COSEWIC
Assessment and Status Report

on the

Mapleleaf
Quadrula quadrula

Great Lakes - Upper St. Lawrence population
Saskatchewan - Nelson Rivers population

in Canada

Great Lakes - Upper St. Lawrence population – SPECIAL CONCERN
Saskatchewan - Nelson Rivers population - THREATENED
2016

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

COSEWIC. 2016. COSEWIC assessment and status report on the Mapleleaf *Quadrula quadrula*, Great Lakes - Upper St. Lawrence population and Saskatchewan - Nelson Rivers population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 86 pp. (http://www.registrelep-sararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1).

Previous report(s):

COSEWIC 2006. COSEWIC assessment and status report on the Mapleleaf Mussel *Quadrula quadrula* (Saskatchewan-Nelson population and Great Lakes-Western St. Lawrence population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 58 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

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Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur la Mulette feuille d'érable (*Quadrula quadrula*), population des Grands Lacs et du haut Saint-Laurent et population de la rivière Saskatchewan et du fleuve Nelson, au Canada.

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COSEWIC
Assessment Summary

Assessment Summary – November 2016

Common name
Mapleleaf - Great Lakes - Upper St. Lawrence population

Scientific name
Quadrula quadrula

Status
Special Concern

Reason 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 three 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 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.

Occurrence
Ontario

Status history
Designated Threatened in April 2006. Status re-examined and designated Special Concern in November 2016.

Assessment Summary – November 2016

Common name
Mapleleaf - Saskatchewan – Nelson Rivers population

Scientific name
Quadrula quadrula

Status
Threatened

Reason for designation
This heavy-shelled mussel has a small range and few locations, and occurs in habitat projected to continue to decline in quality. Present and ongoing threats include pollution from agricultural effluent, urban wastewater, and industrial sources. The arrival and establishment of invasive Zebra Mussel in 2013 represents a new threat of likely high severity. This change in status is a result of new surveys revealing previously unknown locations.

Occurrence
Manitoba

Status history
Designated Endangered in April 2006. Status re-examined and designated Threatened in November 2016.

COSEWIC
Executive Summary

Mapleleaf
Quadrula quadrula

Wildlife Species Description and Significance

Mapleleaf, *Quadrula quadrula,* is a freshwater mussel. The shell is thick, squarish in outline and ranges in colour from yellowish green through light brown to dark brown. Typically, the species can be recognized by two rows of raised bumps or knots extending in a v-shape from the umbo (the beak that protrudes above the hinge of each valve) to the ventral edge of the shell. There are occasional deviations from this nodule pattern. Canadian specimens reach 130 mm in length, 100 mm in height and 50 mm in width. The interior of the shell is white with heavy hinge teeth.

Distribution

In the United States, this species occurs throughout the Ohio-Mississippi drainages ranging from Texas to Alabama in the south to Minnesota and Pennsylvania in the north. Its distribution extends into the Great Lakes drainage in Minnesota and Wisconsin to New York and into the Red River drainage in Minnesota and North Dakota. In Canada, this species is limited in southern Ontario to the coastal areas and medium to large rivers of the Lake Huron, Lake St. Clair, Lake Erie, and Lake Ontario watersheds. In Manitoba, the species is found in the Red River and some tributaries, the Assiniboine River, and Lake Winnipeg and some tributaries.

Habitat

Quadrula quadrula occurs in a variety of habitats ranging from medium to large rivers with slow to moderate current, to lakes and reservoirs in mud, sand, or gravel bottoms. In Ontario and Manitoba, *Q*. *quadrula* is most typically recovered from medium to large rivers in firmly packed coarse gravel and sand to firmly packed clay/mud bottom.

Biology

Quadrula quadrula is dioecious (separate sexes) but sexes cannot be distinguished based on shell morphology. Larvae, called glochidia, are brooded in the gills by the female and are parasitic on catfishes. Known fish hosts are the Flathead Catfish, which does not occur in Canada, and the Channel Catfish, which does occur in Canada. Development on the fish host requires approximately 50-60 days. During this time, the larval mussel transforms to a juvenile, then drops off the fish host and grows to adult size and maturity. Like other freshwater mussels, *Q*. *quadrula* feeds on algae and bacteria filtered from the water column and bottom. *Quadrula quadrula* is a long-lived species with individuals from Manitoba living up to 64 years and averaging 22 years of age, with a generation time of roughly 20 years.

Population Sizes and Trends

In Ontario, *Q. quadrula* is restricted to a few coastal areas and rivers draining into Lake Huron, Lake Erie, Lake St. Clair, and Lake Ontario. A rough estimate for total population size in Ontario is at least 6 million individuals. The mussel community in this region is in decline with many species considered extirpated from areas they once occupied. Comparison with historical records indicates some reduction in the distribution of this species in Ontario. Recent studies indicate that *Q*. *quadrula* is abundant in some areas where it does occur and may be increasing its distribution within the Sydenham River, lower Thames River, and lower Grand River, but with current threats the overall trend may be a slow continuing decline over the next 3 generations.

In Manitoba, although the population size is estimated to range between roughly 1 million and 4 million, densities are generally low and appear to be in decline in some areas. The species occurs in the Red River and in the lower reaches of some of its tributaries, the Assiniboine River, and the lower reaches of some tributaries draining into Lake Winnipeg. Comparison with historical records of distribution indicates that the freshwater mussel community in Manitoba is in decline. Where *Q. quadrula* does occur in Manitoba it is never abundant with many fresh empty valves indicating high levels of recent mortality.

Threats and Limiting Factors

Like almost all North American freshwater mussels, this species is threatened by habitat loss and degradation and the effects of invasive species, particularly Zebra and Quagga mussels in Ontario. Zebra Mussels now threaten *Q. quadrula* in Manitoba, with Zebra Mussel populations becoming established in the Red River, Lake Winnipeg, and in reservoirs in the Red River watershed in North Dakota and Minnesota. Habitat changes associated with Zebra Mussels and modifications to the banks of the Red and Assiniboine rivers (e.g., rip-rap and dikes) that alter the flow hydrology of these rivers are threats. In both Ontario and Manitoba, *Q. quadrula* occurs in areas affected by industrial and municipal pollution and agricultural runoff.

Protection, Status and Ranks

Quadrula quadrula in both Ontario (Great Lakes - Upper St. Lawrence population) and Manitoba (Saskatchewan - Nelson Rivers population) is listed under Schedule 1 of Canada's *Species at Risk Act*. The act prohibits killing or capturing protected species, and protects critical habitat, when this has been described and approved. Populations in Ontario and Manitoba also are protected under each province's endangered species act. *Quadrula quadrula* is considered to be stable in some U.S. states and critically imperilled in others, but in the majority of jurisdictions the species is unranked or ranks are under review. There are large populations in some U.S. Great Lakes states and it is not considered at risk in Michigan or Ohio.

TECHNICAL SUMMARY - Great Lakes - Upper St. Lawrence population

Quadrula quadrula

Mapleleaf, Great Lakes - Upper St. Lawrence population

Mulette feuille d'érable - Population des Grands Lacs et du haut Saint-Laurent

Range of occurrence in Canada (province/territory/ocean): Ontario

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2011) is being used).	Estimate: 20 yrs.
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Yes. Projected decline of 3-30% based on cumulative threats identified in Threats Calculator.
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Projected 3-30% decline over 3 generations; projected decline over 2 generations would be smaller.
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Estimated 12.5% decline in EOO over last 3 generations (i.e., since the invasion of the dreissenids); however, it is unlikely that this resulted in a similar percent decline in number of mature individuals because the species was never abundant in open waters of the Great Lakes. The locations with the largest number of mature individuals (Thames, Sydenham, and Grand rivers) currently appear stable.
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Projected 3-30% decline based on Threats Calculator and projections for continued habitat degradation and continued competition from dreissenids. In addition, the IAO, EOO, and number of mature individuals will most likely decline if the subpopulations with small numbers of individuals (see below) are extirpated.
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	Suspected 3-30% future decline; estimated 12.5% decline in EOO in the past which resulted in an unknown decline in number of mature mussels.
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	a. No b. Yes c. No
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence	26,826 km² based on minimum convex polygon.
Index of area of occupancy (IAO) (Always report 2x2 grid value).	228 km² discrete based on one grid over each observation record (57 2x2 km grids). 660 km² continuous. Based on continuous stretch of river between all observation records (165 2x2 km grids).
Is the population "severely fragmented" i.e., is >50% of its total area of occupancy in habitat patches that are (a) smaller than would be required to support a viable population, and (b) separated from other habitat patches by a distance larger than the species can be expected to disperse?	a. No b. No
Number of "locations"* (use plausible range to reflect uncertainty if appropriate)	21 (or more) locations based on cumulative threats of agricultural, industrial, municipal pollution and impacts of dreissenid mussels: Ausable River, North Sydenham River, East Sydenham River, Thames River, Grand River, Welland River (+ Oswego River and Coyle Creek tributaries), Lake Ontario embayments (Jordan Harbour/Twenty Mile Creek, Sixteen Mile Creek, Fifteen Mile Creek/Pond, and Cootes Paradise), Ruscom River, Baptiste Creek, McGregor Creek, Bayfield River, St. Clair Delta, Lake Huron tributaries (Perch Creek/Tefler Diversion Channel, Cow Creek), Pelee Island (Lake Henry), Rondeau Bay.
Is there an [observed, inferred, or projected] decline in extent of occurrence?	Yes – Projected 3-30%. See above boxes in **Demographic Information**.
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Yes – Projected 3-30%. See box above.
Is there an [observed, inferred, or projected] decline in number of subpopulations?	Yes – Projected 3-30%. See box above.
Is there an [observed, inferred, or projected] decline in number of "locations"*?	Yes – Projected 3-30%. See box above. Subpopulation sizes at some locations may be very small (see **Subpopulations** box below).
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Yes - Projected. Habitat quality continues to decline due to pollution resulting primarily from agricultural runoff. Dreissenid mussels are also contributing to a projected decline in habitat quality.
Are there extreme fluctuations in number of subpopulations?	No
Are there extreme fluctuations in number of "locations"∗?	No

* See Definitions and Abbreviations on COSEWIC website and IUCN (Feb 2014) for more information on this term.

Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each subpopulation)

Subpopulations (give plausible ranges)	**Estimated Mature Individuals**
Ausable River	10,000 – 180,000
North Sydenham River	~25,000
East Sydenham River	1,610,000 – 2,680,000
Thames River	3,765,000 – 8,140,000
Grand River	>325,000
Welland River (including Oswego River and Coyle Creek)	Unknown (1000s)
Lake Ontario embayments (Jordan Harbour/Twenty Mile Creek, Sixteen Mile Creek, Fifteen Mile Creek/Pond, and Cootes Paradise)	Unknown (1000s)
Ruscom River	Unknown
Baptiste Creek	Unknown
McGregor Creek	Unknown, presumed small
Bayfield River	Unknown, small (only 1 live animal collected)
St. Clair Delta	Unknown, small (only 1 live animal collected)
Lake Huron tributaries (Perch Creek/Tefler Diversion Channel, Cow Creek)	Unknown, presumed small
Pelee Island (Lake Henry)	Unknown, presumed small
Rondeau Bay (Lake Erie)	Unknown, presumed small (only fresh shells collected)
Total	Estimated >6,000,000

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, or 10% within 100 years]?	N/A – insufficient data for analyses

Threats (direct, from highest impact to least, as per IUCN Threats Calculator)

Was a threats calculator completed for this species? **Yes** i. Pollution: Habitat degradation from agriculture (siltation, loss of riparian vegetation, streambank erosion, and nutrient loading), municipal and industrial pollution (including oil spills). ii. Natural system modifications and invasive, non-native alien species: Invasive dreissenid mussel infestation may still be causing declines in some subpopulations. However, several river systems where Mapleleaf is found have little chance of becoming infested due to a lack of upstream impoundments that could act as seed populations for dreissenids. What additional limiting factors are relevant? Abundance of host fish probably not an issue.

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	USA: Status apparently secure within most of US distribution, including populations on the US side of the Great Lakes.
Is immigration known or possible?	Possible. Evidence of recent gene flow (N_m>1) between Canadian and US populations in Lake Erie drainage.
Would immigrants be adapted to survive in Canada?	Likely. Habitats are nearly identical on both sides of the Great Lakes.
Is there sufficient habitat for immigrants in Canada?	Yes
Are conditions deteriorating in Canada?[+]	Yes, in places (see **Threats**).
Are conditions for the source population deteriorating?[+]	Yes, in places (similar threats to Canadian subpopulations).
Is the Canadian population considered to be a sink?[+]	No
Is rescue from outside populations likely?	Potentially, given the proximity of several large US populations and the high measured levels of current gene flow between the US and Canadian populations.

Data Sensitive Species

Is this a data sensitive species? No

Current Status

Status History: Designated Threatened in April 2006. Status re-examined and designated Special Concern in November 2016.

[+] See Table 3 (Guidelines for modifying status assessment based on rescue effect).

Status and Reasons for Designation:

Status: Special Concern	**Alpha-numeric code:** not applicable
Reasons 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 three 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 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.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Does not meet criteria. Although the past rate of decline in EOO over the last 3 generations is 12.5% and a suspected decline of up to 30% over the next 3 generations is predicted by the threats assessment, these rates of decline are below threshold values.
Criterion B (Small Distribution Range and Decline or Fluctuation): Does not meet criteria. While the EOO (26,826 km^2 from live individuals or fresh shells observed between 2000 and 2015) is above the threshold for Threatened (<20,000 km^2: B1), the continuous IAO is below the threshold for Threatened (< 2,000 km^2: B2). However, the species is not severely fragmented and is found at well more than 10 locations. There is a projected decline in EOO, IAO, habitat quality and number of locations and subpopulations, but the projected loss of several small-sized subpopulations/locations will result in only a minor decline in the number of mature individuals. The species does not undergo extreme fluctuations.
Criterion C (Small and Declining Number of Mature Individuals): Does not meet criteria. The number of mature individuals is unknown but estimated to be over 6 million and the largest subpopulations currently appear to be stable.
Criterion D (Very Small or Restricted Population): D1 is not applicable as the number of mature individuals is unknown but estimated to be over 6 million. Does not meet criteria for threatened D2 because both the IAO and number of locations are well above the typical thresholds (20 km^2 and less than or equal to 5, respectively).
Criterion E (Quantitative Analysis): Not applicable. Analyses have not been done.

TECHNICAL SUMMARY - Saskatchewan - Nelson Rivers population

Quadrula quadrula

Mapleleaf, Saskatchewan - Nelson Rivers population

Mulette feuille d'érable, Population de la rivière Saskatchewan et du fleuve Nelson

Range of occurrence in Canada (province/territory/ocean): Manitoba

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2011) is being used)	Estimate: 20 yrs.
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Inferred and projected decline of 10-70% based on cumulative threats identified in Threats Calculator.
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Projected 10-70% over 3 generations; projected decline over 2 generations should be similar because impact from invasive dreissenids would be larger soon after infestation.
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	There has been an inferred decline in number of mature individuals based on 42.7% or 25.8% estimated declines in EOO and IAO over the last 3 generations, respectively. Confidence in these estimates is low based on limited sampling effort in the Red and Assiniboine rivers.
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Projected 10-70% decline based on Threats Calculator.
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	Suspected 10-70% future decline; past decline in EOO and IAO are 42.7 and 25.8%, respectively.
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	a. No b. Yes c. No
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence	45,097 km² calculated using a minimum convex polygon.
Index of area of occupancy (IAO) (Always report 2x2 grid value).	92 km² discrete based on one grid over each observation record (23 2x2 km grids). 1544 km² continuous. Based on continuous stretch of river between all observation records (386 2x2 km grids).

Is the population "severely fragmented" i.e., is >50% of its total area of occupancy in habitat patches that are (a) smaller than would be required to support a viable population, and (b) separated from other habitat patches by a distance larger than the species can be expected to disperse?	a. No b. No
Number of "locations"* (use plausible range to reflect uncertainty if appropriate)	Between 11 and 7. 11 locations based on invasive species: Red River, La Salle River, Seine River, Rat River, Cooks Creek, Assiniboine River above Portage Diversion (dam), Assiniboine River below Portage Diversion, Brokenhead River, Wanipigow River, Bloodvein River, and Bradbury River based on threat from Zebra Mussels. 7 locations based on pollution: Red River (including Seine River, La Salle River, and Cooks Creek), Rat River, and Assiniboine River (above and below the Portage Diversion dam) each comprise single locations based on non-point source pollution inputs throughout their drainages (n=3); Brokenhead River, Wanipigow River, Bloodvein River, and Bradbury River represent 4 additional locations all of which drain into Lake Winnipeg separate from the Red River and are not subject to the same magnitude of pollution but would be separate locations based on invasive species.
Is there an [observed, inferred, or projected] decline in extent of occurrence?	Yes. Observed decline of 42.7% over the last 3 generations. Confidence in this estimate is low based on limited sampling effort in the Red and Assiniboine rivers. Even with the threats of pollution and/or Zebra Mussel infestations, peripheral subpopulations could continue to persist for some time.
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Yes. Observed decline of 25.8% over the last 3 generations. Confidence in this estimate is low based on limited sampling effort in the Red and Assiniboine rivers. Zebra Mussel infestation and/or pollution could further reduce IAO in the future.
Is there an [observed, inferred, or projected] decline in number of subpopulations?	Unknown
Is there an [observed, inferred, or projected] decline in number of "locations"*?	Unknown
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Yes. Habitat quality continues to decline due to pollution resulting from agricultural runoff. Zebra Mussels will also contribute to a projected decline in habitat quality.

* See Definitions and Abbreviations on COSEWIC website and IUCN (Feb 2014) for more information on this term.

Are there extreme fluctuations in number of subpopulations?	No
Are there extreme fluctuations in number of "locations"*?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each subpopulation)

Subpopulations (give plausible ranges)	**Estimated Mature Individuals**
Red River	Unknown
Assiniboine River (above Portage Diversion)	Unknown
Assiniboine River (below Portage Diversion)	estimated 1-4 million
Rat River	Unknown
Brokenhead River	Unknown
La Salle River	Unknown
Cooks Creek	Unknown
Bloodvein River	Unknown
Bradbury River	Unknown
Wanipigow River	Unknown
Seine River	Unknown
Total	Unknown, total population estimated at minimum 1-4 million individuals based on extrapolations from 2003-2004 data from the lower Assiniboine River.

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, or 10% within 100 years]?	N/A – insufficient data for analyses.

Threats (direct, from highest impact to least, as per IUCN Threats Calculator)

Was a threats calculator completed for this species? Yes.

i. Invasive, non-native alien species and natural system modifications: Zebra Mussel infestation imminent or occurring at 8 of 11 locations in DU (except Wanipigow, Bloodvein and Bradbury rivers); rip rapping and diking for flood control.

ii. Pollution: Habitat degradation from agricultural activity (siltation, loss of riparian vegetation, streambank erosion, and nutrient loading), municipal and industrial pollution.

What additional limiting factors are relevant?

Abundance of host fish probably not an issue.

* See Definitions and Abbreviations on COSEWIC website and IUCN (Feb 2014) for more information on this term.

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	In same watersheds as Canadian population (Red River) it is either not ranked or is S3 or is in the same state of decline as Canadian population.
Is immigration known or possible?	Possible
Would immigrants be adapted to survive in Canada?	Likely, but needs to be confirmed by testing.
Is there sufficient habitat for immigrants in Canada?	Yes
Are conditions deteriorating in Canada?[+]	Yes
Are conditions for the source population deteriorating?[+]	Unknown, but probable.
Is the Canadian population considered to be a sink?[+]	No
Is rescue from outside populations likely?	Unknown, but possible.

Data Sensitive Species

Is this a data sensitive species? No

Current Status

Status History: Designated Endangered in April 2006. Status re-examined and designated Threatened in November 2016.

Status and Reasons for Designation:

Status: Threatened	**Alpha-numeric code:** B2ab(ii,iii,v)
Reasons for designation: This heavy-shelled mussel has a small range and few locations, and occurs in habitat projected to continue to decline in quality. Present and ongoing threats include pollution from agricultural effluent, urban wastewater, and industrial sources. The arrival and establishment of invasive Zebra Mussels in 2013 represents a new threat of likely high severity. This change in status is a result of new surveys revealing previously unknown locations.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Does not meet criteria. The actual rate of decline in EOO and IAO over the past 3 generations is uncertain. The threats assessment projects a suspected decline of between 10 and 70% in the next 3 generations, with the uncertainty resulting from the impacts of the invasive Zebra Mussel.

[+] See Table 3 (Guidelines for modifying status assessment based on rescue effect).

Criterion B (Small Distribution Range and Decline or Fluctuation): While the EOO (45,097 km^2 – from live individuals or fresh shells observed between 2000 and 2015) is above the threshold for Threatened (< 20,000 km^2: B1), the actual IAO lies between 92 km^2 (discrete) and 1544 km^2 (continuous) and is below the threshold for either Endangered (< 500 km^2) or Threatened (< 2,000 km^2: B2). The species is not severely fragmented and does not undergo extreme fluctuations; however, there are between 7 and 11 locations, with the lower number being below the threshold for Threatened (10 or fewer locations). IAO and number of mature individuals are expected to decline due to the continuing decline in habitat quality.
Criterion C (Small and Declining Number of Mature Individuals): Does not meet criteria. Number of mature individuals is unknown but estimated to be a minimum of 1-4 million.
Criterion D (Very Small or Restricted Population): D1 is not applicable as the number of mature individuals is unknown but estimated to be a minimum of 1-4 million. D2 Threatened is not applicable because both the IAO and number of locations exceed the typical thresholds (20 km^2 and less than or equal to 5, respectively). While the species is prone to the effects of human activities or stochastic events, the species is not expected to meet the thresholds for Critically Endangered within 1 or 2 generations (20-40 years) or become extirpated once these activities or events occur.
Criterion E (Quantitative Analysis): Not applicable. Analyses have not been done.

PREFACE

Since the first COSEWIC (2006) status report on Mapleleaf (*Quadrula quadrula*), a great deal of new distributional data have been collected on the Great Lakes - Upper St. Lawrence Designatable Unit (DU). There have been new occurrences (= locations) discovered in several coastal embayments and drowned river mouths in Lake Ontario, small tributaries of Lake Huron in Lambton County near Sarnia, and a rediscovery of live animals in the Welland River and its tributaries. With the new data incorporated into the distribution for the Great Lakes - Upper St. Lawrence DU, there has been little apparent change in extent of occurrence (EOO) and index of area of occupancy (IAO) and the number of locations is at least 21. Threats in the Great Lakes - Upper St. Lawrence DU remain similar to what was described in the original report: infestation by dreissenid mussels and pollution from agricultural runoff (in riverine systems); however, both of these threats are perhaps not as severe as first feared. For the Saskatchewan - Nelson Rivers DU there are new records of live animals in tributaries of the Red River and of Lake Winnipeg, thus increasing the number of potential locations in comparison to the original report (COSEWIC 2006). The historical data collected in Manitoba have a great deal of uncertainty due to limited sampling effort in the large river systems where Mapleleaf has been found historically, thus making it difficult to confidently determine trends in EOO and IAO. The only other major change for the Saskatchewan-Nelson Rivers DU since the original status report is that Zebra Mussels (*Dreissena polymorpha*) have become established in Lake Winnipeg, the Red River, and upstream of the Canadian occurrences in reservoirs in the Red River watershed in North Dakota and in tributaries of the Red River in Minnesota. The presence of Zebra Mussel in these systems represents an active and ongoing threat as well as a projected threat in the Assiniboine River as these invasive mussels will undoubtedly spread.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2016)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment and Climate Change Canada
Canadian Wildlife Service

Environnement et Changement climatique Canada
Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment and Climate Change Canada, provides full administrative and financial support to the COSEWIC Secretariat.

