moira River
Bayfield River[6]	Salmon River
Southern Lake Huron tributaries (Cow Creek and Perch Creek/Telfer Diversion Channel)[6]	Trent River
Lake Henry (Pelee Island)[6]	
Detroit River (including the Canard River)	
Little Bear Creek	
Southern Lake St. Clair tributaries (including Puce River, Ruscom River, and Jacks Creek Drain)	

[6] Further research is required to determine the current status of the population(s), as it is unclear if recruitment is occurring

7. Broad strategies and measures for the conservation of the species

This management plan includes 4 broad strategies and related measures for the conservation of the species to prevent Mapleleaf and Rainbow from becoming threatened or endangered.

Section 7.1 provides an overview of the actions related to conserving the species already completed and underway. Section 7.2 identifies the broad strategies for the conservation of Mapleleaf and Rainbow. The measures for the conservation of the species to be implemented are summarized in an implementation schedule (tables 8, 9, and 10) in section 7.3, which prioritizes actions and identifies leads, partners, and timelines, to the extent possible at this time. Section 7.4 provides additional information for the measures for the conservation of the species identified in the implementation schedule.

7.1. Actions already completed or currently underway

Many of the recovery measures prescribed for implementation in the original recovery strategies for the species (DFO 2016a, b) are ongoing. Actions that are completed and/or underway include surveys (for estimating abundance and range) and recovery potential modelling (Young and Koops 2011). Investigations testing the efficacy of surveying methods for unionids in different environments have also been completed (Reid et al. 2014, Minke-Martin et al. 2015, Reid 2016; Reid and LeBaron 2019), as well as genetic studies on the Mapleleaf (Paterson et al. 2015, Hoffman et al. 2018, Mathias et al. 2018, VanTassel et al. 2020).

Conservation authorities (for example, Lower Thames Valley, Upper Thames River, Saugeen, St. Clair Region, Maitland Valley, Ausable-Bayfield, Lower Trent, Quinte Region, Niagara Peninsula, Essex Region, Hamilton, and Grand River) continue to play a vital role in stewardship and public education programs, which have resulted in increased awareness of species at risk and improvements to habitat and water quality throughout the range of the Mapleleaf and Rainbow in Ontario.

Single and multi-species recovery strategies have been drafted previously for several unionids whose distributions partly overlap with Mapleleaf and Rainbow. Recovery teams for these species are engaged in the implementation of recovery actions within these watersheds that will benefit Mapleleaf and Rainbow, including recovery actions found in:

- Recovery Strategy and Action Plan for the Fawnsfoot (*Truncilla donaciformis*) and Threehorn Wartyback (*Obliquaria reflexa*) in Canada (DFO 2022b)
- Recovery Strategy and Action Plan for Lilliput (*Toxolasma parvum*) in Canada (DFO 2022a)
- Recovery Strategy for the Northern Riffleshell, Snuffbox, Round Pigtoe, Salamander Mussel, and Rayed Bean in Canada (DFO 2019)
- Recovery Strategy for the Round Hickorynut (*Obovaria subrotunda*) and the Kidneyshell (*Ptychobranchus fasciolaris*) in Canada (DFO 2013)
- Recovery Strategy for the Wavy-rayed Lampmussel (*Lampsilis fasciola*) in Canada (Morris 2006)

Ecosystem-based recovery strategies that overlap with Mapleleaf and Rainbow include:

- Sydenham River Action Plan: This action plan is a multi-species, ecosystem-based plan that addresses the needs of 7 unionids, as well as 2 species of fishes (DFO 2018). The plan builds on the recovery program established 10 years earlier by the Sydenham River Recovery Team (Dextrase et al. 2003); it targets stewardship actions at the landscape level for maximum effectiveness in threat mitigation to recover multiple aquatic species at risk that share similar threats and habitat. A network of monitoring sites for unionid species at risk was established in 2003 (see Metcalfe-Smith et al. 2007b)

- Ausable River Ecosystem Recovery Strategy: The Ausable River Recovery Team (ARRT) is developing an ecosystem recovery strategy for the 14 COSEWIC-designated aquatic species in the Ausable River basin. The overall goal of the strategy is to “sustain a healthy native aquatic community in the Ausable River through an ecosystem approach that focuses on species at risk” (ARRT 2005). Stewardship efforts are ongoing and a monitoring program to track the recovery of endangered unionids in the Ausable River has been established (Baitz et al. 2008)

- Thames River Ecosystem Recovery Strategy: The goal of the strategy is to develop “a recovery plan that improves the status of all aquatic species at risk in the Thames River through an ecosystem approach that sustains and enhances all native aquatic communities” (Thames River Recovery Team [TRRT] 2005). This recovery strategy addresses 25 COSEWIC-designated species, including 7 unionids, 12 fishes, and 6 reptiles. Following the lead of the Sydenham Recovery Team, unionid monitoring stations have been established in the Thames River

- Grand River Fish Species at Risk Recovery Strategy (Portt et al. 2007): While this recovery strategy deals specifically with fish species, many of the same threats apply to Mapleleaf and Rainbow, such as the impacts of sediment and nutrient loadings and invasive species

- Walpole Island Ecosystem Recovery Strategy: The Walpole Island Ecosystem Recovery Team was established in 2001 to develop an ecosystem-based recovery strategy for the area containing the St. Clair River delta, with the goal of outlining steps to maintain or rehabilitate the ecosystem and species at risk (Walpole Island Heritage Centre [WIHC] 2002). Although the strategy is initially focusing on terrestrial ecosystems (Bowles 2005), there are future plans to include aquatic components of the ecosystem

Other activities

- Source Protection Planning: A white paper on watershed-based source protection planning was released in February 2004 (OMOE 2004). Source protection planning identifies potential sources of contamination to the surface water and groundwater, determines how much water is readily available, evaluates where that water is vulnerable to contamination, and implements programs to minimize risk of contamination to water quality, as well as minimizes threats to water quantity

7.2. Broad strategies

To address threats to the species and meet the management objectives, 4 broad strategies were identified: 1) inventory and monitoring; 2) research; 3) management and coordination; and 4) stewardship and outreach. Approaches are identified for each of the broad strategies. These approaches are further divided into numbered conservation measures with priority ranking (high, medium, and low), identification of the threats addressed, and associated timelines (tables 8 to 10). A more detailed narrative for conservation measures is included after the tables (section 7.4).

Implementation of these measures will be accomplished in coordination with relevant ecosystem-based recovery teams and other organizations. Of the broad strategies, higher priority will generally be given to the research and monitoring measures, as the data produced will be used to inform the other 2 strategies (that is, management and coordination, and stewardship and outreach).

7.3. Measures for the conservation of the species

Success in the conservation of this species is dependent on the actions of many different jurisdictions, industries, non-governmental organizations, Indigenous groups, and Canadians in general; it requires the commitment and cooperation of the constituencies that will be involved in implementing the measures set out in this management plan.

The measures set out in this management plan provide the best chance of achieving the management objectives for Mapleleaf and Rainbow, to guide not only activities to be undertaken by DFO, but those for which other jurisdictions, organizations, and individuals may have a role to play. As new information becomes available, these measures and the priority of these measures may change. DFO strongly encourages all Canadians to participate in the conservation of Mapleleaf and Rainbow by undertaking the measures for the conservation of the species outlined in this management plan. DFO recognizes the important role of the recovery team for Mapleleaf and Rainbow and its member organizations and agencies in the implementation of measures for the conservation of this species.

Table 8 identifies the measures for the conservation of the species to be undertaken by DFO. Table 9 identifies the measures for the conservation of the species to be undertaken collaboratively between DFO and its partners, other agencies, organizations, or individuals. Implementation of these measures will be dependent on a collaborative approach, in which DFO is a partner in conservation efforts, but cannot implement the measures for the conservation of the species alone. As all Canadians are invited to join in supporting and implementing this management plan, table 10 identifies the remaining measures for the conservation of the species that represent responsibilities and/or opportunities for other jurisdictions, organizations, or individuals to lead. If your organization is interested in participating in one of these measures, please contact the Species at Risk Program's Ontario and Prairie Region office at:

Fisheries and Oceans Canada
DFO.CASARAConsultations-CALEPConsultations.MPO@dfo-mpo.gc.ca

Federal funding programs for species at risk that may provide opportunities to obtain funding to carry out some of the outlined activities include the Habitat Stewardship Program for Species at

Risk, the Aboriginal Fund for Species at Risk Program, and the Canada Nature Fund for Aquatic Species at Risk.