COSEWIC Status Report

on the

Mapleleaf
Quadrula quadrula

in Canada

2016

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Scientific name: *Quadrula quadrula* (Rafinesque, 1820)

English common name: Mapleleaf

French common name: Mulette feuille d'érable

The current authority for the classification and scientific nomenclature of freshwater mussels in North America is Turgeon *et al.* (1998). The classification currently accepted is:

Phylum: Mollusca

Class: Bivalvia

Subclass: Palaeoheterodonta

Order: Unionoida

Superfamily: Unionoidea

Family: Unionidae

Subfamily: Ambleminae

Tribe: Quadrulini

Genus: *Quadrula*

Species: *Quadrula quadrula*

A complete list of synonymies and the nomenclatural history for *Quadrula quadrula* is provided by Parmalee and Bogan (1998).

Morphological Description

Mapleleaf (*Quadrula quadrula*) is a medium to large freshwater mussel that can be recognized by two bands of nodules radiating in a v-shape from the umbo (the beak that protrudes above the hinge of each valve) to the ventral margin (Figure 1). One band is located centrally and the other is located on the posterior ridge. The rows are separated by a shallow groove. The following species' description has been adapted from Clarke (1981), Cummings and Mayer (1992), Parmalee and Bogan (1998), Graf and Ó Foighil (2000), Cicerello and Schuster (2003), Haag and Staton (2003), and Hay *et al.* (2003). The morphology of Canadian specimens is consistent with the range of variation reported from specimens from the United States. The conchological morphology of sexes is alike. The shell is thick, moderately inflated, and quadrate in outline. The anterior end is rounded, the posterior end is squared or truncated. Umbos are small and slightly raised above the hinge line. The umbo is sculptured; double loops or zigzags radiate to the ventral margin as two rows of raised nodules. Nodules on the umbo are small and crowded, and are generally eroded on older specimens. Nodules distal to the umbo may be elongated or rounded. Nodules radiating from the umbo are separated by a wide, shallow sulcus or furrow. Typically, one row of nodules is centrally located, the other posteriorly. Occasional variations in nodule patterns range from small nodules scattered over shell surface to absent (Neel 1941). Periostracum is variable, ranging from yellowish green to light brown in young individuals, with older individuals ranging from greenish brown through dark brown. Annual growth lines on the shell surface are obvious and well defined, especially in younger individuals; they can be crowded and difficult to distinguish at the shell margin of older individuals.

Pseudocardinal teeth are well developed, vertically elongated and serrated; there are two in the left valve, one in the right (Figure 2). The pseudocardinal tooth in the right valve is heavy, thick and triangular. Pseudocardinal teeth in the left valve are rough, solid and sometimes joined dorsally. Two lateral teeth in the left valve are erect, fairly long and straight, and may be serrated. The single lateral tooth in the right valve is high, long and straight, and may be serrated. The interdentum is wide. The beak (umbo) cavity is deep but open. The nacre is white and iridescent posteriorly.

Parmalee and Bogan (1998) report mature *Q. quadrula* reaching 120 mm in length. In Canada, Clarke (1981) reports *Q. quadrula* reaching 125 mm in length (135 mm according to Morris unpubl. data), 100 mm in height, and 50 mm in width. In Manitoba, individuals have been recorded up to 121 mm in length, 88 mm in height, and 52 mm in width (Carney 2003a).

In Ontario, *Q. quadrula* is most similar to *Quadrula pustulosa* (Pimpleback - Low Priority COSEWIC Mollusc Species Specialist Subcommittee candidate) and *Cyclonaias turberculata* (Purple Wartyback – COSEWIC candidate species in fall 2017 Call for Bids). These can be distinguished as follows. *Quadrula quadrula* has nodules restricted to two bands that extend to the beak whereas they are scattered and more uniformly distributed on *Q*. *pustulosa* and do not extend to the beak. *Quadrula quadrula* is quadrate in outline whereas *Q*. *pustulosa* is rounded in outline. *Quadrula pustulosa* also has a prominent green ray extending from the beak, that is lacking in *Q. quadrula*. *Cyclonaias tuberculata* has a large number of small pustules extending from the beak through the ventral margin to the posterior of the shell; however, these are not in rows as they are in *Q. quadrula*. The nacre in *C. tuberculata* is distinctly purple but white in *Q. quadrula*. Juvenile *C. tuberculata* can be especially difficult to distinguish from juvenile *Q. quadrula*. There are no other mussels in Canada with which *Q*. *quadrula* can be confused.

The following description of soft-tissue morphology is derived from Lydeard *et al.* (1996) and Graf and Ó Foighil (2000). *Quadrula quadrula* uses all four gill demibranchs as marsupia. The interlamellae of gill demibranchs are connected by complete septa. The marsupial water tubes are undivided, not tripartite. There is no swelling of the marsupial interlamellar septa into water tubes. The margin of the gravid marsupium is sharp. The ventral margin of the marsupium does not extend beyond the non-marsupial portion of the gill. The mantle ventral to the incurrent siphon is simple and is not modified with papillae or lure-like elaborations.

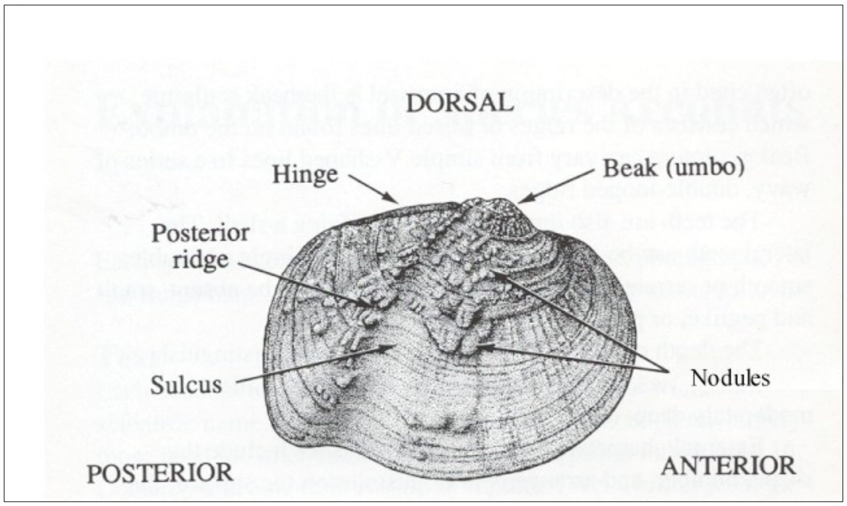


Figure 1. Line drawing showing *Quadrula quadrula* external shell morphology (after Cummings and Mayer 1992).

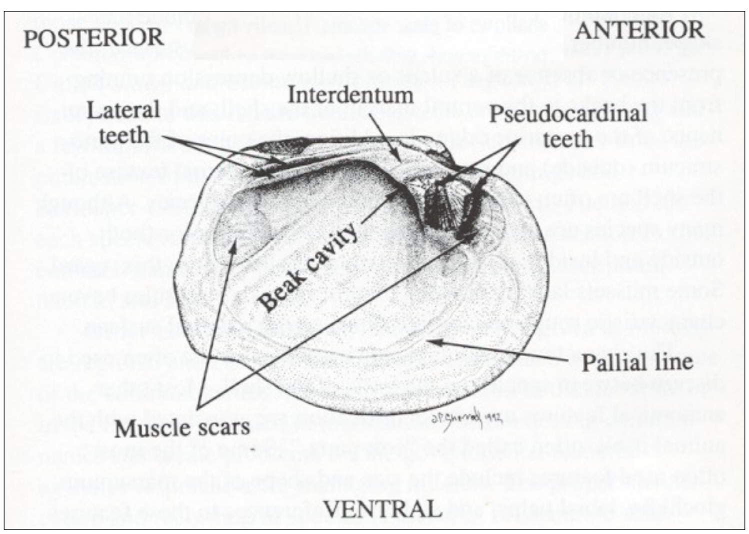


Figure 2. Line drawing showing *Quadrula quadrula* left valve internal shell morphology (after Cummings and Mayer 1992).

Population Spatial Structure and Variability

Davis (1984) and Johnson *et al.* (1998a,b,c) used allozyme electrophoresis to describe genetic variation in populations of *Q. quadrula* from Wisconsin and Arkansas, respectively. They described similar alleles per locus (1.6) and mean polymorphism (0.35-0.36) for these populations. In contrast, the mean in the Wisconsin population was almost twice that in the Arkansas population. These data are in contrast to those reported by Berg *et al.* (1998) who investigated allozyme variation in *Q*. *quadrula* populations from Ohio and the lower Mississippi and found much higher values for mean polymorphism, mean heterozygosity, and alleles per locus than reported by Davis (1984) and Johnson *et al.* (1998a,b,c). Berg *et al.* (1998) also reported much lower values for F_{st} and Nei's genetic distance than reported by Johnson *et al.* (1998a,b). These genetic distance data indicate there is very little genetic variation among the *Q*. *quadrula* populations examined by Berg *et al.* (1998) despite being separated by up to 2,000 km of river. Berg *et al.* (1998) suggested this may be a consequence of high gene flow resulting from using a highly vagile host for the glochidia (see **BIOLOGY: Life Cycle and Reproduction**).

Preliminary analysis (Figure 3) of unpublished data (Levine pers. comm. 2004; Zanatta unpubl. data) on the COI gene region of *Q. quadrula* populations from regions in the United States and from Ontario and Manitoba reveals that the Ontario and Manitoba populations share the majority of their haplotypes with some populations in the United States. This suggests the Canadian populations are subsets derived from the American populations in the Mississippi River drainage. Both the Ontario and Manitoba populations appear to have low haplotype diversity. However, both populations have haplotypes that are unique and not shared with any other region. This indicates there is unique genetic information in each of the Ontario and Manitoba populations.

The genetic population structure of *Q. quadrula* in the Great Lakes region has been thoroughly studied since the previous COSEWIC (2006) report. Galbraith *et al.* (2015) found substantial genetic diversity of *Q. quadrula* sampled from the Sydenham, Thames, and Grand rivers with high allelic richness and heterozygosity at eight microsatellite loci. Genetic structure for *Q. quadrula* was primarily evident among the rivers: the genetic populations of *Q. quadrula* showed evidence of partitioning between the Sydenham and the Grand and Thames sites, with the latter two rivers falling out as a single population (Galbraith *et al.* 2015). Paterson *et al.* (2015) showed clear evidence of gene flow among sample sites, low-level population divergence, and clear isolation-by-distance in coastal areas of western Lake Erie (US side of the lake), the Maumee River and the Grand River (Ontario). On a larger spatial scale, analyses of microsatellite DNA genotypes show that *Q. quadrula* likely entered the Great Lakes at the end of the Pleistocene glaciation via a single route by way of a connection between the Illinois River system (upper Mississippi River drainage) and Lake Michigan, with subsequent dispersal across the Great Lakes region and represent a single genetic population with high levels of gene flow [number of migrants per generation (N_m) >1, Zanatta unpubl. data]. Furthermore, it appears that the subpopulations of *Q. quadrula* in Lake Ontario may have become established recently (last 200 years) with their dispersal into the lake being facilitated by the construction of the Welland Canal (Hoffman and Zanatta unpubl. data).

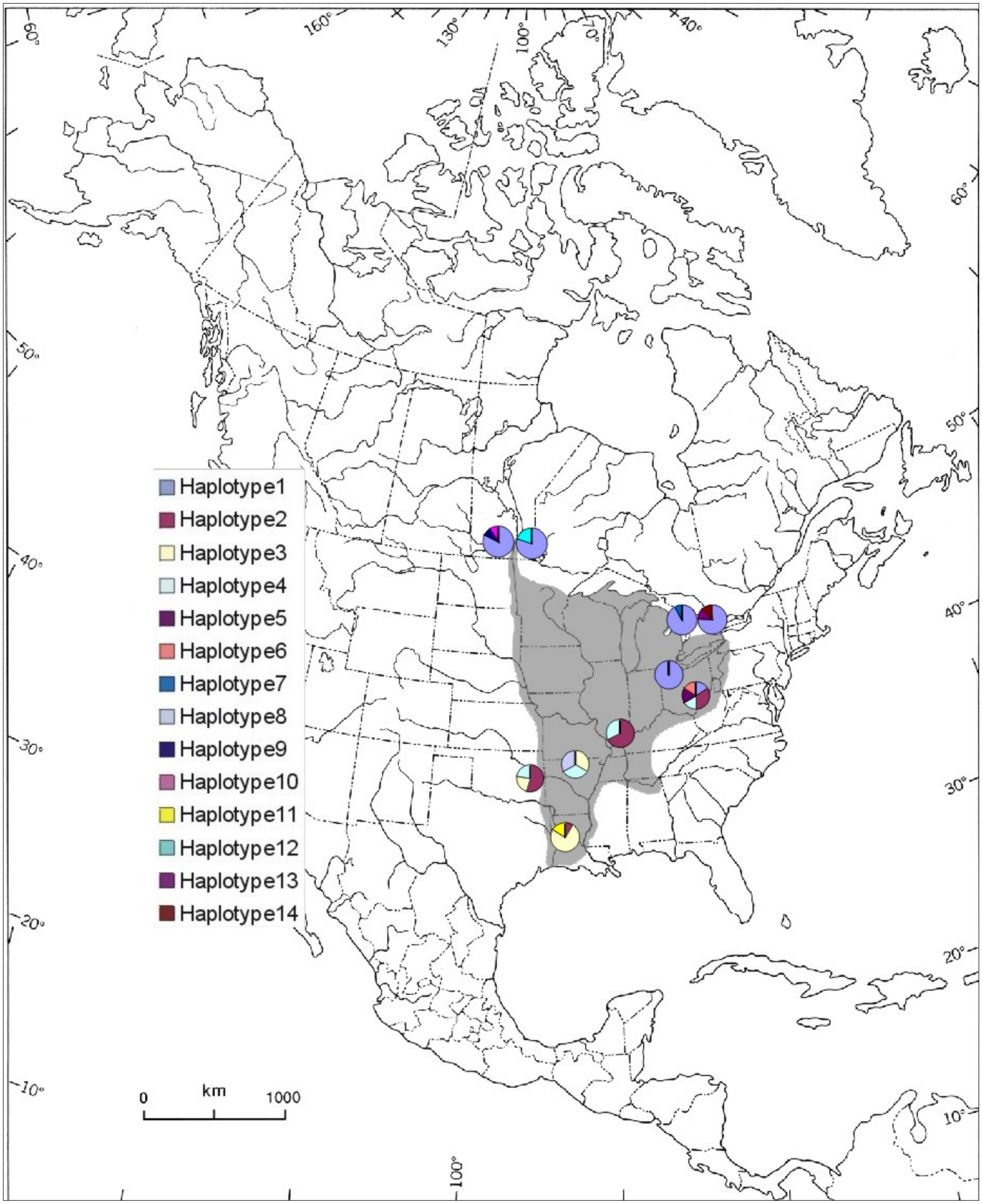


Figure 3. Haplotype distributions for *Quadrula quadrula* subpopulations determined from the cytochrome oxidase I gene of the mitochondrial genome. Shaded area indicates the North American distribution of *Q. quadrula* (map from Parmalee and Bogan 1998).

Designatable Units

COSEWIC can recognize units below the species level as designatable units (DUs). The populations of *Q. quadrula* in Ontario and Manitoba merit distinction as separate designatable units because they are discrete and evolutionarily significant. They satisfy the three criteria for discreteness: occupation of different COSEWIC Freshwater Biogeographic Zones, natural disjunction, and genetic distinctiveness. First, they occupy biogeographically distinct freshwater biogeographic zones. The Ontario population occupies the Great Lakes-Upper St. Lawrence National Freshwater Biogeographic Zone whereas the Manitoba population occupies the Saskatchewan-Nelson Rivers National Freshwater Biogeographic Zone. Second, they are separated by a major range disjunction. The Ontario population is part of the Great Lakes-St. Lawrence watershed and the Manitoba population is part of the Hudson Bay watershed. As aquatic organisms, they and their host fish are limited to dispersal only within these continental scale watersheds. Effectively this means they are isolated and disjunct from each other and from other North American *Q*. *quadrula* populations in the Ohio-Mississippi watershed in the United States. Third, they can be recognized as being genetically distinct. Despite being low in genetic diversity and the majority of individuals sharing a haplotype common throughout North American populations, each population has unique haplotypes. Ontario subpopulations have two distinct haplotypes and Manitoba subpopulations have three distinct haplotypes. Evolutionary significance also is demonstrated by the genetic differences which may indicate local evolutionary adaptation to the different Freshwater Biogeographic Zones, as has been used for freshwater fishes. Two DUs for *Q. quadrula* were previously recognized (COSEWIC 2006), and were named Great Lakes-Western St. Lawrence population and Saskatchewan-Nelson population. These formal names are herein changed to reflect the COSEWIC Freshwater Biogeographic Zones; however, the different DUs may also be referred to as the Ontario and Manitoba populations, respectively in this report.

Special Significance

There are 20 recognized species in the genus *Quadrula* of which one is considered extinct and four are considered endangered in the United States (Williams *et al.* 1993). Many of the remaining species are considered vulnerable to critically imperilled in most of their ranges (NatureServe 2016). Two species of the genus, *Q*. *pustulosa* and *Q*. *quadrula*, are recorded from Canada. *Quadrula quadrula* is the most widespread species of the genus and, in Canada, is present in southwestern Ontario and Manitoba. *Quadrula quadrula* currently appears to be the most stable, in much of its distribution, of all the species in the genus. Considering the state of the members of the genus, *Q. quadrula* may represent the best opportunity to maintain representation of the genus *Quadrula* over the long term. Canadian populations occur in separate continental watersheds that are separate from the main distribution of this species and have unique haplotypes and ecological information important in conserving the diversity of the species.

DISTRIBUTION

Global Range

Quadrula quadrula (type locality Ohio River) is distributed throughout the Ohio-Mississippi River drainages extending southeast to Louisiana, southwest to eastern Texas, and northwest to Minnesota (Clarke 1981; Parmalee and Bogan 1998; Figure 3). It is present in the Red River drainage in North Dakota, Minnesota, and Manitoba (Clarke 1981; Cvancara 1983). In the Great Lakes drainage it has been recorded from the Lake Huron, Lake Erie, Lake St. Clair, and Lake Ontario drainages. In the United States *Q. quadrula* has been reported from Alabama, Arkansas, Iowa, Illinois, Indiana, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Missouri, Mississippi, North Dakota, Nebraska, New York, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Wisconsin, and West Virginia (Parmalee and Bogan 1998; NatureServe 2016).

Canadian Range

In Canada, *Q. quadrula* has been reported only from Ontario and Manitoba (Figure 3). In Ontario (Figures 4 and 5), *Q. quadrula* has been reported from Lake St. Clair, Lake Erie, and the Niagara River and their tributaries: Baptiste Creek, and the Grand, Thames, Ruscom, Sydenham, and Welland rivers. It is also found in tributaries of southern Lake Huron including the Ausable River, Bayfield River, Perch Creek/Tefler Diversion Channel, and Cow Creek. Live *Q. quadrula* were found in Jordan Harbour/Twenty Mile Creek, Cootes Paradise (Hamilton Harbour), Fifteen Mile Creek/Pond, and Sixteen Mile Creek, which are drowned rivermouths in western Lake Ontario. In Manitoba (Figures 6 and 7), *Q. quadrula* has been recorded from the Assiniboine River, Bloodvein River, Bradbury River, Brokenhead River, Cooks Creek, LaSalle River, Rat River, Red River, Roseau River, Seine River, and Wanipigow River.

Extent of Occurrence and Area of Occupancy

The current (2000-2015) extent of occurrence (EOO) for the Great Lakes - Upper St. Lawrence population, calculated using the minimum convex polygon, around sites with live or fresh dead shells is 26,826 km^2 (Figure 5). The total EOO, including all records both historical (prior to 2000) and current (2000-2015) is 32,940 km^2 (Figure 4); this assumes that the range has not expanded since 2000 and that the new occurrence records are a result of sampling effort (see next section). Contraction of the range through losses of subpopulations from the Detroit and Niagara rivers and along the south shore of Lake St. Clair has resulted in a calculated 12.5% decrease in EOO. The current discrete IAO, as calculated by occupancy (of live or fresh dead shells) in each 2 x 2 km grid, is 228 km^2 (Table 1, Figure 5); an identical 228 km^2 discrete IAO is calculated from all records collected before 2000. This apparent similarity is again the result of newly discovered subpopulations and hides the loss of previously occupied grid squares. The current continuous IAO is 660 km^2 (calculated by joining intervening 2 x 2 km grid cells along occupied river systems but excluding the open waters of the Great Lakes where dreissenid mussel [Zebra *Dreissena polymorpha* and Quagga *D. bugensis*] infestation densities are high).

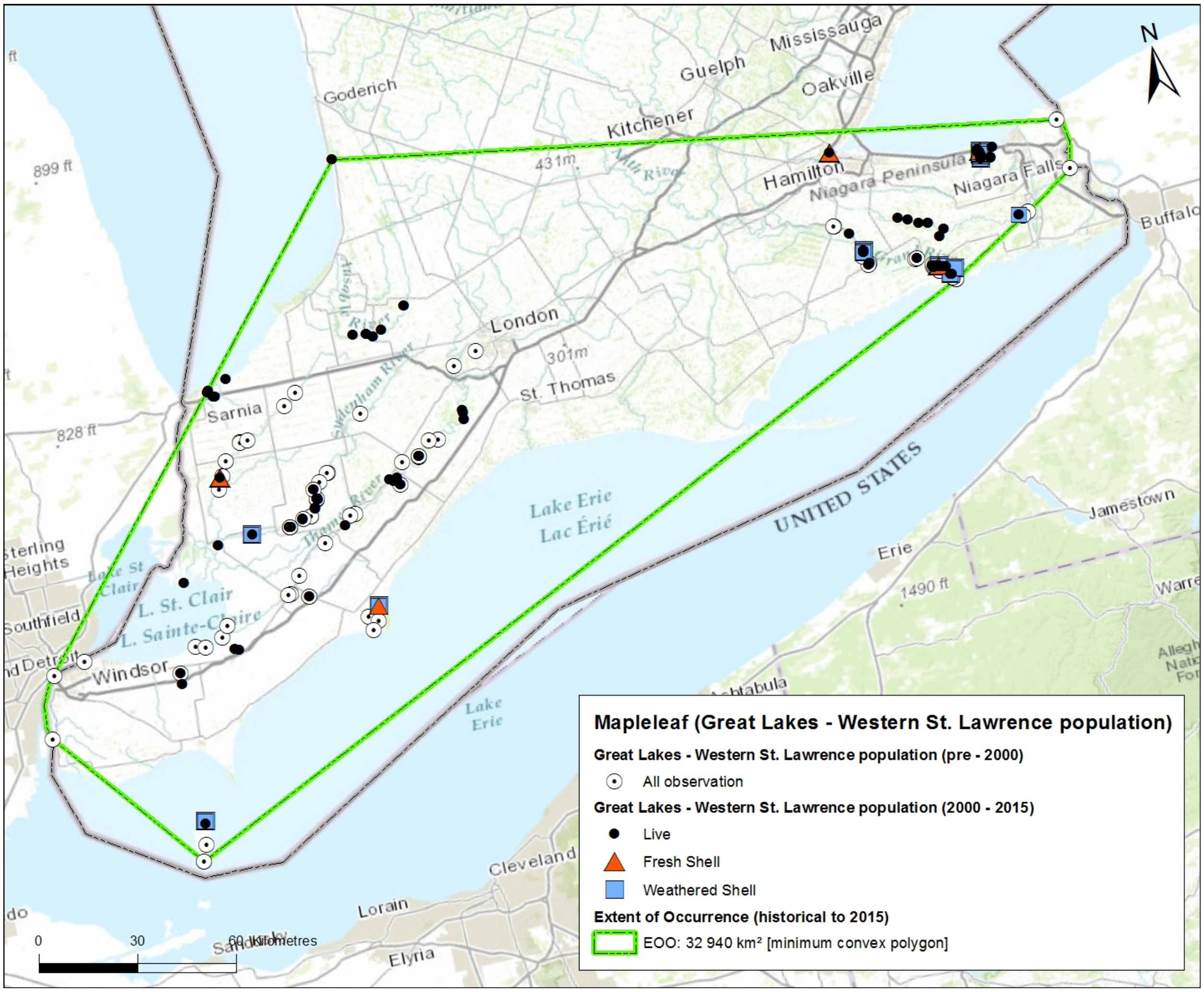


Figure 4. Total distribution of *Quadrula quadrula* in Ontario based on records and surveys prior to and after 2000 reported in the Lower Great Lakes Unionid database. The total calculated extent of occurrence (historical plus current) is shown.