While DFO has already commenced efforts to implement the plan, the measures for the conservation of the species included in this management plan that have not yet been implemented by the department will be subject to the availability of funding and other required resources. As indicated in the tables below, partnerships with specific organizations will provide expertise and capacity to carry out some of the listed measures. However, the identification of partners is intended to be advice to other jurisdictions and organizations, and carrying out these actions will be subject to each group's priorities and budgetary constraints.

Table 8. Measures for the conservation of Mapleleaf and Rainbow to be undertaken by Fisheries and Oceans Canada.

#	Conservation measure	Broad strategy	Priority[7]	Threats or concerns addressed	Status/timeline[8]
1	**Population assessment:** establish routine quantitative surveys to monitor changes in the distribution and abundance of extant Mapleleaf and Rainbow populations (and invasive species in the area)	Inventory and monitoring	High	All	3 to 5 years
2	**Population assessment:** establish stations to monitor changes to Mapleleaf and Rainbow habitat; this monitoring will complement, and be integrated into, the routine population surveys	Inventory and monitoring	High	All	3 to 5 years
3	**Inventory:** conduct surveys to quantify distribution and abundance of any newly discovered populations	Inventory and monitoring	Medium	All	3 to 5 years
4	**Inventory:** conduct surveys of rivers where uncertainty of Mapleleaf and Rainbow persistence exists	Inventory and monitoring	Low	All	3 to 5 years
5	**Threat evaluation:** evaluate threats to habitat for all extant locations to guide local stewardship programs to improve conditions within occupied habitats	Research	High	All	3 to 5 years

[7] "Priority" reflects the degree to which the measure contributes directly to the conservation of the species or is an essential precursor to a measure that contributes to the conservation of the species:

- "High" priority measures are considered likely to have an immediate and/or direct influence on the conservation of the species
- "Medium" priority measures are important but considered to have an indirect or less immediate influence on the conservation of the species
- "Low" priority measures are considered important contributions to the knowledge base about the species and mitigation of threats

[8]Timeline reflects the amount of time required for the measure to be completed from the time the management plan is published as final on the Species at Risk Public Registry.

#	Conservation measure	Broad strategy	Priority[7]	Threats or concerns addressed	Status/timeline[8]
6	**Habitat requirements:** determine Mapleleaf and Rainbow habitat requirements for all life stages	Research	Medium	All	3 to 5 years
7	**Host fish populations:** determine the distribution and abundance of the identified host fish	Research	Low	Host fish	2 years
8	**Coordination of activities**: promote and enhance expertise in unionid identification, biology, ecology, and conservation (for example, mussel identification workshops)	Management and coordination	Medium	All	Ongoing
9	**Awareness:** hold annual mussel identification workshop that incorporates identification, biology, ecology, threats, and conservation of unionid species in Ontario	Stewardship and outreach	High	All	Ongoing
10	**Awareness:** encourage public support and participation in mussel conservation by developing awareness materials and programs; will encourage participation in local stewardship programs to improve and protect habitat	Stewardship and outreach	Medium	All	Ongoing

Table 9. Measures for the conservation of Mapleleaf and Rainbow to be undertaken collaboratively between Fisheries and Oceans Canada and its partners.