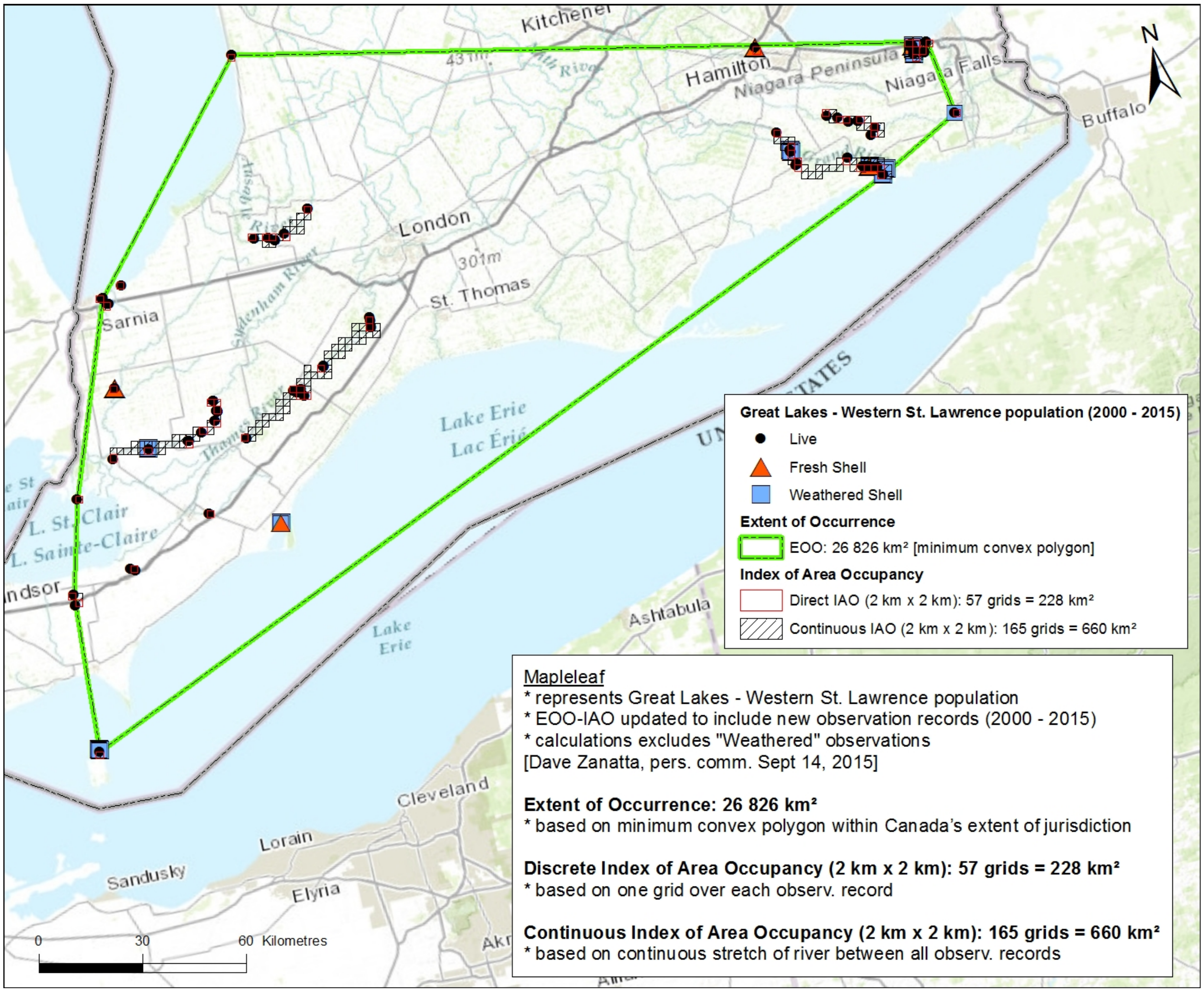


Figure 5. Current distribution of *Quadrula quadrula* in Ontario based on records and surveys from 2000-2015 reported in the Lower Great Lakes Unionid database. The Bayfield River is the northwestern most dot.

Table 1. Index of area of occupancy (IAO) based on 2 x 2 km grid placed over the occurrence records of *Quadrula quadrula* in Ontario collected since 2000.

Locations	Index of Area of Occupancy (km^2)
Ausable River	20
North Sydenham River	4
East Sydenham River	32
Thames River	28
Grand River	44
Welland River	20
Coyle Creek	4
Oswego River	4

Locations	Index of Area of Occupancy (km^2)
Jordan Harbour/Twenty Mile Creek	16
Sixteen Mile Pond	4
Fifteen Mile Creek/Pond	4
Cootes Paradise/Spencer Creek	4
Ruscom River	8
Baptiste Creek	4
McGregor Creek	4
Bayfield River	4
St. Clair Delta	4
Perch Creek/Tefler Diversion Channel	8
Cow Creek	4
Lake Henry (Pelee Island)	4
Rondeau Bay (Lake Erie)	4
TOTAL IAO	228

Comparing historical and current (2000-2015) distribution in Manitoba also is confounded by newly discovered subpopulations and the lack of resurveying previously occupied sites. The current distribution in Manitoba has apparently declined in comparison to that recorded historically (Clarke 1973; Pip pers. comm. 2004; Watkinson pers. comm. 2015; Morris unpubl. data) (Figures 6 and 7). Using a minimum convex polygon of sites with live or fresh dead shells, the current (2000-2015) EOO is approximately 45,097 km^2 (Figure 7) as compared with 78,755 km^2 calculated using all records collected prior to 2000: an apparent decline of 42.7%. The current discrete IAO (occupied 2 x 2 km grid squares with live or fresh dead shells) is estimated to be 92 km^2 (Table 2; Figure 7), as compared to a historical discrete IAO of 124 km^2 calculated using all records collected prior to 2000: a 25.8% decline. The current continuous IAO (following the occupied river systems) is 1544 km^2. The continuous IAO does not include open waters of Lake Winnipeg where *Q. quadrula* has not been reported in recent years and where Zebra Mussels have recently become established (see **Threats**). It is recognized that sampling effort may not have been sufficient to determine if there has in fact been a decline in EOO or IAO with the apparent contraction in EOO being from not recently finding the species either along the Assiniboine River upstream of Brandon or along the west-central shore of Lake Winnipeg; however, neither of these areas has been resurveyed. The calculated declines are based on the available data. The decline in IAO may be more reliable due to the apparent disappearance of the species from Lake Winnipeg.

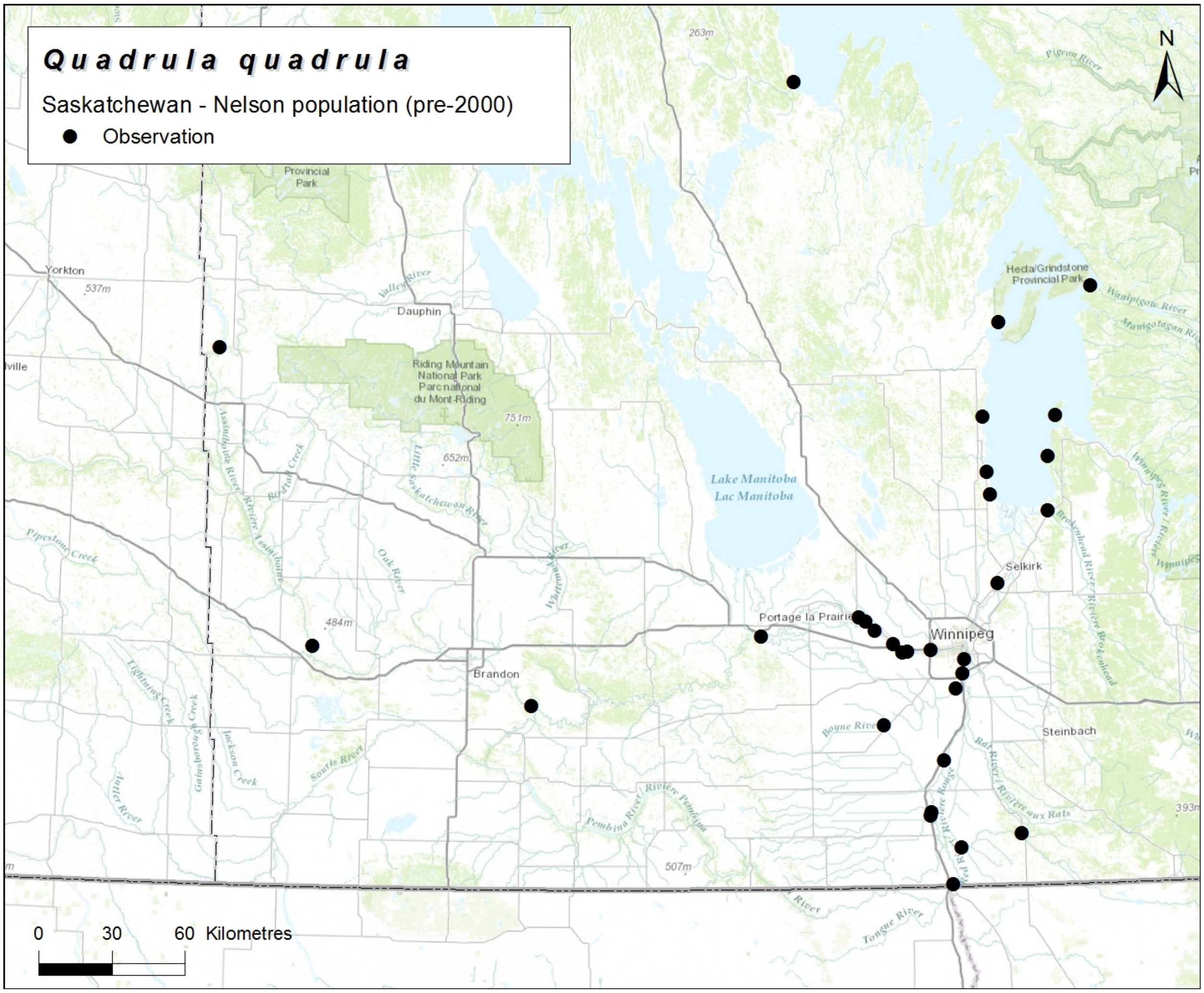


Figure 6. Historical distribution of *Quadrula quadrula* in Manitoba based on records and surveys prior to 1992 reported by Clarke (1973) and Pip (pers. comm. 2004). The Shellmouth Reservoir is the northwestern-most dot.

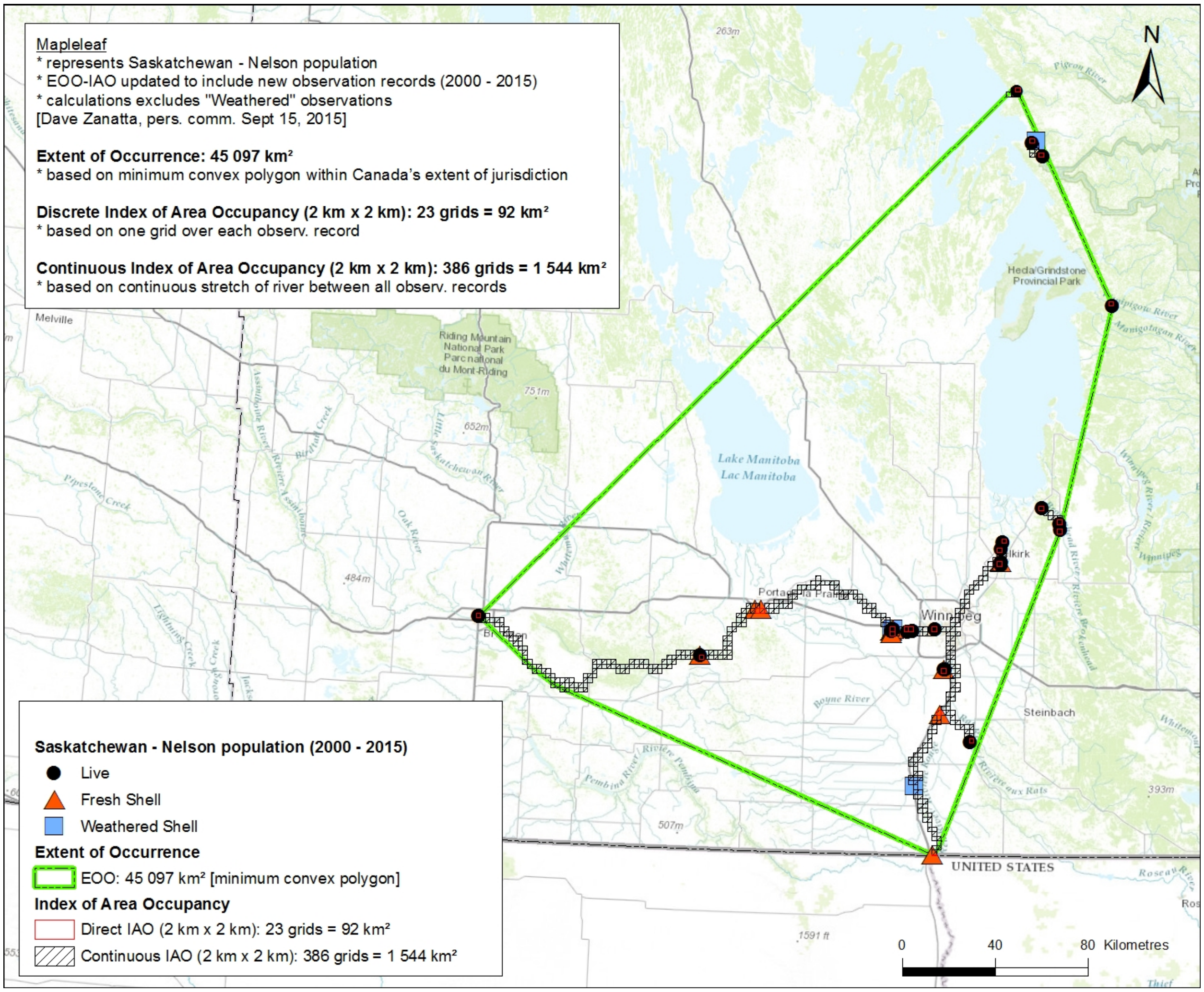


Figure 7. Current distribution and calculation of extent of occurrence and index of area of occupancy of *Quadrula quadrula* in Manitoba based on surveys from 2000-2015. Cooks Creek flows into the Red at Selkirk, before the Red flows into Lake Winnipeg. The following rivers with records of *Q. quadrula* are found along the eastern edge of Lake Winnipeg (south to north): Brokenhead, Wanipigow, Bloodvein (2 dots and square), and Bradbury rivers. The La Salle River (triangle and superimposed dots) flows into the Red River south of Winnipeg.

Table 2. Index of area of occupancy (IAO) based on 2 x 2 km grid placed over the occurrence records of *Quadrula quadrula* in Manitoba collected since 2000.

Locations	**Index of Area of Occupancy(km^2)**
Assiniboine River (above Portage diversion)	16
Assiniboine River (below Portage diversion)	20
Red River	12
Brokenhead River	12
Cooks Creek	4
Rat River	4
La Salle River	4
Wanipigow River	4
Bloodvein River	8
Bradbury River	4
Seine River	4
TOTAL IAO	92

Search Effort and Distribution of *Quadrula quadrula* in Ontario

The Lower Great Lakes Unionid Database was used to identify occurrence records for *Q. quadrula* in Ontario. The database is continually updated with the results of new surveys by Dr. Todd Morris and his team at Fisheries and Oceans Canada (DFO) as well as surveys elsewhere in Ontario by other organizations (e.g., Ontario Ministry of Natural Resources and Forestry - MNRF). The database currently consists of more than 10,000 records for 40 species collected from more than 2,500 sites throughout the Lake Ontario, Lake Erie, Lake St. Clair, and lower Lake Huron drainage basins since 1860. For a detailed description of the database and its historical data sources, see Metcalfe-Smith *et al.* (1998a).

Quadrula quadrula was historically collected from the Detroit, Sydenham, Thames, Grand, Welland, and Niagara rivers as well as Lake Erie and Lake St. Clair. The earliest known records of the species in each of these waterbodies were as follows: between the 1880s and 1930s by various surveyors for the Detroit River (Schloesser *et al.* 2006), 1963 by H.D. Athearn for the Sydenham River near Shetland, 1894 by J. Macoun for the Thames River near Chatham, 1885 by J. Macoun for the Grand River near Cayuga, 1983 by D.J. Berg for the Welland River in Welland, 1934 by J.P. Oughton for the Niagara River, 1894 by J. Macoun for Lake Erie at Rondeau Bay, and 1965 by C.B. Stein for Lake St. Clair near the mouth of the Thames River. Figure 4 shows the total distribution of *Q. quadrula* in Ontario including the historical distribution based on 106 records collected between 1885 and 2000. The current distribution of the species is shown in Figure 5 and is based on 1647 records (live animals) collected between 2000 and 2015 (i.e., within the last generation for *Q. quadrula*).

Populations of *Q. quadrula* and other species of freshwater mussels in the Canadian and U.S. waters of the lower Great Lakes and connecting channels have been almost entirely lost due to the impacts of dreissenid mussels. Small isolated populations of native mussels can still be found in some coastal areas where densities of dreissenids have remained low (e.g., Nichols and Wilcox 1997; Zanatta *et al.* 2002; McGoldrick *et al.* 2009; Crail *et al.* 2011; Zanatta *et al.* 2015, Morris unpubl. data). In the Detroit River, less than 10% of the unionid population and only 13 of 24 species present prior to the dreissenid invasion survived to 1994 (Schloesser *et al.* 1998). Only five living mussels were found during follow-up surveys at several sites in 1998 (Schloesser *et al.* 2006) and none was *Q. quadrula*. Nalepa *et al.* (1996) surveyed 29 sites in the offshore waters of Lake St. Clair in 1986, 1990, 1992, and 1994. *Quadrula quadrula* was found alive at one site in U.S. waters in both 1986 and 1990 but not during later surveys. Gillis and Mackie (1994) surveyed an area off the mouth of the Puce River on the southwestern shore of Lake St. Clair between 1990 and 1992. The number of species found declined from 11 in 1990 to four in 1991 and no live mussels were found in 1992. They did not find any *Q. quadrula* during their surveys. Zanatta *et al.* (2002) surveyed 95 sites in nearshore areas around Lake St. Clair between 1999 and 2001 and found one *Q. quadrula* at a site near the mouth of the Thames River in 1999. Metcalfe-Smith *et al.* (2004) surveyed 28 sites in Canadian and U.S. waters of the Lake St. Clair delta in 2003 and did not find any live *Q. quadrula.* One live animal was subsequently collected from the delta in 2005 but none since (McGoldrick e*t al.* 2009). *Quadrula quadrula* was reported from Rondeau Bay on the north shore of Lake Erie in 1894 and 1961, but only old weathered shells were found during a survey in 2001 (Zanatta unpubl. data). Additional sampling in 2014 and 2015 by the Ontario MNRF at 15 sites (4.5 person-hours of search effort at each site) in Rondeau Bay revealed four live unionid species including large numbers of Giant Floater (*Pyganodon grandis*); two fresh shells of *Q. quadrula* were found (Reid *et al.* 2016). There are records for *Q. quadrula* from Pelee Island in 1962, 1978, and 1985 and shells were collected in 1992. Although there have been no further surveys around Pelee Island, 19 sites around the nearby Bass Islands (U.S. waters, a few kilometres south of Pelee Island) were surveyed in 1998 and no live unionids were found (Ecological Specialists Inc. 1999). One site on South Bass Island had supported 27 live species of mussels in 1960. An informal Ontario MNRF survey of Lake Henry (a coastal embayment) at the north end of Pelee Island found two live *Q. quadrula* in summer 2015 (Cairns pers. comm. 2015). There are two historical records for *Q. quadrula* from the Niagara River. Thirteen sites were surveyed in 2001 for the New York Power Authority. Old shells of 16 species were found and one site had living animals of three species; unfortunately, the consultant who did the survey was unable to disclose the names of the species found alive (Schneider pers. comm. 2002). Additional (limited) sampling on the US side of the Niagara River in 2011 did not recover any living *Q. quadrula* (Zanatta *et al.* 2015). Live *Q. quadrula* were confirmed in the Welland River in 2008 with 25 live animals collected from a single site near Warner in the Niagara Region, Ontario (Morris *et al.* 2012a). The same site on the Welland River was revisited in 2014 and searched for 12.5 person-hours, yielding 58 live *Q. quadrula* (Hoffman unpubl. data) and additional live specimens were collected in 2015 from Coyle Creek and the Oswego River (Welland River tributaries, Morris unpubl. data).

In 2010, *Q. quadrula* was discovered in Jordan Harbour, a coastal embayment of western Lake Ontario. Additional suveys in 2011, 2013, 2014, and 2015 have confirmed a large number of live animals in Jordan Harbour/Twenty Mile Creek and live specimens from additional Lake Ontario coastal embayments: Sixteen Mile Creek, Fifteen Mile Creek/Pond, and Cootes Paradise/Spencer Creek (Hamilton Harbour) (Reid *et al.* 2014; Minke-Martin *et al.* 2015; Ontario MNRF unpubl. data; McNichols-O'Rourke and Morris unpubl. data).

According to Metcalfe-Smith *et al.* (2003), *Q. quadrula* was encountered more frequently in the Sydenham River during 1999-2004 surveys than in the past (pre-1991). It was found at 56% of 16 sites surveyed in 1997-1999 vs. 30% of 23 sites surveyed in the same reaches between 1929 and 1991. Intensive survey work on the Sydenham River has continued and by the end of 2004 a total of 18 sites had been sampled semi-quantitatively and 15 sites quantitatively (13 sites were sampled using both techniques). The range of *Q. quadrula* in the east branch of the Sydenham River is now known to extend from Tupperville to approximately 10 km upstream of Alvinston. Many successful sampling sites along this stretch of the Sydenham River were re-sampled from 1997 to 2015 and continually yielded *Q. quadrula* (Metcalfe-Smith and Zanatta 2003; Bouvier and Morris 2010; Morris unpubl. data). *Quadrula quadrula* has been found more sporadically in the north branch of the Sydenham River (Bear Creek) from Petrolia downstream to Wallaceburg (Metcalfe-Smith and Zanatta 2003).

There are only scattered historical records available for mussels in the Thames River. However, *Q. quadrula* was reported from several sites in the middle and lower reaches in 1894, 1934, 1963, 1973, 1985, and 1991-92. The river was extensively surveyed in the 1990s and 2000s. Morris (1996) surveyed 30 sites in 1994, focusing on the smaller tributaries, and found *Q. quadrula* at one site on McGregor Creek in Chatham. Metcalfe-Smith *et al.* (1998b, 1999) surveyed 16 sites, mainly on the main stem, in 1997-98 and observed the species at seven sites in the lower part of the watershed. Morris surveyed 25 sites in the Upper Thames River above Delaware in 2004 and did not find *Q. quadrula* at any site. In 2005, Morris returned to the lower Thames River and found *Q. quadrula* at 10 sites. Although his data do not extend the range in the Thames they do fill some previous gaps in coverage and show that most of the lower Thames is occupied by *Q. quadrula* (Morris and Edwards 2007). The available data do not indicate any change over time in the distribution of *Q. quadrula* in the Thames River.