#	Conservation measure	Broad strategy	Priority[7]	Threats or concerns addressed	Timeline[9]	Potential partnerships
11	**Coordination of activities:** develop an implementation plan to respond to the direct threat of dreissenids on Mapleleaf and Rainbow in the St. Clair River delta	Management and coordination	Medium	All	Medium-term	Walpole Island First Nation
12	**Coordination of activities:** work with municipal planning authorities to ensure the protection of Mapleleaf and Rainbow habitat within official plans	Management and coordination	Medium	All	Medium-long-term	Municipal planning departments
13	**Coordination of activities:** support the development and implementation of legislation and policies at all levels of government that will aid in the protection of existing populations and enhance the conservation of those populations	Management and coordination	Medium	All	Long-term	All Levels of Government
14	**Awareness:** increase awareness within the angling community about the role of host fish for Mapleleaf and Rainbow	Stewardship and outreach	Medium	Invasive species, host fish	Medium-term	Conservation authorities, angling groups
15	**Awareness:** increase public awareness of the potential impacts of transporting/releasing invasive species (including baitfish)	Stewardship and outreach	Low	Invasive species, host fish	Medium-term	Ontario Ministry of Natural Resources and Forestry, Ontario Federation of Anglers and Hunters

[9] "Timeline" separates measures into 3 categories, based on the projected length of time it will take to accomplish them:

- "Short-term" equals 1 to 2 years
- "Medium-term" equals 3 to 5 years
- "Long-term" equals greater than 5 years

Table 10. Measures for the conservation of Mapleleaf and Rainbow that represent responsibilities and/or opportunities for other jurisdictions, organizations, or individuals to lead.

#	Conservation measure	Broad strategy	Priority[7]	Threats or objective addressed	Suggested jurisdictions or organizations
16	**Host fish:** identify/confirm functional host fish species for Mapleleaf and Rainbow	Research	Medium	Host fish	Academia
17	**Threat evaluation:** determine sensitivity of Mapleleaf and Rainbow glochidia, juvenile, and adults to relevant environmental contaminants	Research	Medium	Contaminants and toxic substances	Academia
18	**Coordination of activities:** implement stewardship programs to improve habitat conditions and reduce threats; priorities and mitigation approaches to be informed through threat evaluation research	Management and coordination	High	All	Conservation Authorities

7.4. Narrative to support the measures for the conservation of the species

Inventory and monitoring

Population and assessment (measures 1 and 2): A network of monitoring stations should be established throughout the current range of Mapleleaf and Rainbow, similar to that developed for unionids within the Sydenham River (Metcalfe-Smith et al. 2007b). This network would build on existing monitoring stations already established for several watersheds (for example, Ausable, Thames, and Grand rivers). The results of the monitoring program will allow for assessment of the progress made toward achieving management objectives and improve understanding of Mapleleaf and Rainbow life cycle and habitat requirements. Monitoring sites should be established in a manner to permit:

- quantitative tracking of changes in mussel abundance and demographics (size, age, sex), and that of their hosts
- the ability to detect and track invasive species (to permit early detection, additional monitoring stations should be set up in areas where there is a likely source location for the establishment of dreissenid mussels [for example, reservoirs])

If invasive species are detected via routine monitoring practices, a coordinated plan should ensure a quick response. Dreissenid mussels in Lake St. Clair cannot be eliminated; however, their presence in the delta can be monitored to determine if their numbers are increasing or decreasing. At present, dreissenid mussels threaten multiple populations of at-risk mussels within the St. Clair River delta and it is an area of great concern. Mussel monitoring methods that can be adapted to lake and wetland habitats where Mapleleaf is found (for example, Jordan Harbour, lower Grand River within impounded reaches) need to be developed. Additional sampling effort is required to determine if remnant populations may persist in river mouths and coastal wetland habitats of lakes Erie and St. Clair (as populations were detected in 2012 in U.S. waters).

Inventory (measures 3 and 4): Further surveys are required to confirm the current distribution of Mapleleaf and Rainbow in Canada, which is key information necessary to inform effective conservation measures.

Research

Host fish populations (measures 7 and 16): To determine if Mapleleaf and Rainbow are host-limited, it is necessary to confirm the host fish. The identification of host specificity in some mussel species requires that hosts be identified for local populations wherever possible. Once the functional Canadian hosts have been confirmed, the distribution, abundance, and health of the host species can be determined.

Habitat requirements (measure 6): Detailed analysis of habitat data collected from the monitoring program will help inform habitat use, as well as help track changes in the use or availability of habitat.