Live *Q. quadrula* have been found in the Ruscom River, a tributary of Lake St. Clair, and Baptiste Creek, a tributary of the lower Thames River where nine specimens were found in 2011 surveys (McNichols-O'Rourke *et al.* 2012). In the Ruscom River, *Q. quadrula* was first discovered by Zanatta (2000) in 1998 in limited surveys. Additional surveys by DFO yielded 26 live specimens at two of six sites in 2010 (McNichols-O'Rourke *et al.* 2012).

The Grand River is one of the best studied watersheds for mussels in Ontario, with nearly 1,000 records available from 1885-2014. Collections have been made in nearly every decade. Major surveys were conducted in 1970-72 (68 sites, Kidd 1973) and in 1995 and 1997-98 (94 sites, Metcalfe-Smith *et al.* 2000a). There have been no changes over time in the distribution of *Q. quadrula* in the Grand River; it has always occurred in the lower 50 km of the river between Caledonia and Port Maitland. Numerous live specimens were found above the dam in Dunnville in 2008 (Paterson *et al.* 2015). In 2011, five sites were surveyed in the lower Grand River and *Q. quadrula* was found alive at all sites (McNichols-O'Rourke *et al.* 2012). Live specimens were again collected in 2014 below the dam in Dunnville (Hoffman unpubl. data; Minke-Martin *et al.* 2015).

Quadrula quadrula can also be found in some southern Lake Huron tributaries. Detweiler (1918) surveyed the Ausable River in 1916 primarily for thick-shelled species that could be used in the pearl button industry. There are also records from 1929 and 1950 for a site near Hungry Hollow in the lower portion of the watershed and Morris and Di Maio (1998-1999) surveyed six sites on the river in 1993-94. *Quadrula quadrula* was not among the 14 species found during these surveys. Metcalfe-Smith *et al.* (unpubl. data) surveyed 25 sites throughout the river from 1998-2004 and found 23 species of mussels alive including *Q. quadrula*, which was restricted to four sites in a short stretch of the lower main stem of the river. Additional quadrat surveys by the Ausable Bayfield Conservation Authority (ABCA) and DFO between 2009 and 2013 confirm this distribution in the Ausable River (ABCA unpubl. data; Bouvier and Morris 2010). One live specimen was found at the mouth of the Bayfield River in 2007 during an extensive bioblitz of the watershed (Morris *et al.* 2012b). Surveys in 2014 of two small tributaries (Perch Creek/Tefler Diversion Channel and Cow Creek) draining into southern Lake Huron near Sarnia reported 24 live *Q. quadrula* (Carroll unpubl. data). These are new records of previously unsurveyed streams in the Lake Huron watershed. Surveys of the Maitland and Saugeen river watersheds failed to find any evidence of *Q. quadrula* (McNichols-O'Rourke *et al.* 2012) and it seems unlikely that Q*. quadrula* ever occurred in the lower Lake Huron drainage north of the Bayfield River.

Search Effort and Distribution of *Quadrula quadrula* in Manitoba

There are few historical records for *Q. quadrula* in Manitoba. Clarke (1973) summarized the history of malacological research in the Canadian Interior Basin as well as results from investigations into mollusc distributions from 1959-1969. During this time, surveys within Manitoba were conducted for 7 years. A total of 103 stations were examined and approximately 15,310 specimens representing 13 species were collected. Sampling methods included visual search in clear water, using a glass-bottomed viewing box, and feeling by hand. This indicates collecting was done close to shore in water that would not exceed waist deep (approximately 1 m). From 1961 to 2000 Pip (pers. comm. 2004) investigated freshwater molluscs in Manitoba and recorded the presence of freshwater mussels at a variety of sites along the Assiniboine River, tributaries of the Red River, and Lake Winnipeg. These two sources, with the contribution of a single study by Scaife and Janusz (1992), provide the bulk of information for the distribution of *Q. quadrula* in Manitoba up to 2000.

Results summarized by Clarke (1973) indicated that, within the Hudson Bay drainage, *Q. quadrula* was distributed within the Red River and lower reaches of larger tributaries of the Red River such as the Assiniboine and Roseau rivers in Manitoba (Figure 6), Red Lake River in Minnesota, and the Pembina and Sheyenne rivers in North Dakota. Within Manitoba, Clarke (1973) records *Q*. *quadrula* from the Red River at St. Jean Baptiste and Aubigny and reports additional historical records from the Red River at Fort Garry, Winnipeg, and Emerson. *Quadrula quadrula* was also collected from the Assiniboine River in and near Winnipeg and from the Roseau River near Tolstoi. Data recorded by Pip (pers. comm. 2004) extended the distribution to the length of the Assiniboine River from Lake of the Prairies to Winnipeg and from sites on the Shell, Rat, Morris, Seine, and LaSalle rivers and from Lake Winnipeg. With the exception of the lower Assiniboine near Winnipeg, these are sites from which *Q*. *quadrula* had not previously been observed (Clarke 1973). Watson *et al.* (1998) and Carney (2003a; unpubl. data) also did not record *Q. quadrula* from those additional sites reported by Pip. The study by Scaife and Janusz (1992) in the Assiniboine River near Winnipeg, recorded *Q*. *quadrula* well within the distribution established by both Clarke (1973) and Pip (pers. comm. 2004). Taken in concert, it seems reasonable to conclude that the historical distribution of this species was limited to the Red River and the lower reaches of its tributaries, the Assiniboine River, and Lake Winnipeg.

Investigations into the freshwater mussel fauna of Manitoba in the late 1990s and early 2000s suggested a decline in the distribution of *Q. quadrula*. Within the Assiniboine River drainage Watson *et al.* (1998) and Carney (2003a) reported *Q*. *quadrula* from the lower Assiniboine River, in the stretch below the Portage Diversion, a large water control dam located at Portage la Prairie that diverts water from the Assiniboine River north to Lake Manitoba. Watson *et al.* (1998) surveyed 18 sites on 157 km of the Assiniboine River between Portage la Prairie and Winnipeg and recovered *Q*. *quadrula* from four sites. Watson *et al.* (1998) searched an additional 167 sites on 15 rivers draining into the Assiniboine River and encountered no evidence of *Q*. *quadrula* at any of these sites. Carney (2003a, 2004a,b) surveyed 67 sites on ten rivers and recovered live *Q*. *quadrula* from some sites on the lower Assiniboine River in many of the same stretches as reported by Watson *et al.* (1998). In addition, Carney (2003a) collected a single, small individual approximately 50 km upstream of the Portage Diversion (Figure 7). This represented the only documented case of *Q*. *quadrula* upstream of the Portage Diversion at that time. Extensive subsequent surveys from the Portage Diversion upstream to the Shellmouth Reservoir did not encounter any other individuals of this species (Carney unpubl. data). However, Mazur (2007) as part of a mussel relocation associated with a bridge construction, reported four live *Q. quadrula* in the Assiniboine River at the town of Brandon. These animals were recovered using SCUBA in a transect across the river. This suggests that *Q. quadrula* is present in the full stretch of the Assiniboine River up to the Shellmouth Reservoir, but confirmation will require searches using SCUBA in deep water not accessible using the previous search methods (by hand in shallow water).

Surveys by Pip (pers. comm. 2004) throughout Lake Winnipeg in the 2000s found no evidence of *Q*. *quadrula*. A single live *Q. quadrula* was reported (Staton pers. comm. 2005) from the Bloodvein River, which drains into Lake Winnipeg, during a canoe trip. This area had never been surveyed for mussels before. This serendipitous discovery raised the possibility that *Q quadrula* is present in tributaries on the eastern side of Lake Winnipeg, and perhaps still exists in Lake Winnipeg itself. Further surveys in 2015 confirmed a large number of live *Q. quadrula* in the Bloodvein River (Watkinson pers. comm. 2015). The Bradbury River, a Lake Winnipeg tributary to the north of the Bloodvein River, had two live *Q. quadrula* recorded (Oliver and Lowdon 2015). A new site in the Wanipigow River (a Lake Winnipeg tributary) was also discovered in 2015 with three live animals being found (Watkinson pers. comm. 2015). Surveys of the Brokenhead River reported a total of six live *Q. quadrula* from three sites near its mouth at Lake Winnipeg (Morris unpubl. data). Collectively, these new discoveries suggest there may be isolated *Q. quadrula* subpopulations in tributaries on the east and north shores of Lake Winnipeg. These data are stored in the Lower Great Lakes Unionid Database.

Surveys by DFO (Morris unpubl. data) of Cooks Creek, a tributary of the Red River north of Winnipeg, recorded seven live *Q. quadrula* in 2013 and three live animals as well as fresh shells in 2014. Surveys of the LaSalle River at La Barriere Park south of Winnipeg reported a single live *Q. quadrula* in 2011. The presence in this site was confirmed with three and 29 live individuals recorded in 2013 and 2014, respectively (Morris unpubl. data). The Rat River was surveyed in 2013 and a single live individual recorded (Morris unpubl. data). Carney (2004a) encountered no live *Q*. *quadrula* from the same sites along the Red River investigated by Clarke (1973) although there was ample evidence of fresh-dead individuals stranded due to low water levels in 2003. In 2004, Carney and Watkins (unpubl. data) investigated sites along the Red River south of Winnipeg, including those reported by Clarke (1973), and found no live *Q*. *quadrula*. They did find half a dozen highly weathered empty valves. Surveys performed by DFO in 2013 near Highway 75 recorded no live animals but did recover 80 fresh whole shells (Morris unpubl. data). This supports the idea that there is a healthy assemblage of *Q. quadrula* in the Red River, but confirmation will be extremely difficult given the nature of the river. In 1992, live *Q*. *quadrula* were recovered from the Roseau River (Carney unpubl. data), but not in the surveys conducted in 2003-2004. It has not been recorded from this river since.

Populations in the Assiniboine appear to occur as assemblages of a few widely separated individuals separated by long stretches of river bottom composed of drifting sand that is completely unsuitable habitat. It is very likely that subpopulations persist in the Red River based on the historical record, river size, and presence of recently dead animals represented by fresh shells. The absence of extensive search effort in this river reflects the difficulty and danger associated with surveying this river due to its size, current, and turbidity. The presence of *Q. quadrula* in tributaries suggests the species is present in the Red River but this has not been confirmed due to the difficulties in sampling. The presence in Bloodvein, Bradbury, and Wanipigow rivers raises the distinct possibility of undiscovered assemblages in other rivers draining into Lake Winnipeg. It is unknown if subpopulations persist in the Roseau River. Recent investigations have not recovered evidence of this species in this river at sites where it has been reported. However, the limited amount of search effort on this river, and low mussel densities cannot preclude the presence of *Q*. *quadrula* in the Roseau River. All of these are within the historical EOO, but do increase IAO.

HABITAT

Habitat Requirements

Quadrula quadrula is found in a variety of habitats, including medium to large rivers with slow to moderate current, big river embayments, Great Lakes coastal wetlands and embayments, shallow lakes, and in deep river impoundments. It has been recorded from mud, sand, and gravel substrates. Preferred substrates have been reported as sand and fine gravel (Parmalee and Bogan 1998) to mud and sand (Clarke 1981). This variability likely reflects the adaptability of this species to particular habitats and a variety of substrates. In Canada, *Q*. *quadrula* is most typically recovered from medium to large rivers in firmly packed coarse gravel and sand to a substrate of firmly packed clay/mud. *Quadrula quadrula* is usually recovered at the surface of the substrate in the “tombstone” position with its posterior margins exposed to the water current and the anterior firmly embedded in the substrate. In both Ontario and Manitoba, it has been recorded historically from larger lakes, but data indicate it has largely been lost from open water habitats due to competition and habitat alteration by dreissenids and agricultural runoff (Schloesser and Nalepa 1994; Pip pers. comm. 2004).

Habitat Trends in Ontario

The invasion of the Great Lakes by the dreissenid mussels began in 1986 (with Zebra Mussels) and resulted in the near extirpation of native mussels from Lake Erie, Lake St. Clair, and the Detroit and Niagara rivers by the mid-1990s. Only isolated communities with reduced species' richness and relatively low abundance still survive in several bays and marshes along the U.S. shore of Lake Erie and in the delta area of Lake St. Clair. As *Q. quadrula* has always been rare in these waters, the loss of these habitats is less significant for this species' overall population than for many other unionids. Interestingly, *Q. quadrula* is the dominant species of unionid in coastal areas of western Lake Erie (US side of the lake), representing >60% of the remnant fauna where unionids have been able to survive the dreissenid mussel invasion (Zanatta *et al.* 2015). Despite similar types of habitat (embayments, drowned rivermouths, and coastal wetlands) on the Canadian side of Lake Erie, *Q. quadrula* is only currently found in Lake Henry (a coastal embayment on Pelee Island, Cairns pers. comm. 2015), Rondeau Bay, and at the mouth of the Grand River. The habitats in coastal embayments of western Lake Ontario are very similar hydrologically to those where *Q. quadrula* is present in western Lake Erie (Zanatta *et al.* 2015). The watersheds of the Lake Ontario coastal embayments where *Q. quadrula* is currently found are: Twenty Mile Creek (Jordan Harbour), Sixteen Mile Creek, Fifteen Mile Creek/Pond, and Cootes Paradise (Hamilton Harbour), and all show signs of heavy nutrient loading (phosphorus) and degraded forest and riparian zone conditions (NPCA 2012).

Mussel communities in the Grand River declined dramatically from a historical total of 32 species to only 17 by the early 1970s. Kidd (1973) blamed this decline on pollution, siltation, and the presence of dams. He found few mussels living below dams or in reservoirs and noted that none of the dams had fishways. He also found that dissolved oxygen concentrations were low and turbidity was high in the lower reaches of the river, most likely due to agricultural runoff. Sewage pollution was probably the major cause of the decline of mussels in this river (Metcalfe-Smith *et al*. 2000b). At the time of Kidd's surveys, only seven of the river's 22 sewage treatment plants (STPs) had secondary treatment in place for the past 10 years, seven others had upgraded from no treatment to secondary treatment during that time, and the remaining eight were in the process of installing treatment facilities for the first time. Twenty-five years later, Metcalfe-Smith *et al*. (2000b) found that the mussel communities of the river had rebounded – most likely in response to significant improvements in water quality and a corresponding increase in the number of warmwater fishes from 16 to 26 species (Coleman 1991). McNichols *et al.* (2012) confirm that 26 mussel species can be found alive in the Grand River as of 2011, including four species listed as Endangered under the Canadian *Species at Risk Act* (SARA). All of the five species which appear to have been lost from the Grand River are also listed as Endangered under SARA. The human population of the watershed almost tripled from 375,000 to 985,000 between 1971 and 2014 and is expected to grow to 1.53 million by 2051 (GRCA 1997, 2014). The percentage of the minimum daily flow consisting of treated effluent from STPs ranged from 1% to 22% in 1993 and the capacity of the river to receive additional wastewater at reasonable cost is in question. The proportion of the Grand River basin in agricultural use increased from 68% in 1976 to 75% by 2014 (GRCA 2014). Row crop farming has increased, and along with it the potential for greater soil erosion and runoff of pesticides and fertilizers. Livestock production has changed, becoming more concentrated and specialized, and focusing on pigs and sheep rather than cattle. There has also been a change in manure handling from solid to liquid, and inadequate management of these liquid wastes has become a problem in some areas (GRCA 1998). The dam at Dunnville near the mouth of the Grand River has been in place since 1829 and is known to be a barrier to upstream fish movement despite the existence of a fishway (Bunt *et al.* 2000). Despite being a barrier to upstream fish movement and being in the middle of the area occupied by *Q. quadrula* in the Grand River, the Dunnville dam does not appear to have any effect on the genetic structure of *Q. quadrula* with no significant differentiation between upstream and downstream subpopulations (Hoffman and Zanatta unpubl. data). It is possible that the dam has not been in place long enough (given the generation time of *Q. quadrula*) for genetic differentiation to become evident.

Habitat trends for the Sydenham River watershed are summarized from Staton *et al*. (2003) and SCRCA (2013). Prior to European settlement, the Sydenham River watershed was 70% forest and 30% swamp. By 1983, 81% of the land area was in intensive agriculture (mainly corn and soybean crops), with only 12% forest and <1% swamp remaining. Sixty percent of the watershed is tile drained. Total phosphorus (TP) levels have consistently exceeded the provincial water quality objective (PWQO) over the past 30 years. SCRCA (2013) suggests phosphorus is stabilizing or improving between 2005 and 2010 in the Lower East Sydenham and Middle East Sydenham sub-watersheds where *Q. quadrula* is recorded. Chloride levels have been relatively low but are slowly increasing – a widespread pattern that has been attributed to the increased use of road salt. Sediment loadings from overland runoff and tile drains are high and the north branch of the river is particularly turbid. Wooded riparian zones, which are important for bank stabilization and interception of nutrients and sediments from overland runoff, are very limited. The human population of the Sydenham River watershed is small (74,000), with 50% rural and 50% living in towns and villages. Despite a modest rate of population growth, all municipalities have upgraded their sewage treatment facilities over the past 30 years. Leakage of nutrients and contaminants from rural septic systems is a significant and ongoing problem, especially in the north branch.

Habitat trends for the Thames River watershed (including Baptiste Creek) are summarized from Taylor *et al*. (2004), UTRCA (2012), and LTVCA (2012). Agriculture is the dominant form of land use in the Thames River watershed, with 75% of the land area in the upper Thames and 88% in the lower Thames in agricultural use. Forested areas have been reduced to 11.3% of the land area in the upper Thames and 10% in the lower Thames. Ten percent of the watershed is classified as urban, with an overall population of 515,640 concentrated in the cities of London, Stratford, and Woodstock in the upper watershed and Chatham in the lower watershed. As the land was cleared, flooding became a serious problem. Three large dams and reservoirs were constructed in the upper watershed between 1952 and 1965. Numerous private dams and weirs have been installed since the 1980s and there are now 177 structures in the upper watershed and 65 in the lower watershed. Dreissenids were discovered in Fanshawe and Springbank reservoirs in 2003 and have since spread downstream where they were found attached to native mussels in 2004 (Morris unpubl. data). Tile drainage dominates 56% of the land in the watershed. Water quality data collected since the 1960s show that concentrations of phosphorus and heavy metals are declining while nitrate and chloride levels are on the rise. The number of pollution spills has risen to 670 reported incidents in 2006 - 2010 from 380 incidents in a timespan five years earlier. The upper Thames River hosts 22 wastewater treatment facilities.

Habitat trends for the Ausable River watershed are summarized from Nelson *et al*. (2003) and ABCA (2013). Mussel habitat in the Ausable River has been dramatically altered over time. Prior to European settlement, 80% of the basin was covered in forest, 19% was in lowland vegetation, and 1% was marsh. By 1983, 85% of the land area was in agriculture (70% in row crops) and only 13% remained in small unconnected woodlots, similar to the current amount (14%). Over 70% of the basin is now in tile drainage and TP concentrations have increased in at least the upper Ausable River, in contrast to *E. coli* levels, which have dropped since 2007. The natural course of the lower portion of the river was destroyed in the late 1800s, when it was diverted in two places to alleviate flooding. The Ausable River has been described as “event responsive”, which means that there are large increases in flow during runoff events following storms. The nearby Sydenham and Thames rivers are more stable in this regard (Richards 1990). There are 21 dams in the watershed that cause sediment retention upstream and scouring downstream. Nitrate levels currently exceed federal guidelines for the prevention of eutrophication and the protection of aquatic life and are slowly rising. Mean total suspended solid concentrations in the lower Ausable River exceed levels required for good fisheries. The Bayfield River falls into the care of the

Ausable Bayfield Conservation Authority and fares worse than the Ausable River in some aspects of habitat trends. The amount of forest cover is less, at 7.2% in 2012, and *E. coli* concentrations are more than double. In terms of pollution, TP levels are lower in the Bayfield River headwaters than the watershed average, similar to the amount of area occupied by agriculture (83%; ABCA 2013).

The Welland River watershed has been drastically altered over the last 200 years with the construction of the Welland Canal. The reach upstream of the canal (including the Oswego River and Coyle Creek) where *Q. quadrula* is currently found is an agricultural watershed with poor surface water quality due to very high nutrient loadings (phosphorus) and degraded forest cover and riparian zones (NPCA 2012). The lower river is largely fed by waters diverted from the Welland Canal (Lake Erie) and the reach of the river from Chippawa, Ontario to the Niagara River has had its flow reversed to enter the power plant diversion canal around Niagara Falls. There are historical records of *Q. quadrula* from the lower reach of the river. The water quality in the lower Welland river is poor due to high nutrient loads (phosphorus), but forest and riparian cover is considered fair (NPCA 2012).

Habitat trends in the other watersheds where *Q. quadrula* are known include the Ruscom River and some small streams in southern Lake Huron (Lambton County). The Ruscom River is highly degraded in terms of nutrient loading (phosphorus) and forest cover, being in nearly a completely agricultural landscape (Watershed Checkup 2015). Cow Creek and Perch Creek/Tefler Diversion Channel in Lambton County are highly degraded, deteriorating small streams in suburban Sarnia; both have poor water quality due to nutrient loading (phosphorus) and have poor to very poor forest and riparian zone conditions (SCRCA 2013).

Habitat Trends in Manitoba

The Red and Assiniboine river drainages flow through what once was tall-grass to mixed-grass prairie. This is one of the most altered biomes on the planet with less than 1% remaining (Meffe and Carroll 1997). European colonization, breaking of the land with the plow, and contemporary industrial-scale agriculture have all contributed to the demise of this biome. The majority of the land within these watersheds is now agricultural, being tilled for grain and oilseed crops, being used for grazing, or urban/industrial. The growing hog industry with high density hog barns being established throughout the watershed presents a potential threat due to nutrient loading as a consequence of runoff, or catastrophic failure of sewage storage systems such as lagoons (Vandean 2003). The effect on the rivers that flow through this landscape cannot be understated. The major current concern is non-point source nutrient enrichment from agricultural runoff (Manitoba Conservation 2000). A second issue is damage to river banks resulting from uncontrolled access of cattle herds to the river. Industrial water removal and usage is also a water quality concern. The most recent issue relating to water quality in Manitoba relates to industrial hog barns. These are operations raising hundreds to thousands of hogs per site annually. The waste produced is of particular concern either due to the potential for catastrophic spills from storage tanks or from runoff after the waste has been applied to the land as a “natural fertilizer”.

The major concern for *Q. quadrula* habitat in Manitoba is water quality. Jones and Armstrong (2001) analyzed existing data on water quality in Manitoba and reported a significant increase in total nitrogen (TN) and TP in the Red River and Assiniboine drainage in the previous 30 years. These increases ranged from 29% to 62% for TP in the Red and Assiniboine rivers, respectively, and from 54% to 57% for TN in the Red and Assiniboine rivers, respectively. These two nutrients are major contributors to nutrient enrichment and loading of waterways that can result in cultural eutrophication and degradation of water quality. Jones and Armstrong's (2001) study was followed by Bourne *et al.* (2002) who focused on the Red and Assiniboine watersheds. The data were reported as TN and TP expressed as tonnes per year due to extreme variation in nutrient loads at weekly, seasonal, and yearly time scales. Bourne *et al.* (2002) found that nutrient enrichment was substantial and primarily resulted from non-point sources, in particular agricultural runoff; they reported that from 1994-2001 the Assiniboine River on average carried 3,682 tonnes per year of TN and 637 tonnes per year of TP near its outflow into the Red River. During this same time period, the Red River on average carried 15,301 tonnes per year TN and 4,269 tonnes per year TP. The result of this nutrient input has been the increasing eutrophication of Lake Winnipeg such that basin-wide algae blooms are visible from space (Lake Winnipeg Implementation Committee 2005). These nutrient inputs and high loads are not limited to the Red and Assiniboine. Graveline *et al.* (2005) report similar situations for the Rat River and Joubert Creek. Corriveau *et al.* (2013) reported that phosphorus and nitrogen inputs into the watershed are most strongly affected by spring runoff and snowmelt.