Threat evaluation (measures 5 and 17): Although some preliminary work has been done on evaluating threats for some populations (refer to section 5), little is known regarding threats to other populations (for example, Mapleleaf: recently discovered populations within the Welland River and Twenty Mile Creek/Jordan Harbour; Rainbow: Saugeen, Maitland, and Bayfield rivers). More comprehensive threat evaluations for all extant populations will help inform stewardship programs to ensure the most efficient and effective use of limited resources, while promoting an ecosystem approach wherever possible.

Some initial research has been completed on selected contaminants, including chloride, ammonia and copper, for early life stages of unionids. However, further work that is specific to Mapleleaf and Rainbow is required. PFOS contamination is known from the upper Welland River and may be impacting downstream populations of Mapleleaf.

Management and coordination

Coordination of activities (measures 8,11 to 13 and 18): Implementation of many conservation actions can be accomplished through partnerships with groups actively involved in stewardship, or research and monitoring within watersheds where Mapleleaf and Rainbow populations are present. In particular, these groups would include Conservation Authorities (that is, Lower Thames Valley, Upper Thames River, Saugeen, St. Clair Region, Maitland Valley, Ausable-Bayfield, Lower Trent, Quinte Region, Niagara Peninsula, Essex Region, Hamilton, and Grand River), as well as existing ecosystem-based conservation initiatives, including those for the Ausable, Sydenham, Thames, and Grand rivers.

Expertise in unionid identification, distribution, life history, and genetics is limited to a small number of biologists in Ontario. This capacity could be increased by training personnel (both within government as well as non-government organizations and Indigenous groups with a conservation focus) and encouraging graduate and post-graduate research directed towards the conservation of freshwater mussels. Such efforts would enhance partnering opportunities to implement conservation measures for unionids.

Many of the threats affecting Mapleleaf and Rainbow populations are similar to those affecting other fish and mussel species at risk. Therefore, efforts to remediate these threats (where spatial overlap exists) should be done in close cooperation with other recovery teams and relevant groups to eliminate duplication of efforts (refer to section 7.1 for relevant ecosystem-based conservation initiatives). For rivers not currently covered by existing watershed recovery programs, threat evaluations will inform local stewardship programs for mitigation priority. As with other mussels, measures to improve habitat for Mapleleaf and Rainbow may include stewardship actions involving best management practices for agricultural and residential properties within catchment areas impacting occupied habitats.

Stewardship and Outreach

Awareness (measures 9,10,14,15,19): Increasing unionid knowledge and identification can be assisted through the development of awareness material, such as the Photo Field Guide to the Freshwater Mussels of Ontario (Metcalfe-Smith et al. 2005) and the application called Clam Counter, available for free download from the App Store and the Google Play Store. In addition, an annual hands-on mussel identification workshop is offered by DFO to government, agency, non-government organizations, Indigenous Peoples, and the public.

Increased public knowledge and understanding of the importance of Mapleleaf and Rainbow, and mussels in general, will play a key role in the conservation of unionids. A communications plan to increase awareness and support for the protection and conservation of Mapleleaf and

Rainbow will provide overall direction for all outreach. Such activities should include increasing awareness of the potential impacts of transporting/releasing invasive species (including baitfish) into new waters.

8. Measuring progress

A successful management program will achieve the overall goal of protecting self-sustaining populations to prevent decline, and restoring degraded populations to healthy self-sustaining levels by improving the extent and quality of habitat (where feasible). Progress towards meeting these objectives will be reported in the report on the progress of the management plan implementation. The performance indicators presented below provide a way to define and measure progress toward achieving the management objectives:

1. Surveys identify the current distribution, and abundance of Mapleleaf and Rainbow by 2030
2. Comprehensive evaluations for threats, particularly for new populations, have been conducted and actions have been taken to mitigate these threats by 2030
3. Measures have been taken to promote awareness and stewardship actions to conserve the Mapleleaf and Rainbow and their habitats by 2025
4. Measures have been taken to promote continued awareness of, and compliance with, existing regulations to maintain quality and quantity of Mapleleaf and Rainbow habitats by 2025

Detailed reporting on implementation of this management plan under section 72 of SARA will be done by assessing progress towards implementing the broad strategies and conservation measures. The implementation of this management plan will be monitored every 5 years after the plan has been posted to the SARA Registry.

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Appendix A: Effects on the environment and other species

In accordance with the Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals (2010), SARA recovery planning documents incorporate strategic environmental assessment (SEA) considerations throughout the document. The purpose of a SEA is to incorporate environmental considerations into the development of public policies, plans, and program proposals to support environmentally sound decision-making and to evaluate whether the outcomes of a recovery planning document could affect any component of the environment or achievement of any of the Federal Sustainable Development Strategy's goals and targets.

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

This management plan will clearly benefit the environment by promoting the conservation of Mapleleaf and Rainbow. In particular, it will encourage the protection and improvement of riverine and coastal wetland habitats in the lower Great Lakes. These habitats support many other aquatic species at risk (including fishes, birds, reptiles, and plants), and thus the implementation of conservation measures for Mapleleaf and Rainbow will contribute to the preservation of biodiversity in general. The potential for these conservation actions to inadvertently lead to adverse effects on other species was considered. The SEA concluded that the implementation of this document will clearly benefit the environment and will not entail any significant environmental effects.

Appendix B: Record of cooperation and consultation

Management plans are to be prepared in cooperation and consultation with other jurisdictions, organizations, affected parties and others as outlined in SARA section 66. Fisheries and Oceans Canada (DFO) has utilized a process of recovery team review to seek input for the development of this management plan. Information on participation in the recovery team is included in table 11.

Table 11. List of partners and stakeholder groups from whom Fisheries and Oceans Canada sought input for the development of the management plan for Mapleleaf and Rainbow.

Member / Attendee	Affiliation
Dave Balint	DFO - SARP
Amy Boyko	DFO - SARP
Kelly McNichols	DFO - Science
Dr. Todd Morris (Co-chair)	DFO - Science
Shawn Staton (Co-chair)	DFO - SARP
Dr. Alan Dextrase	Ontario Ministry of Natural Resources and Forestry - retired
Scott Gibson	Ontario Ministry of Natural Resources and Forestry
Dr. Scott Reid	Ontario Ministry of Natural Resources and Forestry
Dr. Patricia Gillis	Environment and Climate Change Canada
Daryl McGoldrick	Environment and Climate Change Canada
Dr. Josef Ackerman	University of Guelph
Dr. Gerry Mackie	University of Guelph
Dr. Daelyn Woolnough	Central Michigan University
Dr. Dave Zanatta	Central Michigan University
Dr. Astrid Schwalb	University of Waterloo
Crystal Allan	Grand River Conservation Authority
Muriel Andreae	St. Clair Region Conservation Authority
Mike Nelson	Essex Region Conservation Authority
Dr. Frederick Schueler	Bishop Mills Natural History Centre
Lee-Ann Hamilton	Niagara Peninsula Conservation Authority
Kari Jean	Ausable Bayfield Conservation Authority
John Schwindt	Upper Thames River Conservation Authority
Valerie Towsley	Lower Thames River Conservation Authority
Mari Veliz	Ausable Bayfield River Conservation Authority

In addition, consultation on the draft management plan occurred through correspondence with all Indigenous groups whose traditional territory overlaps with the current and historical distribution of Mapleleaf and Rainbow. Input on the development of this joint management plan was sought from a total of eleven Indigenous groups (Aamjiwnaang First Nation, Anishnabek/Ontario Fisheries Resource Centre, Association of Iroquois and Allied Indians, Caldwell First Nation, Chippewas of Kettle & Stony Point First Nation, Chippewas of the Thames

First Nation, Delaware Nation [Moravian of the Thames], Metis Nation of Ontario, Mississaugas of the New Credit First Nation, Munsee-Delaware Nation, and Oneida Nation of the Thames).

Additional stakeholder, Indigenous, and public input was sought through the publication of the proposed document on the Species at Risk Public Registry for a 60-day public comment period. Comments received informed the final document.