There is an accumulating body of evidence that freshwater mussels are sensitive to ammonia at levels below what is acceptable by the U.S. Environmental Protection Agency (U.S.E.P.A. 2013) (Augspurger *et al.* 2003; Bartsch *et al.* 2003; Mummert *et al.* 2003). The juvenile stage appears most vulnerable to this exposure, which can result in adult populations persisting, but no recruitment. This could lead to the illusion of a healthy population based on the persistence of adult populations. None of the aforementioned studies specifically tested *Q. quadrula*, or any members of that genus. However, tests revealed juvenile sensitivity to low ammonia concentrations across a variety of species (Augspurger *et al.* 2003) that may be extended to *Q*. *quadrula*. The increasing trajectory of nitrogen loading in Manitoba streams coupled with the apparent absence of recruitment into some of the existing *Q*. *quadrula* populations (see **Manitoba, Abundance** and **Fluctuations and Trends**) is therefore of concern.

BIOLOGY

Life Cycle and Reproduction

Freshwater mussels in the family Unionidae have a complex life cycle that includes a larval stage called a glochidium (pl. glochidia) that is an obligate parasite, most commonly on a fish host. The life history of *Q. quadrula* reflects the general pattern of unionid mussels. During the spawning period, the male releases sperm into the water through the excurrent siphon. Sperm are carried by the water current, taken in by the female through the incurrent siphon, and gills filter the sperm out of the water. In the female, ova are released and held in a specialized area of the gill called the marsupium (pl. marsupia). The sperm that has been filtered from the water is carried into the marsupium where the ova are fertilized. Fertilized ova develop into glochidia and are brooded in the marsupium.

Quadrula quadrula is dioecious. Males and females cannot be distinguished based on external morphology. Females are considered to be a short-term brooders (tachytictic). Reports on the length of the brooding season appear to vary with the locality ranging from May to August in the U.S. (Parmalee and Bogan 1998) and late spring to early summer in Canada (Clarke 1981) and may be temperature dependent. In the Sydenham River, gravid *Q. quadrula* have been found between mid-July and mid-August (Morris unpubl. data). In Manitoba, *Q*. *quadrula* brooding glochidia have not been observed, and ova have never been observed in the marsupium later than mid-June (Carney 2003a, pers. obs.). This would seem to suggest that at least in Manitoba, there may not be successful reproduction every year and that there is a very limited time during which glochidia are available for host infestation.

Quadrula quadrula glochidia are ovate, lack hooks, and measure approximately 80 µm in length and height (Clarke 1981; Morris unpubl. data). *Quadrula quadrula* releases glochidia in lanceolate conglutinates that are approximately 10 mm in length and 3 mm in width at the broad end. The conglutinate (a solid aggregation of glochidia) is typically white and may have sparse randomly distributed dark “dots”. Presumably the fish host is infested when it bites the conglutinate releasing the glochidia, which can then attach to the gills. While not directly observed in *Q. quadrula*, other closely related members of the genus *Quadrula* have been observed using a mantle lure that is hypothesized to assist in attracting their catfish hosts (Seitman *et al.* 2012). There are no data on the fecundity of *Q*. *quadrula*. Haag and Staton (2003) investigated reproductive traits of several mussel species including the congeners *Q. asperata* and *Q. pustulosa* collected from sites in Mississippi and Alabama. For those two species, they report that fecundity increases with shell length. There were differences in maximum fecundity, and fecundity as a function of age, for these two species. *Quadrula asperata* had a maximum fecundity approaching 30,000 developing ova in the gills whereas *Q*. *pustulosa* had a maximum fecundity of approximately 50,000 ova. Haag and Staton (2003) also report differences in age at which reproductive capacity is maximized for these two species. Maximum fecundity for *Q*. *asperata* is reached around 15 years of age while *Q*. *pustulosa* reaches maximum fecundity around 30 years of age (Haag and Staton 2003). Fecundity for both species declines following those maxima. *Quadrula quadrula* likely reaches sexual maturity around the same age as *Q*. *asperata* and *Q*. *pustulosa*, somewhere between three and ten years. The differences reported for these two congeners make it difficult to predict maximum fecundity and age after which fecundity declines for *Q*. *quadrula*. It seems likely that cooler summers and longer, colder winters in Canada could extend time to maturity and would result in fecundity values that are much less than those reported for *Q*. *asperata* and *Q*. *pustulosa* from individuals collected from the southern U.S.

Howard and Anson (1922) identified the Flathead Catfish (*Pylodictus olivaris*) as a suitable host. The Flathead Catfish is not considered to be native to Canada (Scott and Crossman 1973) although four specimens have been caught in Canadian waters of Lake Erie (Crossman and Leach 1979; Gagnon pers. comm. 2005). There are no documented specimens of this species recorded from Manitoba. The Flathead Catfish was the only known host for *Q. quadrula* until Schwebach *et al.* (2002) reported successful transformation of *Q*. *quadrula* glochidia on Channel Catfish (*Ictalurus punctatus*), a species common in both Manitoba and Ontario (Scott and Crossman 1973; Stewart and Watkinson 2004). The time required for successful metamorphosis was 51-68 days with water temperature starting at 13°C and ending at 20°C (Schwebach *et al.* 2002). It seems reasonable to assume that Channel Catfish would serve as a suitable host for Canadian *Q*. *quadrula* populations. Other *Quadrula* species have also been recorded as having catfish species as suitable hosts (Fuller 1974). It is worth noting that the Brown Bullhead (*Ameiurus nebulosus*) has a range that is closest, and almost identical, to that of *Q*. *quadrula* (Lee *et al.* 1980) and it seems likely that this catfish species would be a suitable host, although this has yet to be demonstrated.

Quadrula quadrula is a long-lived species. Carney (2003a,b, pers. obs.) using shell thin sections (Clark 1980; Neves and Moyer 1988) reported individuals from the Assiniboine River in Manitoba up to 64 years old with an average age of 22.1 years (n = 47). Age data specific to Ontario populations are not available but are likely to be consistent with those reported from Manitoba. Therefore the average generation time is estimated to be 20 years.

Physiology and Adaptability

No studies specific to the physiology of *Q. quadrula* are known. As molluscs, they would require a supply of calcium sufficient for shell growth during their lifetime. Juveniles of other unionid species are known to be sensitive to ammonia at levels below current U.S.E.P.A. water quality criteria and it seems likely this sensitivity would extend to *Q*. *quadrula* (see **Habitat Trends in Manitoba**). *Quadrula quadrula* must be able to survive a wide range of temperatures. In winter the rivers in Manitoba would be ice covered with water temperature at or near 0ºC while in summer water temperatures can reach 27ºC.

The range of suitable habitats suggests this species is quite adaptable. Glochidia have been successfully transformed in an experimental situation using Channel Catfish as host. Informal accounts of these mussels being successfully transplanted by commercial interests suggest this species can be transported and transplanted.

Dispersal and Migration

Adult freshwater mussels are largely sessile, typically moving no further than 100 m, and usually much less than that. Therefore the ability of the adult stage to disperse or migrate is highly constrained, although still possible (Schwalb and Pusch 2007). The known hosts of *Q. quadrula* are catfish species that can travel great distances over short time periods (Wendel and Kelsch 1999; Stewart and Watkinson 2004; Butler and Wahl 2011). This would suggest that *Q*. *quadrula* is capable of being dispersed over large distances.

Berg *et al.* (1998) used allozyme variation to show there were high levels of gene flow among distant populations of *Q. quadrula* within the Ohio and Mississippi drainages. Populations in Ontario and Manitoba each lie within drainages that are isolated from each other and have been separated from the Ohio-Mississippi drainages for thousands of years so dispersal between these watersheds is not possible (see **Rescue Effect** for dispersal within drainages connected with the U.S for each DU).

Interspecific Interactions

For information on host fish usage, see **Life Cycle and Reproduction**.

Predators of mussels include fishes, mammals, and birds. Baker (1918) identified Freshwater Drum (*Aplodinotus grunniens*), Lake Sturgeon (*Ascipenser fulvescens*), Pumpkinseed (*Lepomis gibbosus*), Round Goby (*Neogobius melanostomus*), and suckers (*Catostomus* spp.) as fish predators of mussels. Muskrat (*Ondatra zibethicus*) predation can be an important factor that may limit some mussel populations (Tyrrell and Hornbach 1998) and muskrats have been reported to prey upon *Q. quadrula* (Nakato *et al.* 2005). Muskrats have been reported to eat as many as 37,000 mussels annually in a northern Alberta lake (Convey *et al.* 1989; Hanson *et al.* 1989) and may represent a serious threat to endangered species and populations (Neves and Odum 1989). Larval chironomids feeding on mussel tissue can result in the loss of up to 50% of the gill (Gordon *et al.* 1978), affecting both respiration and reproduction, and may represent either parasitism or predation depending on definitions used.

Mussels are parasitized by helminths (Digenea) and mites which may have a detrimental effect on the infected mussel. Mussels can be infected by both adult digeneans and by larval digeneans that include the sporocyst or metacercaria stages. Parasitism by sporocysts can result in sterilization of the infected mussel (Esch and Fernandez 1993). An extensive survey of mussels in Manitoba that included examination for parasites did not show parasitism of *Q. quadrula* by sporocysts (Carney 2003a). A single individual *Q. quadrula* was infected with metacercariae but this stage has not been demonstrated to cause sterility and there was no indication of sterility in that infected individual. A variety of adult helminths also can parasitize mussels. *Aspidogaster conchicola* in the pericardial sac and kidney and *Cotylogaster occidentalis* in the gut have both been reported from *Q. quadrula* (Hendrix *et al.* 1985). Carney (2003a) examined *Q. quadrula* from the Assiniboine River in Manitoba and reported approximately 60% infected with *A. conchicola* and 6% infected with *C. occidentalis*. Mean intensity of infection ranged from 1-71 (mean = 17) and 1-2 for *A. conchicola* and *C. occidentalis*, respectively. Infection by *A. conchicola* may cause damage to the renal epithelium (Williams 1942; Michelson 1970).

Adult mites belonging to the family Unionicolidae are common symbionts in the mantle cavity of mussels and also in the mantle tissue as parasitic larvae, and there may be close evolutionary ties between the two groups that possibly represent examples of coevolution, in some cases (Vidrine 1996). Carney (2003a) reported no *Q. quadrula* collected from the Assiniboine River in Manitoba to be infested with mites.

To date there are no data pertaining to parasitism of *Q*. *quadrula* from Ontario. It does seem likely that what has been reported from Manitoba would also be valid for populations in Ontario, given that the hosts and parasites are present in both regions (Hendrix *et al.* 1985; Carney 2003a).

There has been extensive debate regarding the food and source of nutrition of unionid mussels. Much of this debate has centred on the fact that there are problems in separating what is ingested and what is actually assimilated. As unionids filter water, they feed by sorting food particles in the mantle cavity before ingestion and in the stomach after ingestion (Nichols and Garling 2000). Although the feeding and nutrition of *Q. quadrula* has not been specifically addressed, Raikow and Hamilton (2001) and Christian and Smith (2004) indicate that a variety of mussel species were using similar food resources. The following discussion assumes that what has been reported for other mussel species can be extended to *Q*. *quadrula*.

Available information indicates adult mussels feed upon fine particulate organic matter suspended in the water column (Tanklersley 1996; Ward 1996). However, it is unclear which components of this suspended material are actually used for nutrition (Gatenby *et al.* 1993; Nicholls and Garling 2000). Allen (1914) reported diatoms and algae in the gut of unionids and proposed that algae, protozoa, bacteria, and organic material were the primary sources of nutrition (Allen 1921). Some ingested materials are not necessarily digested but may survive passage through the digestive tract (Churchill and Lewis 1924; Miura and Yamashiro 1990). Imlay and Paige (1972) suggested that unionids derive their nutrition from feeding on bacteria and protozoa. Nichols and Garling (2000) studied the diet of seven mussel species using stable isotope analysis, gut contents, and biochemical analyses and determined there was positive selection of food items in the diet based on the concentration of algae and diatoms in the gut. Although algae and diatoms were selectively ingested and concentrated in the gut, the main source of nutrition was bacteria. However, algae were still a necessary part of the diet by providing essential nutrients (Nichols and Garling 2000).

There is also uncertainty regarding the degree to which mussels feed upon detritus and organic matter within the substrate. Juvenile mussels may use cilia on their foot to feed from the substrate, a method called pedal feeding. Gatenby *et al.* (1993) suggested juveniles fed on algae and silt. Yeager *et al.* (1993) and Yeager and Cherry (1994) have shown that juvenile mussels may feed primarily on bacteria from within the substrate but the importance of this as a source of nutrition for adults is less clear. Adult mussels are capable of filtering suspended particles ranging in size from 0.9 – 250 µm (Silverman *et al.* 1997) suggesting suspended organic materials are important in the diet and nutrition of mussels. However, Raikow and Hamilton (2001) used stable isotope ratios to determine diets of 12 mussel species and suggested their diet was composed of 80% deposited material and 20% suspended material.

If the preceding data apply to *Q. quadrula* the following conclusions regarding feeding may be drawn. Feeding on interstitial material may be the primary source of nutrition for juveniles. Adults may also be feeding from the substrate as well as upon organic materials suspended in the water column. Bacteria appear to be the primary source of nutrition with algae supplying many essential elements in the diet. Clearly there is much more research required to clarify the food habits and nutrition of unionid mussels.

POPULATION SIZES AND TRENDS

Ontario

<u>Sampling Effort and Methods</u>

Historical surveys

Approximately 80% of the information on the historical distribution of *Q. quadrula* in Ontario is based on either museum specimens or presence-absence data. There is little if any information on sampling method, search effort, numbers of sites visited where the species did *not* occur, or even whether the animals were dead or alive when collected. Data on relative abundance (Catch-Per-Unit-Effort or CPUE) are available from timed-search surveys of ten sites on the Sydenham River in 1985 (Mackie and Topping 1988) and 16 sites on the same river in 1991 (Clarke 1992). Two of the sites surveyed by Mackie in 1985 were re-surveyed 12-13 years later by Metcalfe-Smith *et al.* (1998b, 1999), so these data can be compared. Three of the sites surveyed by Clarke in 1991 were also re-surveyed in 1997-98, but *Q. quadrula* was never found at any of these sites. Kidd (1973) surveyed 68 sites on the Grand River in 1970-72 and 14 of these sites were re-surveyed 25 years later using a similar sampling effort (Metcalfe-Smith *et al.* 2000a). Nine sites were in the upper and middle reaches of the river, which is outside the species' distribution in the system, but five sites were in the lower reaches and can be compared.

Modern Surveys

Surveys conducted between 1995 and 2015 within the range of *Q. quadrula* in Ontario have been either semi-quantitative (timed-searches) or quantitative (quadrat surveys). The same sampling methods and efforts were used throughout and are described below. The only exception was the 1995 survey on the Grand River, which used a lower sampling effort than other surveys (see Metcalfe-Smith *et al.* 2000a).

Timed-search surveys:

In rivers, surveys were conducted using an intensive timed-search technique developed by Metcalfe-Smith *et al.* (2000a). Briefly, the riverbed is visually searched by a team of three or more persons using waders, polarized sunglasses, and underwater viewers for a total of 4.5 person-hours (p-h) of sampling effort. Where visibility is poor, searching is done by feel. The length of reach searched varies depending on river width, but is generally 100-300 m. Live mussels are held in the water in mesh diver's bags until the end of the search period when they are identified to species, counted, measured (shell length), sexed (if sexually dimorphic), and returned to the riverbed. Over the past 20 years, such surveys have been conducted in the Grand, Thames, Sydenham, Ausable, Maitland, Welland, Bayfield, Saugeen, Moira, Trent, and Salmon rivers and several smaller tributaries to Lake Ontario, Lake Erie, and Lake Huron by several different researchers. Between 2011 and 2015, the Ontario MNRF has surveyed 40 Lake Ontario coastal wetlands and embayments using visual/tactile and clam rake searches (12 hours each; Reid *et al.* 2014).

In Lake St. Clair, searches at waters depths greater than 2 m were conducted by two SCUBA divers for a total effort of 0.5 p-h whereas searches at depths less than 2 m were conducted by three people using mask and snorkel for a total of 0.75 p-h (Zanatta *et al.* 2002). At sites where live mussels were found (all were shallow), snorkel searches were extended to a total of 1.5 p-h. Additional intensive surveys were conducted by McGoldrick *et al.* (2009), Morris (unpubl. data), and Zanatta *et al.* (2015) in 2011 with similar amounts of effort to what was used by Zanatta *et al.* (2002).

Quantitative surveys:

Surveys in rivers employed an intensive quantitative sampling technique that would allow the generation of precise estimates of demographic variables such as density, size class frequencies, and recruitment levels. Strayer and Smith (2003) is the standard guide for monitoring freshwater mussels. The quantitative sampling technique employed in wadeable Ontario rivers is summarized below:

Sampling employed a 2-person search team and a data recorder and required approximately two days of work per site. At each site, roughly 400 m^2 of the most productive portion of the reach (usually a riffle) was selected for sampling; because the most productive portions are chosen, caution should be used when extrapolating to estimate subpopulation sizes for entire watersheds. Quantitative sampling was conducted using 1 m^2 quadrats and a systematic sampling design with three random starts. The area to be sampled was divided into blocks of equal size (5 m long × 3 m wide) and each block was further divided into 15 – 1 m^2 quadrats. The same three randomly chosen quadrats were sampled in each block; thus, 20% of the 400 m^2 area was sampled at each site. Each quadrat was searched by two people until all live mussels had been recovered (~ 8 person-minutes). All embedded stones (except large boulders) were removed and the substrate was excavated to a depth of 10-15 cm in order to obtain juveniles (young mussels are known to burrow deeply in the substrate for the first three years of life). All live mussels found in each quadrat were identified, counted, measured, sexed where possible, and returned to the riverbed. Several habitat variables (e.g., depth, current velocity, substrate composition) were also measured. Quantitative surveys have been conducted on the Sydenham, Thames, and Ausable rivers and portions of the Grand River (Bouvier and Morris 2010). Note that the habitat for *Q. quadrula* in the lower Grand River is not especially suitable for this type of survey.

A different type of quantitative survey was conducted in the delta area of Lake St. Clair. At each site, sampling was performed by several (usually three) 2-person teams, with each team consisting of a snorkeler and a helper to carry the gear and mussels. Each snorkeler swam until a mussel was seen, then surveyed a 65 m^2 circular area around the mussel and collected any other live mussels found. Each team surveyed ten such circle plots. All live mussels were identified, counted, measured, sexed, and returned to the lake bottom. Methods are described in detail in Metcalfe-Smith *et al.* (2004) and McGoldrick *et al.* (2009). Such surveys were conducted in 2001 and 2003 and to a limited extent in 2004 and 2011 (Morris unpubl. data).

A new semi-quantitative approach for surveying coastal areas of the Great Lakes has been used in recent surveys (Minke-Martin *et al.* 2015; Zanatta *et al.* 2015). This method uses a 2 p-h timed search in a 0.5 ha area. This method was used in 2011 surveys of the St. Clair Delta and in the 2014 surveys of the lower Grand River (below Dunnville dam) and coastal embayments in western Lake Ontario.

<u>Abundance</u>

Quadrula quadrula no longer occurs in the open (deep offshore) waters of the Great Lakes and connecting channels, so there are no abundance data to discuss for these waters (see **Fluctuations and Trends**). *Quadrula quadrula* appears to be functionally extirpated from Lake St. Clair (only one individual found in last 15 years despite extensive surveys). A new record from Pelee Island suggests that it is not completely gone from the Canadian side of western Lake Erie (Cairns pers. comm. 2015) as do the fresh shells from Rondeau Bay (Reid *et al.* 2016). New discoveries in coastal embayments in western Lake Ontario suggest fairly large population sizes (>150 live animals collected since 2010), but no density information is currently available and the area of occupancy in these coastal embayments is fairly small (Minke-Martin *et al.* 2015; Morris unpubl. data). Catch-per-unit effort estimates for Jordan Habour (3.4/p-h) suggest a relatively high density in comparison to the large subpopulation sizes in the Grand, Thames, and Sydenham rivers; however, the area of occupancy of these coastal areas is relatively small.

In lotic systems, the species presently occurs in the Grand River (Lake Erie drainage), the Welland River watershed (Niagara River drainage), in the Lake St. Clair drainage in the Thames River watershed (including McGregor Creek and Baptiste Creek), the Sydenham River (including the North Branch/Bear Creek) and Ruscom River, the Ausable River (southern Lake Huron drainage), and some other southern Lake Huron tributaries of southwestern Ontario. The vast majority (estimate >75% of the total population) of *Q. quadrula* in Ontario appear to be in the Thames, Sydenham, and Grand rivers. Timed-search surveys were conducted at 113 sites on these rivers between 1997 and 2004 using

4.5 p-h sampling effort/site. Results of such semi-quantitative surveys can be used to compare the relative abundance of *Q. quadrula* populations among rivers (Table 3). *Quadrula quadrula* appears to be abundant at only three of the sites surveyed in the Welland River watershed, but where present in the Welland, CPUE is similar (4.6 p-h) to the rivers where *Q. quadrula* is found at high density in southwestern Ontario (Bouvier and Morris 2010; DFO unpubl. data). The population in the Ausable River appears to be small, with only 18 live specimens found. If CPUE is compared using only those data from sites in the occupied reaches of each river, population density is greatest in the Grand River (CPUE = 6.9 specimens/p-h), followed by the Thames (2.9), Sydenham (2.0), and Ausable (1.0). However, DFO personnel completed timed-search (4.5 p-h) surveys at each of ten sites on the lower Thames River in 2005 and found 3134 living specimens and 20 species, of which 422 were *Q. quadrula* (Table 3). The species was the second to third most abundant at virtually all sites (Morris and Edwards 2007). The CPUE for this species in the survey was 9.6 specimens/p-h, which is over three times the CPUE reported in previous surveys (2.9 specimens/p-h). It appears that the Thames River may have the largest population of *Q. quadrula* in southwestern Ontario.

Table 3. Relative abundance of *Quadrula quadrula* from four southwestern Ontario rivers.

River	# sites surveyed	# live mussels collected (all species)	Frequency of occurrence of *Q. quadrula* (% of sites)	Relative abundance of *Q. quadrula* (% of community)	Catch-per-unit-effort for *Q. quadrula* (#/person-hour)	Year(s) of surveys
Ausable	25	5013	16%	0.4%	0.2/p-h	1998[2], 2002[3], 2004[3]
Sydenham	18	2357	50%	3%	1.0/p-h	1997-98[1,2], 2003[3]
Thames	41 10	4906 3134	17% 100%	2% 13.5%	0.5/p-h 9.6/p-h	1997-98[1,2], 2004-2005[4]
Grand	29 5	1903 74	17% 80%	8% 55%	1.1/p-h 4.1/p-h	1997-98[1,2], 2004[3] 2011[5]

[1]Metcalfe-Smith *et al.* (1998b); [2]Metcalfe-Smith *et al.* (1999); [3]Metcalfe-Smith *et al.* (unpubl. data); [4]Morris and Edwards (2007). [5]Minke-Martin *et al.* (2015)

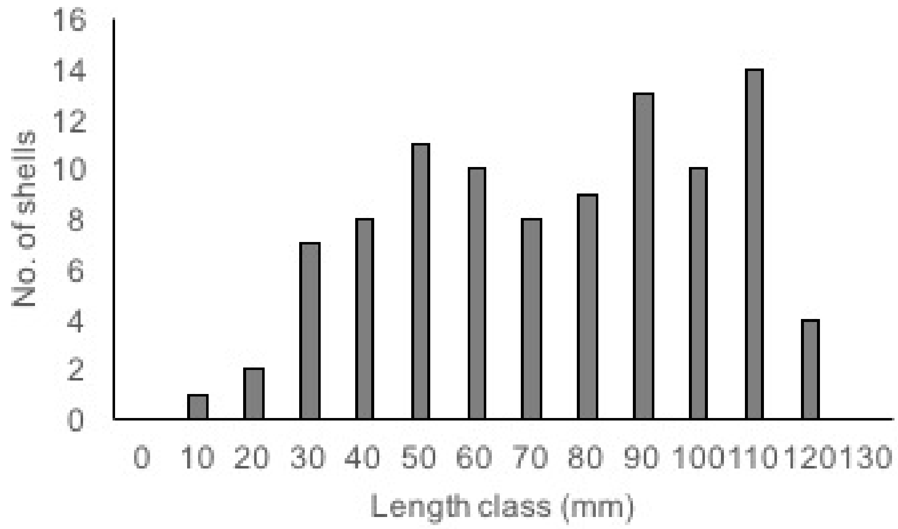
Catch-per-unit effort data obtained from timed-search surveys provide information on *relative* population density. True density estimates are only available for the Ausable, Grand, Sydenham, and Thames rivers. Table 4 presents density estimates for these rivers and extrapolates population sizes based on these densities and the biological area of occupancy (average stream width x reach length occupied) – but see caution in **Ontario – Modern Surveys**. The Thames and Sydenham rivers likely have populations over one million animals, while the Ausable is at least an order of magnitude smaller in population size. The Grand River only had a single site surveyed using quadrats where *Q. quadrula* was present (and the populations were qualitatively estimated to be more dense further downstream), thus the population size is likely underestimated (Bouvier and Morris 2010; Morris unpubl. data).

Shell length was measured for every live mussel collected during the above-described surveys. Size frequency distributions for live *Q. quadrula* collected during recent timed-search surveys on the Grand, Ausable, Sydenham, Thames, Welland, and Ruscom rivers are presented in Figures 8-13. Where possible, comparisons were made in size class distributions between data collected prior to the original status report and data collected since (e.g., after 2006). The data clearly show recent recruitment in all of these rivers. The only exception to this pattern of recent recruitment was in Jordan Harbour on Lake Ontario, which showed a size distribution skewed towards an older population, with little evidence of recent recruitment (Figure 14); however, excavations of the substrate were not done in Jordan Harbour.

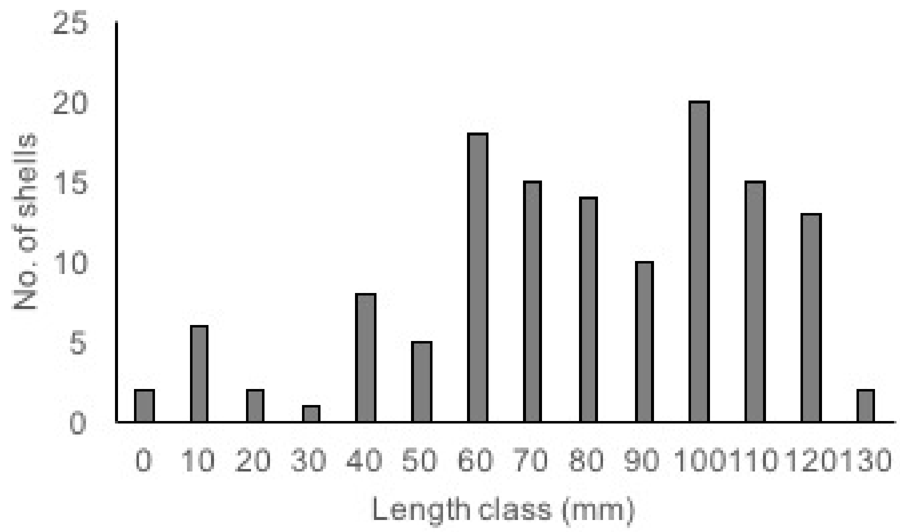
Table 4. Current population estimates for the Great Lakes - Upper St. Lawrence population of *Quadrula quadrula* for sites with density estimates using quadrat methods. Note: ** indicates that density estimates are only available from a single site and therefore Standard Error (SE) is not available. Modified from Bouvier and Morris (2010) and from Morris (unpubl. data) from the Sydenham River.

Population	Average Total Unionid Density (#/m^2) (SE)	*Q. quadrula* Density (#/m^2) (SE)	Area of Occupancy (m^2)	Estimated Population Size
Ausable River	2.065 (±1.945)	0.135 (±0.121)	712,637	~9977 – 183,005
Grand River**	2.253**	0.030**	10,827,716	~324,831
Sydenham River[1]	5.826 (±1.587)	0.370 (±0.092)	5,800,645	~1,612,579 – 2,679,898
Thames River	5.045 (±0.748)	0.508 (±0.187)	11,733,405	~3,765,144 – 8,144,262

[1] Morris unpubl. data



A)



B)

Figure 8. Size class distribution for live *Quadrula quadrula* collected from the Grand River (A) in 1997 (n = 97) and (B) since 2008 (n = 131) (Morris unpubl. data). Specimens <50 mm are considered juveniles and indicative of recent recruitment.

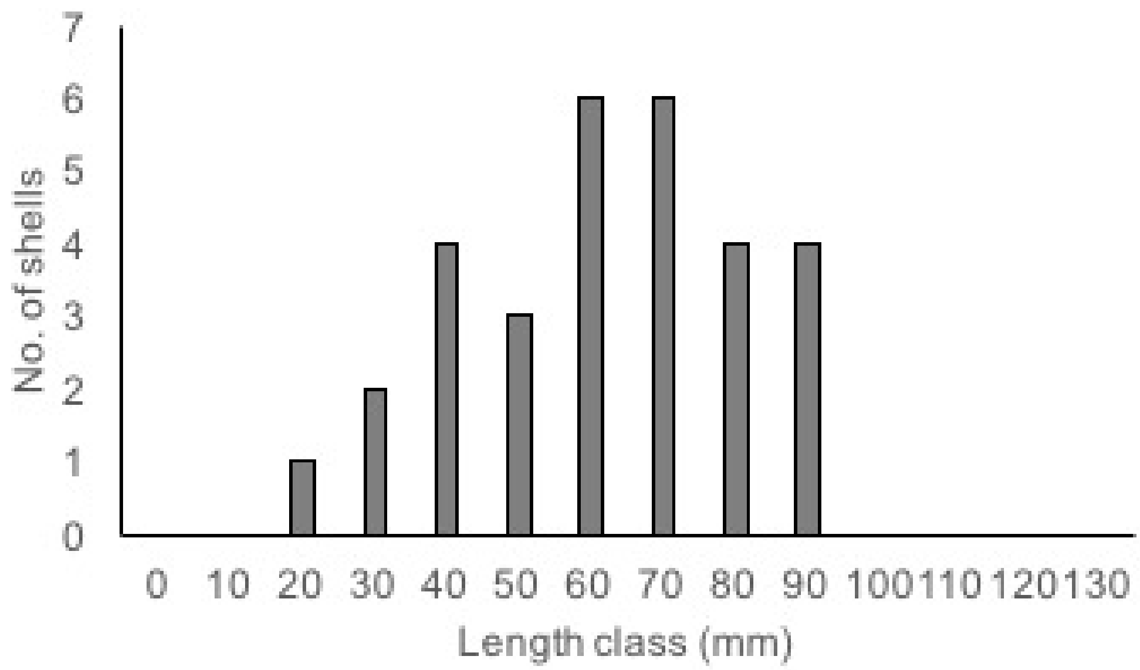
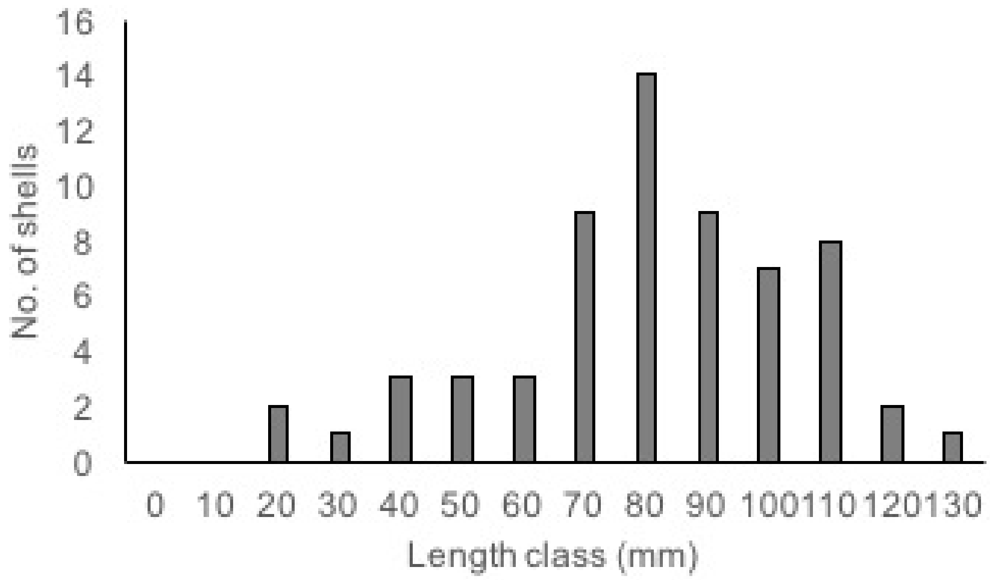
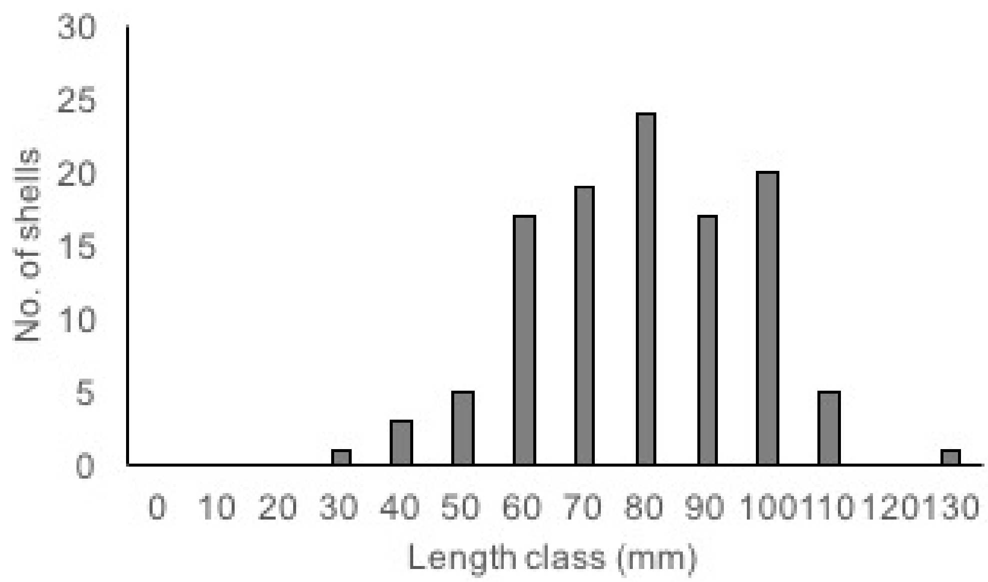


Figure 9. Size class distribution for live *Quadrula quadrula* collected from the Ausable River from 2002 to 2013 (n = 30) (Morris unpubl. data). Specimens <50 mm are considered juveniles and indicative of recent recruitment.

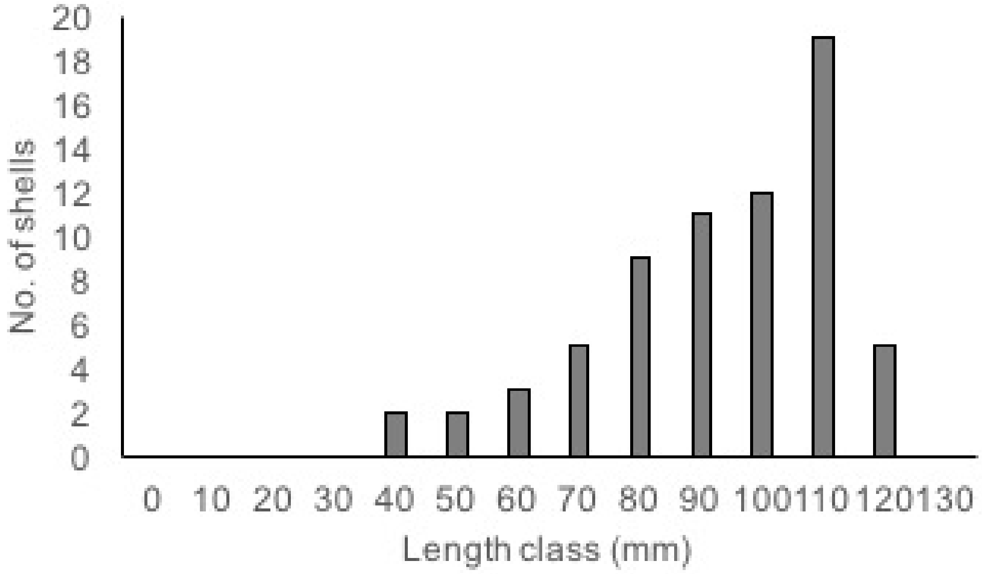


A)

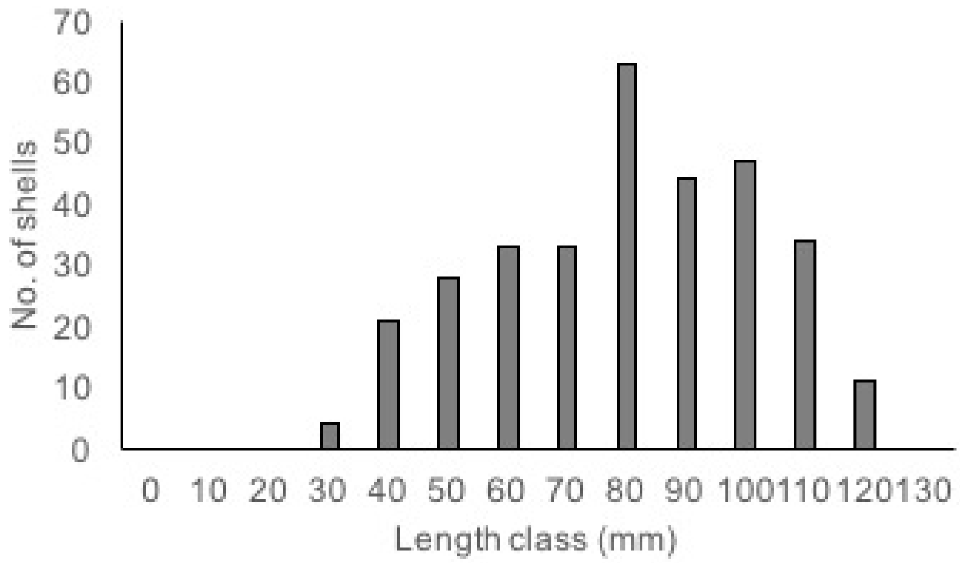


B)

Figure 10. Size class distribution for live *Quadrula quadrula* collected from the Sydenham River (A) in 1997 and 1998 (n = 62) and (B) from 2008 to 2011 (n = 112) (Morris unpubl. data). Specimens <50 mm are considered juveniles and indicative of recent recruitment.



A)



B)

Figure 11. Size class distribution for live *Quadrula quadrula* collected from the Thames River (A) in 1997 and 1998 (n = 68) and (B) from 2005 to 2008 (n = 318) (Morris unpubl. data). Specimens <50 mm are considered juveniles and indicative of recent recruitment.

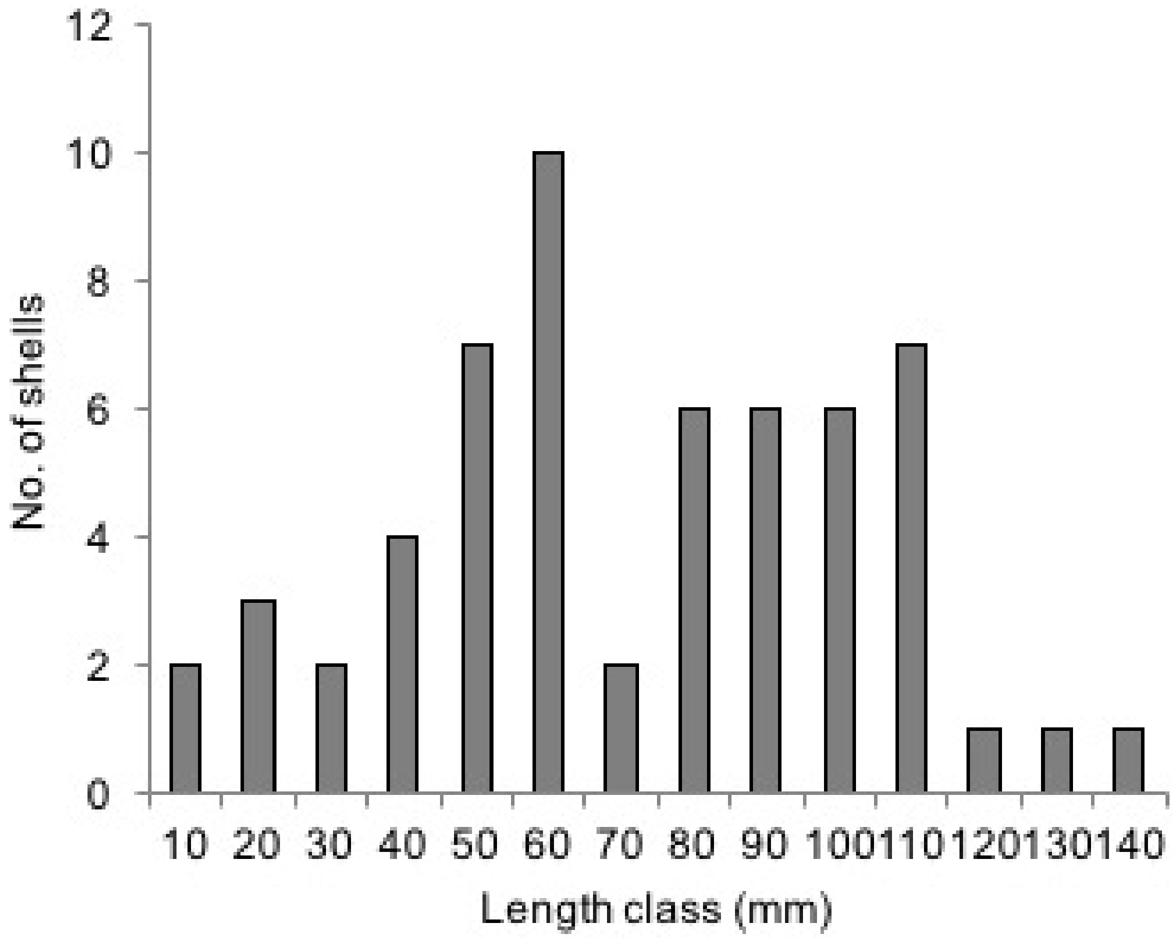


Figure 12. Size frequency distribution for live *Quadrula quadrula* (n = 58) collected during timed-search surveys in the Welland River, Ontario in 2014 (data collected for this report). Specimens <50 mm are considered juveniles and indicative of recent recruitment.

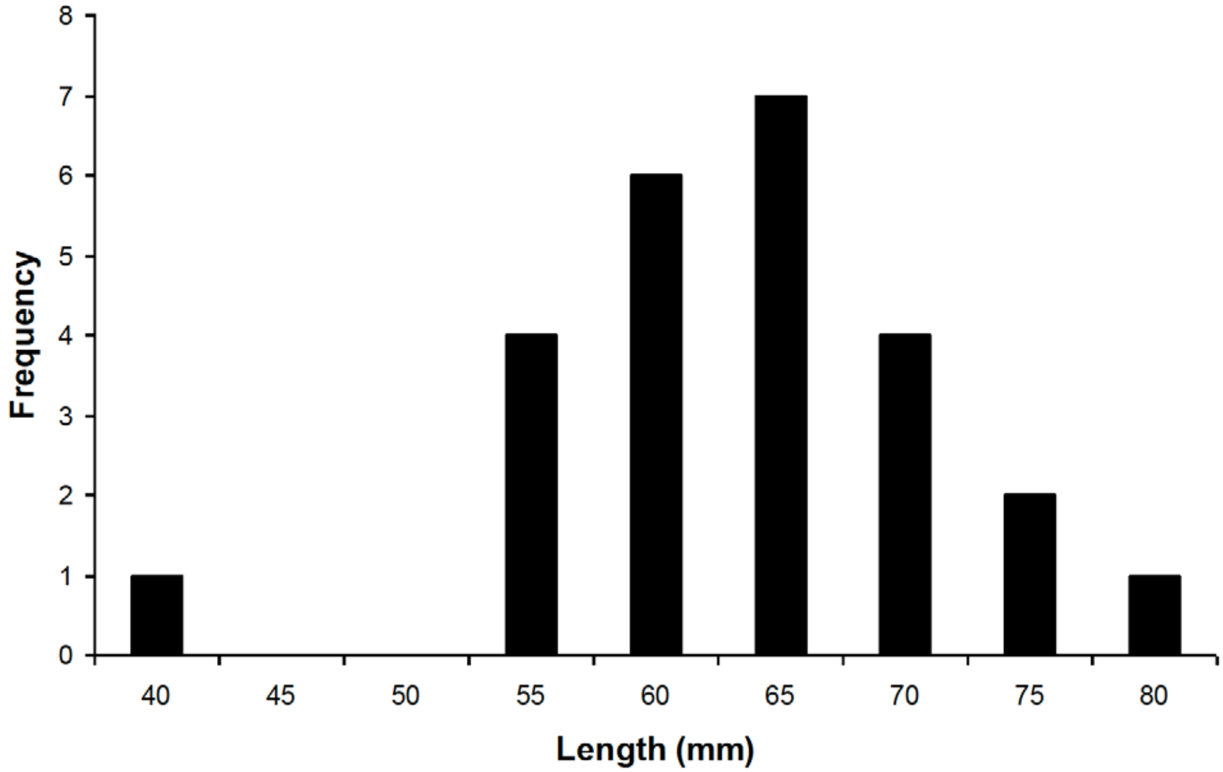


Figure 13. Size frequency distribution for live *Quadrula quadrula* (n=26) collected during timed-search surveys in the Ruscom River, Ontario in 2010 (Morris unpubl. data). Specimens <50 mm are considered juveniles and indicative of recent recruitment.

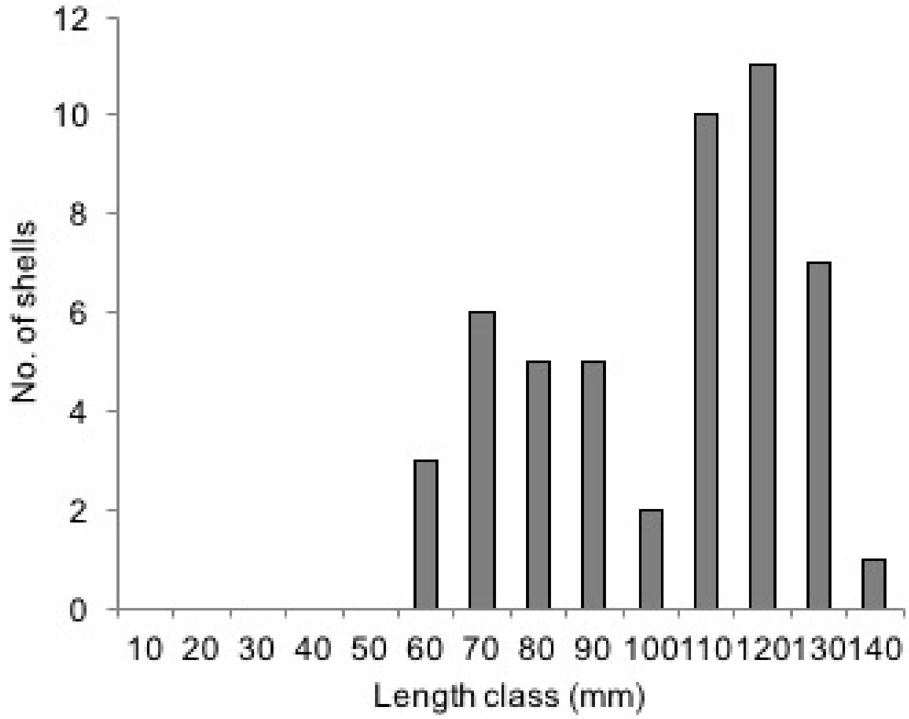


Figure 14. Size frequency distribution for live *Quadrula quadrula* (n = 50) collected during timed-search surveys in Jordan Harbour, Ontario in 2014 (data collected for this report). Specimens <50 mm are considered juveniles and indicative of recent recruitment. Data may be biased towards larger animals as only timed search surveys were conducted (without excavations of the substrate).

Fluctuations and Trends

Quadrula quadrula appears to be extirpated from open waters of the Canadian side of Lake Erie (with the exception of the newly discovered animals in Lake Henry on Point Pelee and fresh shells at Rondeau Bay), Lake St. Clair (one live animal in 2005, none in surveys in 2011-2012), and the Detroit and Niagara rivers due to impacts of the Zebra and Quagga mussels; however, it was always extremely rare in these waters. For example, there are some scattered records from Canadian waters of Lake Erie, but only for shells. These records include four from Rondeau Bay (1894, 1961, one with no date, and 2015), five from Pelee Island (1962, 1978, 1992, 2004, and 2015) and one from Port Maitland at the mouth of the Grand River in 1936. *Quadrula quadrula* was found at only one of 29 sites surveyed in the offshore waters of Lake St. Clair in 1986 prior to the Zebra Mussel invasion and represented 0.7% of the 281 mussels collected from all sites (Nalepa *et al.* 1996). Similarly, only one of 1279 live mussels (0.08%) collected from 13 sites throughout the Detroit River in 1982-83 was *Q. quadrula* (Schloesser *et al.* 1998). Zanatta *et al.* (2002) collected 2356 live mussels from 95 sites in the nearshore waters of Lake St. Clair between 1999 and 2001, and only one mussel (0.04%) was a *Q. quadrula* (collected in 1999 at the mouth of the Thames River). Nevertheless, even at low population densities, because of their enormous size these waterbodies must have once supported a substantial proportion of the Ontario population of this species but it has not been found in the lake despite continued work through the 2000s (McGoldrick *et al.* 2009) and 2011 (Morris unpubl. data). In Lake Erie, except for fresh shells at Rondeau Bay and recent findings of live animals in Lake Henry on Pelee Island, *Q. quadrula* has not been observed on the Canadian side of Lake Erie since the establishment of dreissenid mussels. *Quadrula quadrula* in the coastal embayments of western Lake Ontario was unknown prior to 2010, thus there are no data on trends. Despite heavy dreissenid mussel presence in Lake Ontario, the *Q. quadrula* in the coastal embayments remain and are relatively free of heavy dreissenid mussel infestation. These coastal habitats appear to be similar to those on the U.S. side of western Lake Erie (Zanatta *et al.* 2015).

Catch-per-unit-effort for *Q. quadrula* in the Sydenham River was 1.4/p-h over ten sites in 1985 (Mackie and Topping 1988), 0.12/p-h over six sites in 1991 (Clarke 1992), and 1.1/p-h over 18 sites in 1997-98 and 2003 (Metcalfe-Smith *et al.* 1998b; Metcalfe-Smith and Zanatta 2003). Two sites were surveyed in both 1985 and 1998; CPUE for a site on the East Sydenham was 8.0/p-h in 1985 and 1.1/p-h in 1998, and CPUE for a site on Bear Creek was 5.0/p-h in 1985 and 1.3/p-h in 1998 and was anecdotally still abundant in 2010 (Morris unpubl. data). These data suggest that *Q. quadrula* may have been declining in abundance in the system but this is inconsistent with evidence showing that the species is encountered more frequently now than in the past (see **Search Effort and Distribution of *Quadrula quadrula* in Ontario**).

Kidd (1973) collected 0, 0, 0, 1, and 9 *Q. quadrula* from five sites on the lower Grand River in 1971-72 whereas Metcalfe-Smith *et al.* (2000a) collected 0, 0, 1, 57, and 27 specimens from the same sites 25 years later. Kidd (1973) found that the number of mussel species living in the river had declined dramatically from historical counts – only six of 25 species previously reported from the lower reaches were still present in the 1970s. This decline was attributed to siltation, the creation of dams and reservoirs, and especially sewage pollution. *Quadrula quadrula* was one of the species that had survived. Populations of most mussel species, including *Q. quadrula*, have since rebounded due to significant improvements in water quality.

There are no data available for determining if there have been changes in population size over time for *Q. quadrula* in the Ausable or Thames rivers, although the recent data on 10 sites in the lower Thames suggests a healthy population (Figure 11).

Overall, the population size appears stable in the Great Lakes - Upper St. Lawrence (or Ontario) DU. The large majority of the population for this DU appears to reside in three rivers: the Thames, Sydenham, and lower Grand with millions of animals estimated. Density estimates made over the last 15 years and recent size class data indicate that these are all apparently stable and relatively healthy; however, the longevity of this mussel could also mask abundance trends. Less can be elucidated about subpopulation sizes or trends in most of the other currently occupied waterbodies, but several of these may also be quite large and apparently stable (e.g., the Welland River watershed, and coastal wetlands and embayments in western Lake Ontario) with evidence of recent recruitment.

Rescue Effect

While Ontario subpopulations of *Q. quadrula* are isolated from one another and from subpopulations in the U.S., there is a possibility of rescue. Even though subpopulations in tributaries to the lower Great Lakes on both sides of the Canada/U.S. border may once have been connected by those in Lake Erie and Lake St. Clair, native mussels have been virtually extirpated from the lakes due to impacts of Zebra and Quagga mussels, making connections difficult. But, given that the catfish hosts are highly vagile (Wendel and Kelsch 1999; Butler and Wahl 2011) and that there are several large subpopulations (e.g., coastal areas of western Lake Erie, Maumee River, Belle River, Saginaw River) remaining on the U.S. side of Lake Erie (Zanatta *et al.* 2015) and Lake Huron (Zanatta unpubl. data), rescue could potentially occur although intervening areas may be unsuitable for both mussel and host. Recent genetic work (Paterson *et al.* 2015; Hoffman and Zanatta unpubl. data; Mathias and Zanatta unpubl. data) has shown a high degree of recent gene flow (N_m>1, see: **Population Spatial Structure and Variability**) between US and Canadian populations although there also was evidence of limited gene flow between subpopulations in coastal areas of western Lake Erie, the lower Grand River, the Welland River, and embayments in western Lake Ontario.

Manitoba

Sampling Effort and Methods

Historical surveys

All the historical information for the distribution of *Q. quadrula* in Manitoba consists of either museum specimens or presence-absence data (e.g., Clarke 1973). Data on sampling methods and search efforts are unavailable. Sites where *Q*. *quadrula* did not occur can be determined by comparison with sites from which other species were recovered. However, there are no data on sites that were examined from which no mussel species were recovered.

Modern Surveys

Recent surveys in Manitoba can be divided into two time periods. There are those that occurred from the early 1990s to about 2005, and those that occurred after 2011, with a single mussel relocation effort in Brandon in 2007. The goals of these surveys differed, as did the collecting methods and efforts. This makes comparisons difficult.

In 1992, under the direction of Dr. Terry Dick from the University of Manitoba, Carney and colleagues (unpubl. data) surveyed four sites on the Assiniboine River and one site on the Roseau River to provide a preliminary determination of which mussel species were present. *Quadrula quadrula* was recovered from three sites on the Assiniboine and from the single site on the Roseau River. This undertaking is best considered as qualitative because of different times spent searching involving different numbers of people (range from 1-5). Search in all cases was by feel. The effort expended varied from a low of 2 p-h to a high of 10 p-h (Table 5).

Table 5. Relative abundance of *Quadrula quadrula* from the Assiniboine River in Manitoba from surveys based on timed searches.

Source	# sites surveyed	# live mussels collected (all species)	Frequency of occurrence of *Q. quadrula* (% of sites)	Relative abundance of *Q. quadrula* (% of community)	Catch-per-unit-effort for *Q. quadrula* (#/person-hour)
Carney 1992 unpubl.	3	540	100%	11%	1.26
Watson *et al.* 1998	18	75	27%	8%	0.66
Pip 2000	302	n/a	0.006%	n/a	n/a
Carney 2003a (below Portage Diversion)	6	239	33%	18%	1.5
Carney 2003a (above Portage Diversion)	16	316	6%	0.3%	0.025
Watkins 2003 unpub.	6	485	33%	6.19%	1.54
Watkins and Carney 2004 unpubl.*	1	n/a	100%	n/a	2

*This survey was targeted to *Quadrula quadrula* and no other species were recorded. Numerous individuals of several species were recovered.

Scaife and Janusz (1992) investigated the viability of a commercial shell harvest from the lower Assiniboine River. They reported the results of a survey over 21 km using randomly placed 1 m^2 quadrats and SCUBA, found 62 *Q. quadrula* from 24 of 120 quadrats, and an average density of 0.52/m^2.

Watson *et al.* (1998) undertook a study to determine the distribution and abundance of freshwater mussels in the lower Assiniboine River and 15 of its tributaries. Sampling sites on the Assiniboine between Portage la Prairie and Winnipeg were selected following a stratified sampling design (Watson *et al.* 1998). Eighteen transects across the river were sampled using a mini bullrake. Collecting involved raking the bullrake across the substrate five times at each of five equidistant points across the river. Tributaries were sampled by sight, by feel, or by using the bullrake, depending on water clarity and depth. Thirty person-minutes were spent searching at each site. They (Watson *et al.* 1998) recovered a total of six live *Q. quadrula* from five of the 17 sites surveyed on the Assiniboine River, with empty valves recorded at one additional site. There was no evidence of *Q*. *quadrula* from any of the 167 sites surveyed in tributaries of the Assiniboine.

Pip (2000) undertook a very large survey of freshwater molluscs in Manitoba in 1998 to compare with results from previous surveys. She resurveyed 302 of 312 sites surveyed about 20 years previously. Although the focus of these surveys was on gastropods, there were results for mussels, in particular, a decline from four to two in the number of sites from which *Q. quadrula* was recorded. This decline occurred in the 20 year interval from the previous survey. Unfortunately no collecting methodology, site information, or abundance data were reported (Pip 2000).

Carney (2003a, 2004a) collected mussels from sites along the length of ten different rivers in Manitoba. The purpose was to collect tissue for DNA analyses, determine the reproductive status and demographics, and investigate the parasites of the mussels. Permits restricted the number to no more than 20 individuals of any one species from any single site, excepting one reference site on the lower Assiniboine. Once 20 individuals of a species had been collected that species was no longer collected. As a result, collecting effort on common species would stop and the focus would be on the less common species. Nonetheless, time spent searching was noted so effort in terms of p-h could be determined. At no site was the limit for *Q. quadrula* reached and in fact, effort was focused on this species due to its rarity and absence of evidence for successful production of glochidia.

Carney (2004b) reported the results of a quantitative survey of mussels in the Assiniboine River through Spruce Woods Provincial Park. A total of 620 1 m^2 quadrats at 49 transects were searched with no *Q. quadrula* being recovered. The average density for all species in this study was estimated to be 0.08/m^2.

Quadrula quadrula from the Bloodvein River, which drains into the east side of Lake Winnipeg, was reported in 2004 (Staton pers. comm. 2005). A survey in 2010 did not find this species in the Bloodvein, but there is no information on methods. Three sites on the Brokenhead River near its mouth on Lake Winnipeg surveyed in 2013 had between one and three live *Q. quadrula* recorded, with numbers increasing with distance from the lake. Because there is no information on effort or methods, it is difficult to reach any conclusions on this apparent trend. A more extensive survey in July 2015 yielded 30 live animals (Watkinson pers. comm. 2015). There have been no historical surveys of mussels in this, or other rivers, from the east side of Lake Winnipeg. An additional site was also discovered in the Wanipigow River in 2015. Three live animals were found here, but no information on survey methods are currently available.

In 2007, a mussel relocation project was undertaken in association with bridge construction over the Assiniboine River at Brandon. Four adult individuals were discovered. It had been thought that the historical range in the Assiniboine River, which extended to the Shellmouth Dam (northwestern-most dot in Figure 6), had contracted to the Portage Diversion (directly north of Portage la Prairie, Figures 6 and 7). The discovery of *Q. quadrula* in Brandon, well above the Portage Diversion, indicates this species is still present in the upper Assiniboine and its distribution may extend to its historical range. Confirmation of this, and assessment of any subpopulations that exist above the Portage Diversion, would require considerable effort due to the size, turbidity, and current of the Assiniboine River. Fisheries and Oceans Canada conducted a mussel identification workshop on the Assiniboine River in 2009 that recorded a single live *Q. quadrula* at a site where it had been previously collected.

New surveys in Manitoba began in 2011 on the LaSalle River, a tributary of the Red River, near La Barriere Park, under the direction of DFO (Morris pers. comm. 2015); *Quadrula quadrula* was recorded in 2011 (1 individual), 2013 (3 individuals), and 2014 (29 individuals). No information on effort or methodology is currently available. Cooks Creek, a tributary of the Red River near Selkirk, was surveyed in 2013 and 2014. Seven live *Q. quadrula* were recorded in 2013 and a single individual was recorded in 2014 (Morris pers. comm. 2015). The Rat River, also a tributary of the Red River, had *Q. quadrula* recorded in 2013 with a single individual being observed (Morris pers. comm. 2015). This was recorded near St. Pierre Jolys, which is quite a distance upstream from the confluence with the Red River. Due to dangerous sampling conditions, no live individuals have been recovered from the Red River itself, although fresh shells were reported in 2013 (Morris unpubl. data). These data are encouraging; however, these sites fall within the existing EOO for this species, but do increase the IAO compared to the previous COSEWIC report.

Abundance

Estimating the density of *Q. quadrula* in Manitoba is possible only for the lower Assiniboine River using the results reported by Scaife and Janusz (1992). As described previously, they recovered 62 *Q*. *quadrula* from 24 of the 120 quadrats using SCUBA. This would result in an average density of 0.52 *Q*. *quadrula*/m^2. This should be considered an upper bound inasmuch as Carney (2004b) reported an average density of 0.08/m^2 for all mussel species from a larger survey on a different shallower stretch of the Assiniboine River sampled by wading from shore to shore.

If 0.52/m^2 is accepted as an approximate upper estimate of the density of *Q. quadrula,* then the subpopulation size within this stretch of the Assiniboine River can be estimated. The biological area of occupancy (AO), based on the length of the occupied reach (150 km) times the mean width of the reach (50 m), for this stretch of the Assiniboine River is 7.5 km^2. A density of 0.52 per m^2 yields an estimated total subpopulation of 3,900,000 individuals in this river. This should be considered an extreme upper limit because long stretches of the Assiniboine have a substrate of drifting soft sand, unsuited as mussel habitat as reflected in the much lower density values for all species reported by Carney (2004b) in such stretches. Furthermore, Watson *et al.* (1998) only recovered *Q*. *quadrula* from 27% of sites along the Assiniboine River. This many samples along the Assiniboine without *Q*. *quadrula* clearly indicates that this species does not occur along the entire length of this river. Using this value (27%) to calculate the proportion of the river suitable for *Q*. *quadrula* yields a revised subpopulation estimate of 1,050,000 individuals. Thus the *Q*. *quadrula* subpopulation in the Assiniboine River is estimated to be between 1 and 4 million individuals, with the lower limit seeming more credible. These widely divergent numbers only serve to highlight the pressing need for more data on mussels from this, and the other Manitoba watersheds.

There are no data amenable to estimating *Q. quadrula* subpopulation sizes in the Red or Roseau rivers. Live specimens have not been recovered from the Red River since the investigations reported by Clarke (1973). The last live specimen from the Roseau was one individual collected in 1992 (Carney unpubl. data). Six other individuals were recorded by Manitoba Fisheries staff in 1991 from the lower Roseau (Erickson pers. comm. 2005). It seems probable they exist in the Red River simply based on the size of the river; but there is no basis for this supposition in the Roseau River. The absence of regular collection information from the Bloodvein River, Brokenhead River, Cooks Creek, LaSalle River, Red River, or Rat River, and the paucity of abundance data, precludes any attempt to estimate abundance trends in these rivers. These data are useful for presence/absence of the species and do contribute to our increasing knowledge of the distribution of *Q. quadrula* in Manitoba.

Neither Watson *et al.* (1998) nor Scaife and Janusz (1992) reported size values for the mussels they collected. All individuals collected by Carney (2003a) were measured and aged using thin sections but only lengths of mussels collected from the Assiniboine River are presented (Figure 15), to maintain consistency with the data presented for Ontario. Specimens ranged in size from 53 mm to 123 mm (mean = 101 mm). There was an absence of small individuals, which seems to be the common situation for the Manitoba population (Carney pers. obs.). The absence of smaller individuals, even in the range of 50-100 mm, is indicative of little or no recruitment. Carney (2003a, unpubl. data) has only ever recovered two female *Q. quadrula* gravid with glochidia. This apparent lack of reproduction is consistent with little or no recruitment.

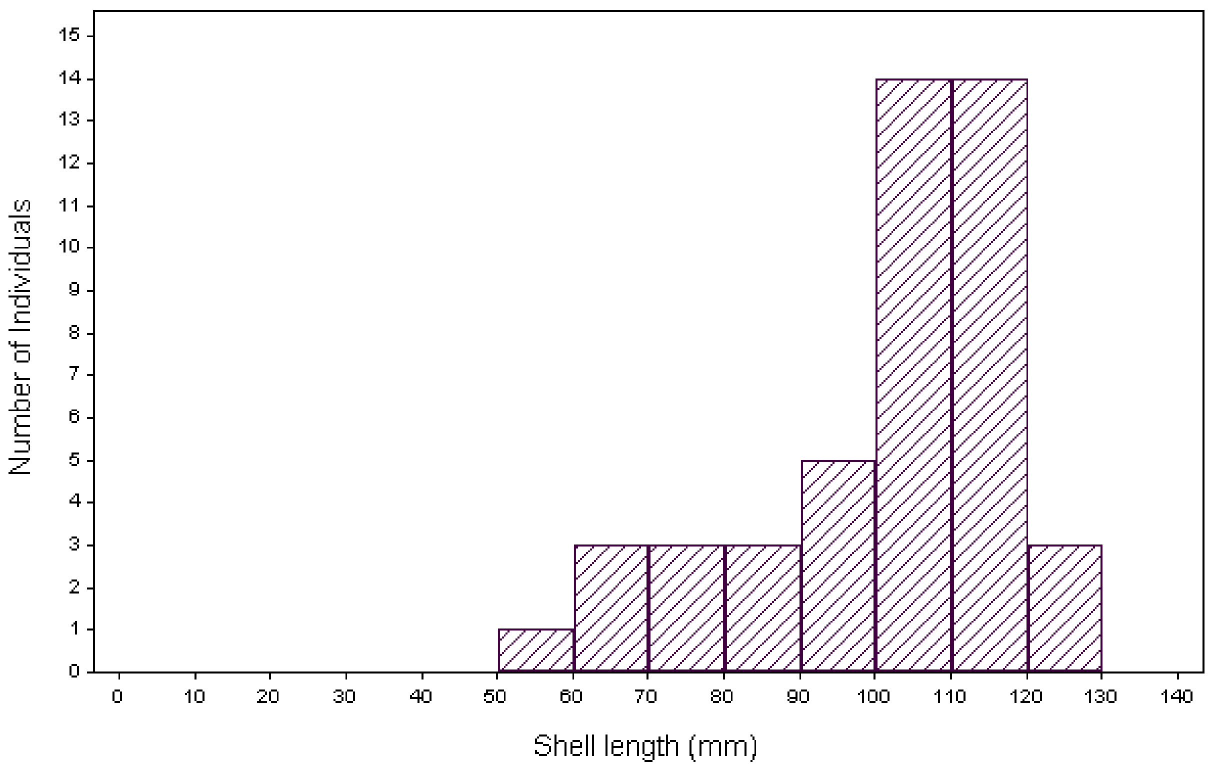


Figure 15. Size frequency distribution for *Quadrula quadrula* collected from the Assiniboine River, Manitoba (Carney 2003a). Specimens <50 mm are considered juveniles and indicative of recent recruitment.

Fluctuations and Trends

Clarke (1973) indicated that *Q. quadrula* was relatively common to abundant (Table 2, page 12) on the one hand, but in the text indicated it was "…ordinarily uncommon…" (page 33). Where Clarke (1973) does provide collecting data, the numbers collected within Manitoba are never very high. Current information is consistent with *Q. quadrula* being uncommon. Watson *et al.* (1998) surveyed the greatest number of sites in the lower Assiniboine River (below the Portage Diversion) and recorded the presence of *Q. quadrula* at 27% of the sites examined, recovering just six individuals over 157 km of river with an estimated CPUE of 0.66 (Table 5). Comparisons of CPUE indicate subpopulation densities are quite variable, even within rivers, from a low of 0 in the Red and Roseau rivers to a high of 1.5 in the Assiniboine (Table 5). In 2003 Watkins (unpubl. data) surveyed six sites in the Assiniboine within Winnipeg for 19.5 p-h with a CPUE of 1.54 (range 0-9). In 2004 Carney and Watkins (unpubl. data) resurveyed one of these sites (which had a CPUE = 9) for 3 p-h and recorded a CPUE of 0.37, more than an order of magnitude below the value of the previous year. The available data indicate *Q*. *quadrula* abundance is the highest in the Assiniboine River within and near the western perimeter of Winnipeg and then decreases proceeding upstream to the Portage Diversion and downstream toward the confluence with the Red River. Just a single individual has been documented from the almost 900 km of the Assiniboine upstream of the Portage Diversion (Carney 2003a).

Historical records indicate a distribution that includes the Red River and many tributaries, the length of the Assiniboine River to Lake of the Prairies, and many sites in Lake Winnipeg (Figure 6). In the time period from 1992-2004, *Q*. *quadrula* has only been recorded from about half the length of the Assiniboine River, with the Portage Diversion representing a line of demarcation. The discovery of *Q. quadrula* in 2007 at Brandon suggests that the distribution may not have been reduced. The abundance status of any subpopulations above the Portage Diversion remain unknown. No live specimens have recently been recovered from the Red River or from Lake Winnipeg (Figure 7; black dot just south of Winnipeg is from multiple records along the La Salle River while those north of Winnipeg are from Cooks Creek, both tributaries of the Red River).

Quadrula quadrula is likely declining in abundance within Manitoba. Clarke (1973) reported *Q*. *quadrula* from the Roseau River. Since then six individuals have been recorded in 1991 (Erickson pers. comm. 2005) and one individual in 1992 (Carney unpubl. data). No live *Q*. *quadrula* have been recently observed in the Red River (Carney 2004a; Carney and Watkins unpubl. data) although fresh shells were reported in 2013 (Morris unpubl. data). Clarke (1973) reported collecting 25 *Q*. *quadrula* from the Red River at St. Jean Baptiste. During exceptionally low water in 2003, Carney (2004a) was able to sample the entire width of the river at the same site and found no living specimens, but observed many empty valves along the shore. None of these valves were fresh. In 2004, Carney and Watkins (unpubl. data) returned to this, and other sites along the Red from which Clarke (1973) had collected *Q*. *quadrula* and found just a few, highly weathered empty valves. Although the Red River is exceptionally difficult to sample, the fact that Clarke was able to collect 25 live individuals, and nobody has subsequently, strongly suggests there has been a decline in abundance of *Q*. *quadrula* within the Red River in Manitoba.

The additional sites reported to harbour *Q. quadrula* only add dots within the previously known distribution of the species, and these are in tributaries of the Red River and Lake Winnipeg. The absence of any report of this species in Lake Winnipeg (Pip pers. comm. 2004) suggests it has been lost from this lake; the Zebra Mussel invasion will prevent it re-establishing. The overall abundance can still be declining even with new sites being discovered. If the species' abundance is declining, newly discovered sites do not negate the decline. Size class data collected prior to 2003 showed an apparent lack of recruitment throughout the Assiniboine (Figure 15) and was consistent with a population that is maintaining its distribution but slowly senescing. However, data collected from 2013 to 2015 from across the range in Manitoba (including 24 specimens from the Assiniboine) show evidence of recent recruitment (Figure 16). The continuing decline in water quality and new threat caused by Zebra Mussels all lead to a defensible conclusion that the abundance may be in decline, new sites not withstanding.

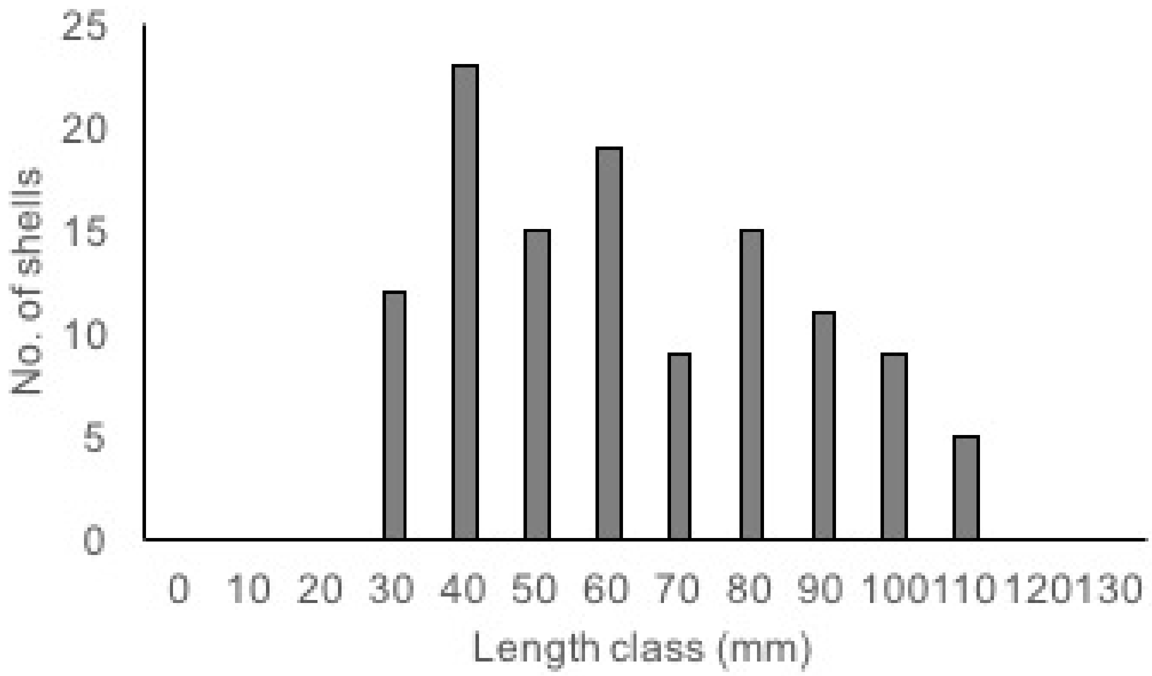


Figure 16. Size class distribution for live *Quadrula quadrula* collected from across its range in Manitoba from 2013 to 2015 (n = 118) (Watkinson unpubl. data). Specimens <50 mm are considered juveniles and indicative of recent recruitment.

Rescue Effect

The Red River drainage is part of the Hudson Bay drainage with no natural connection to the adjacent Mississippi River drainage. Thus there could be no natural rescue of the populations in the Red River drainage from populations in the Mississippi/Missouri drainages to the east and south, respectively. Although Manitoba subpopulations appear to occur as widely separated assemblages of individuals, there are few barriers limiting the movement of potential fish hosts, and as such, *Q. quadrula* can reasonably be considered to be a single, diffuse population in Manitoba. The Portage Diversion on the Assiniboine River, locks on the Red River at Lockport, and lowhead dams on the Roseau represent the only barriers to fish movement within the extent of occurrence in Manitoba. The Portage Diversion is an impassable barrier and represents a complete barrier for the upstream dispersal of glochidia-infested hosts.

The status of this species in the North Dakota and Minnesota portions of the Red River drainage are not well known. There is no information from North Dakota (Dyke pers. comm. 2004). Carney (2003b) did not encounter this species from sites in North Dakota reported by Cvancara (1970) to hold *Q. quadrula*. Limited investigations in the upper Red River undertaken by Minnesota Department of Natural Resources staff recovered just three *Q*. *quadrula* (Davis pers. comm. 2004). A survey by Hart (1995) of the Otter Tail River, a tributary of the Red River in Minnesota, recovered just ten *Q*. *quadrula* from a total of 4,851 individual mussels. A project to translocate mussels from two bridge construction sites on the Otter Tail River (Ceas 2001) reported no *Q*. *quadrula*. This would essentially be a census of the mussels from these two sites. These reports suggest that *Q*. *quadrula* is an uncommon component of the mussel fauna of the Red River drainage in Manitoba, North Dakota, and Minnesota. The known mobility of Channel Catfish potential hosts (Stewart and Watkinson 2004) within the Red River suggests a limited capacity for rescue from populations within the Red River system outside Manitoba. However, the current evidence indicates that there are few populations in North Dakota and Minnesota to act as a source for rescue. In addition, American populations within the Red River drainage in North Dakota and Minnesota have been subject to the same inferred population declines as in Manitoba (Hart 1995; Ceas 2001; Carney 2003b).

THREATS AND LIMITING FACTORS

Threats

The IUCN Threats Calculator (Master *et al.* 2009) determined the impacts from standardized threats categories. Impacts are calculated by scoring the scope (proportion of the Canadian population exposed to the specific threat in the next 10 years), severity (percent reduction in the proportion of the population exposed to the threat caused by the threat in the next three generations), and timing of the various threats. While the overall calculated impact for the Great Lakes - Upper St. Lawrence population (Table 6) yielded a range of high-medium, it was adjusted to medium impact, meaning a population decline of between 3 and 30% is expected in the next three generations caused by the various threats acting in the next 10 years. Similarly, the overall calculated impact for the Saskatchewan - Nelson Rivers population (Table 7) yielded a range of very high to low, but was adjusted to high, meaning a 10 to 70% decline is projected for the next three generations caused by the various threats acting in the next 10 years; there was much uncertainty in the magnitude of the impact from the Zebra Mussel invasion. These overall threat impacts are the only means currently available for projecting future population declines. Threats are arranged from the highest to lowest calculated impact for each DU.

Table 6. Threats assessment for Great Lakes - Upper St. Lawrence population of *Quadrula quadrula*.

Species Name	Mapleleaf (*Quadrula quadrula*) Great Lakes - Upper St. Lawrence population			
Date :	8/19/2015			
Assessor(s):	Dwayne Lepitzki (facilitator, responsible co-chair), Dave Zanatta (co-writer), Jordan Hoffman (co-writer), Joe Carney (co-writer), Todd Morris (SSC, DFO), Doug Watkinson (DFO), Sarah Hogg (OMNRF), Daelyn Woolnough (SSC), Andrew Hebda (SSC)			
References:	Draft threats assessment based on draft status report; formal threats assessment occurred on 19 August 2015 using updated range maps			
			Level 1 Threat Impact Counts	
	Threat Impact		**high range**	**low range**
	A	Very High	0	0
	B	High	0	0
	C	Medium	2	0
	D	Low	2	4
		Calculated Overall Threat Impact:	**High**	**Medium**
		Assigned Overall Threat Impact:	**C = Medium**	
		Impact Adjustment Reasons:	Medium (3-30% decline) makes more sense than High (10-70% decline) even given the accumulated impacts, especially because this species does seem to survive in eutrophic waters. Climate change impact is unknown for now, especially in the short term.	
		Overall Threat Comments	All locations in DU are impacted by dreissenid infestation and/or agriculture runoff.	

Threat		**Impact (calculated)**		**Scope (next 10 Yrs)**	**Severity (10 Yrs or 3 Gen.)**	**Timing**	**Comments**
1	**Residential & commercial development**						
1.1	Quadrula quadrulaHousing & urban areas						
1.2	Quadrula quadrulaCommercial & industrial areas						
1.3	Quadrula quadrulaTourism & recreation areas						No known new marinas or boat launches, so no perceived threat.
2	**Agriculture & aquaculture**						
2.1	Quadrula quadrulaAnnual & perennial non-timber crops						
2.2	Quadrula quadrulaWood & pulp plantations						
2.3	Quadrula quadrulaLivestock farming & ranching						No new stockyards or hog barns, no perceived threats of trampling from livestock.
2.4	Quadrula quadrulaMarine & freshwater aquaculture						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
3	**Energy production & mining**						
3.1	Quadrula quadrulaOil & gas drilling						
3.2	Quadrula quadrulaMining & quarrying						No new gravel extraction known that would be a threat.
3.3	Quadrula quadrulaRenewable energy						No known windfarms going into riparian areas.
4	**Transportation & service corridors**	D	Low	Small (1-10%)	Extreme (71-100%)	High (Continuing)	
4.1	Quadrula quadrulaRoads & railroads						
4.2	Quadrula quadrulaUtility & service lines		Negligible	Negligible (<1%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	Eastern Gateway pipeline may be a threat but this needs to be looked into.
4.3	Quadrula quadrulaShipping lanes	D	Low	Small (1-10%)	Extreme (71-100%)	High (Continuing)	Dredging for shipping lanes, harbours, marinas in the lower Grand R., Jordan Harbour, and coastal habitats. One third of population is in the Grand.
4.4	Quadrula quadrulaFlight paths						
5	**Biological resource use**		Negligible	Negligible (<1%)	Unknown	High (Continuing)	
5.1	Quadrula quadrulaHunting & collecting terrestrial animals						
5.2	Quadrula quadrulaGathering terrestrial plants						
5.3	Quadrula quadrulaLogging & wood harvesting						
5.4	Quadrula quadrulaFishing & harvesting aquatic resources		Negligible	Negligible (<1%)	Unknown	High (Continuing)	Effect on fish host and glochidia.
6	**Human intrusions & disturbance**		Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	
6.1	Quadrula quadrulaRecreational activities		Negligiible	Large (31-70%)	Negligible (<1%)	High (Continuing)	ATVs in river, boating, anglers.
6.2	Quadrula quadrulaWar, civil unrest & military exercises						
6.3	Quadrula quadrulaWork & other activities		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Research activities.

	Threat	Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
7	**Natural system modifications**	CD	Medium - Low	Restricted (11-30%)	Moderate – Slight (1-30%)	High (Continuing)	
7.1	Quadrula quadrulaFire & fire suppression						
7.2	Quadrula quadrulaDams & water management/use		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	There are dams that block fish movements. Host fish do not jump barriers. On the Thames R. the subpopulation is below the dam, but it could limit the expansion. No new dams planned. There is water removal for irrigation which does affect a large portion of the subpopulations, but severity may be minimal. Effect of Dunville Dam is much more long term based on modelling (unpubl. data).
7.3	Quadrula quadrulaOther ecosystem modifications	CD	Medium - Low	Restricted (11-30%)	Moderate – Slight (1-30%)	High (Continuing)	Snag removals, managing coastal areas for waterfowl and vegetation (not for mussels), Dreissenids modify habitat, invasive fish species (carp). Dewatering for waterfowl has been lethal for this species in the US, but not permitted because they are protected where applicable (SARA and Ontario ESA.)
8	**Invasive & other problematic species & genes**	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	
8.1	Quadrula quadrulaInvasive non-native/alien species	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Smothering by dreissenids and molluscivore invasive fishes (e.g. Round Gobies). They are in the systems (both dreissenids - low numbers in Thames and Grand - and gobies).
8.2	Quadrula quadrulaProblematic native species		Negligible	Negligible (<1%)	Extreme (71-100%)	High (Continuing)	Muskrat middens have had Mapleleaf, but very few individuals are affected. Those that are preyed upon are killed. Therefore low scope, but extreme severity. Uncertain if there is a human-caused increase of this over background.
8.3	Quadrula quadrulaIntroduced genetic material						
9	**Pollution**	CD	Medium - Low	Pervasive (71-100%)	Moderate – Slight (1-30%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
9.1	Quadrula quadrulaHousehold sewage & urban waste water	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Road salt, urban wastewater and runoff. The subpopulations are below major urban centres so they are exposed. Majority of river flow has passed through a sewage treatment plant.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.2	Quadrula quadrulaIndustrial & military effluents	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	Spills from pipelines, rail, industrial effluents; Welland canal has overflow. If it happens it will be bad therefore moderate severity. The most severe threat is a spill, which is not a continuous exposure.
9.3	Quadrula quadrulaAgricultural & forestry effluents	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	A chronic long term impact that may be causing a slow decline.
9.4	Quadrula quadrulaGarbage & solid waste						
9.5	Quadrula quadrulaAir-borne pollutants						
9.6	Quadrula quadrulaExcess energy						
10	**Geological events**						
10.1	Quadrula quadrulaVolcanoes						
10.2	Quadrula quadrulaEarthquakes /tsunamis						
10.3	Quadrula quadrulaAvalanches/landslides						
11	**Climate change & severe weather**		Unknown	Pervasive (71-100%)	Unknown	Moderate – Low	This DU is exposed to all of these influences (pervasive), but the impact may ultimately be neutral as the effects may be a benefit to the host fishes (thereby expanding the potential range). No current evidence that climate change is actually affecting the population.
11.1	Quadrula quadrulaHabitat shifting & alteration						
11.2	Quadrula quadrulaDroughts						
11.3	Quadrula quadrulaTemperature extremes						
11.4	Quadrula quadrulaStorms & flooding						

Threats to the Great Lakes - Upper St. Lawrence population (Table 6)

Pollution (Threat 9: impact medium – low)

Strayer and Fetterman (1999) identify non-point source input of nutrients, sediments, and toxins as the major threats to unionid mussels, with agricultural activities as the major contributor. Agricultural activity comprises 75% of land use in the Grand River basin and about 80% of land use within the Sydenham and the Thames river basins. Nutrients have been recorded to be consistently above accepted standards in the Sydenham basin. Dams and siltation are of concern in the Thames watershed. The pattern is the same in the Ausable River with approximately 80% of the land being used for agriculture, and suspended solids and nutrient levels exceed federal guidelines. There is also an expectation of increasing human populations within these watersheds resulting in increased urbanization with concomitant effects on water quality (see **Habitat Trends in Ontario**). Most of the *Q. quadrula* subpopulations are in areas of high agricultural and or urban land use and are exposed to runoff; however, with most and the largest subpopulations appearing relatively stable and apparently reproducing, it appears *Q. quadrula* may be tolerant of chronic exposure to high nutrients and suspended solids. At worst, agricultural effluents may be causing a slow decline.

Spills from pipelines (e.g., petroleum products), rail, and industrial sources appear to have the greatest potential toxic impact. The entire DU has the potential to be exposed to industrial spills, with potentially moderate to slight impacts, depending on the magnitude and type of spill. This type of toxic exposure would be brief but potentially catastrophic.

Natural system modifications (Threat 7: impact medium – low)

Dreissenid mussels compete with unionids for food and modify habitat making it less hospitable to unionid mussels (details below). Up to 30% of all *Q. quadrula* in this DU are potentially impacted by this threat.

Invasive and other problematic species (Threat 8: impact low)

Smothering by dreissenids and predation by Round Goby have the potential to impact the entire DU. Dreissenids are present in low numbers in both the Thames and Grand rivers and have the potential to impact >50% of all *Q. quadrula* in the DU. Round Goby is present in low numbers in all of the sites, but the impact of predation on juvenile *Q. quadrula*, if any, is unknown.

Many mussel species within the Great Lakes have had local subpopulations destroyed by the establishment of the invasive Zebra Mussel (Schlosser *et al.* 1996). Zebra Mussels attach to the unionid mussel shell and impair burrowing, movement, feeding, respiration, and other physiological activities (Haag *et al.* 1993; Baker and Hornbach 1997). This impairment results in the death of the unionid mussel. Because Zebra Mussel has such explosive population growth they can effectively eliminate entire unionid mussel subpopulations in a very short time as a result of direct fouling and competition for food and modification of habitat. The evidence indicates that *Q. quadrula* has been largely extirpated from Lake Erie, Lake St. Clair, and the Niagara and Detroit rivers as a result of infestations by the Zebra Mussel. Reports of Zebra Mussel from the Fanshawe Reservoir on the Thames River indicate the subpopulations of *Q*. *quadrula* in this river may be threatened by this invasive species (Maskant 2004). Zebra Mussel is still considered a serious threat to *Q*. *quadrula* and all unionid mussel species. However, the Great Lakes - Upper St. Lawrence population of *Q. quadrula* may now be past the worst stage of the dreissenid invasion and coexistence may be possible where dreissenid densities are lower (Lucy *et al.* 2014). The newly discovered sites in coastal embayments of western Lake Ontario are in close proximity to waters that are heavily infested with dreissenid mussels. However, only limited numbers of dreissenid (Zebra and Quagga mussels) were seen infesting the shells of *Q. quadrula* in these areas and it seems that the threat severity is only slight.

Round Gobies are another potential threat to unionids as they feed on juvenile unionids and compete with some hosts for space and predate on eggs (Poos *et al.* 2010). They could also be a population sink for glochidia. The overall threat impact to *Q. quadrula* may only be slight as catfish also predate on gobies and the shell of even juvenile *Q. quadrula* may be too thick for gobies to crush. The result is that this may only be a negligible impact threat.

Transportation and service corridors (Threat 4: impact low)

Dredging the benthos to deepen shipping lanes, harbours, and marinas in the lower Grand River, and in coastal habitats in western Lake Ontario occurs frequently. Approximately one third of the estimated population is found in the lower Grand River and up to 10% of the total *Q. quadrula* population could be affected by this type of impact.

Threats to the Saskatchewan-Nelson Rivers population (Table 7)

Invasive and other problematic species (Threat 8: impact high – low)

The invasive Zebra Mussel is considered to be established in the Red River and Lake Winnipeg (Watkinson pers. comm. 2015). The first discovery of Zebra Mussels in the Red River drainage was in Pelican Lake, Minnesota in 2009 (Owen 2015). By 2010 they had migrated 120 km to Wahpeton North Dakota on the Red River. This is 800 km south of the Manitoba border, but it is upstream so it was inevitable that Zebra Mussels would continue their migration down the Red River and into Manitoba. Zebra Mussels were discovered in harbours at Balsam Bay, Gimli, Silver Harbour, and Winnipeg Beach in 2013 (Watkinson pers. comm. 2015). These harbours were “bulk treated” with liquid potash to kill the mussels. This was apparently successful in those sites, but in August 2014 Zebra Mussels were found in other parts of the south basin. High numbers of veligers were reported in early 2015 in the Red River where it enters Manitoba at Emerson from North Dakota (Watkinson pers. comm. 2015), and adults have been reported at a boat launch in Selkirk and attached to Pink Heelsplitters (*Potamilus alatus*) as part of a mussel relocation associated with a pipeline crossing of the Red River (Watson pers. comm. 2015). Therriault *et al.*’s (2013) risk assessment concluded that the largest ecological impacts associated with dreissenid invasions were negative impacts on biota that inhabit the offshore zones of lakes or rivers, for example, losses in productivity for phytoplankton, zooplankton, and planktivorous fishes, and to unionid mussels, with effects on the latter being severe declines in abundance and biodiversity. The Great Lakes are an example of what can happen when Zebra Mussel invades (see this same threat impact for the other DU). It seems reasonable to predict that native unionid populations in the Red River and Lake Winnipeg will decline, but the magnitude of the decline within the next three generations caused by the threat acting in the next 10 years is uncertain, hence the large range for the severity (Table 7). Some small pockets will most likely survive the initial infestation. The major concern is if Zebra Mussel becomes established in the Assiniboine River. This is possible if Zebra Mussel manages to be introduced into the Shellmouth Reservoir near the headwaters of the Assiniboine River. This seems probable as a result of movement of boats between watersheds. Fishing is popular in the Red River, Lake Winnipeg, and in the Shellmouth Reservoir. It is simply a matter of time for a boat contaminated with Zebra Mussel veliger larvae in the bilge water or trailer frame to move from an infested site to the Shellmouth Reservoir. Once in the Shellmouth, this source of Zebra Mussel larvae will continually seed the rest of the Assiniboine, with the expected demise of the local unionid mussel fauna.

Table 7. Threats assessment for Saskatchewan - Nelson Rivers population of *Quadrula quadrula*.

Species Name	Mapleleaf (*Quadrula quadrula*) Saskatchewan - Nelson Rivers population			
Date :	8/19/2015			
Assessor(s):	Dwayne Lepitzki (facilitator, responsible co-chair), Dave Zanatta (co-writer), Jordan Hoffman (co-writer), Joe Carney (co-writer), Todd Morris (SSC, DFO), Doug Watkinson (DFO), Sarah Hogg (OMNRF), Daelyn Woolnough (SSC), Andrew Hebda (SSC)			
References:	Draft threats assessment based on draft status report; formal threats assessment occurred on 19 August 2015 using updated range maps			

		Level 1 Threat Impact Counts	
Threat Impact		**high range**	**low range**
A	Very High	0	0
B	High	1	0
C	Medium	2	0
D	Low	0	3
Calculated Overall Threat Impact:		**Very High**	**Low**

Assigned Overall Threat Impact:	**B = High**
Impact Adjustment Reasons:	Based on the potential threat from Zebra Mussels (10 - 70% decline is expected in the next 3 generations) coupled with the other threats
Overall Threat Comments	Entire DU threatened by agricultural impacts. Zebra Mussel infestation throughout DU is unlikely within the next 10 years.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1	**Residential & commercial development**		Negligible	Negligible (<1%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
1.1	Housing & urban areas						
1.2	Commercial & industrial areas						
1.3	Tourism & recreation areas		Negligible	Negligible (<1%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	No new marinas or boat launches in the rivers, but in Lake Winnipeg in the short term there are continuing inquiries regarding marina expansion and new boat launches.
2	**Agriculture & aquaculture**						
2.1	Annual & perennial non-timber crops						Ongoing changes in crops grown. Not sure of effect. Not scored.
2.2	Wood & pulp plantations						
2.3	Livestock farming & ranching						Unclear as to increase in hog farms, might be an ongoing moratorium on new hog barns. Little evidence of trampling. Not scored.
2.4	Marine & freshwater aquaculture						
3	**Energy production & mining**						
3.1	Oil & gas drilling						
3.2	Mining & quarrying						
3.3	Renewable energy						
4	**Transportation & service corridors**		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	
4.1	Roads & railroads		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	New road being built up the east side of Lake Winnipeg. The road crosses rivers where the mussels occur.
4.2	Utility & service lines		Negligible	Negligible (<1%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	Pipelines such as Eastern Gateway. Applies for the new east-west pipeline and as well as upkeep on existing pipelines.
4.3	Shipping lanes						
4.4	Flight paths						
5	**Biological resource use**		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
5.1	Hunting & collecting terrestrial animals						
5.2	Gathering terrestrial plants						
5.3	Logging & wood harvesting						
5.4	Fishing & harvesting aquatic resources		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	Possible commercial fishery for catfish (host) in Lake Winnipeg. Current and ongoing recreational fishery for Channel Catfish in the Red River.
6	**Human intrusions & disturbance**		Negligible	Restricted (11-30%)	Negligible (<1%)	High (Continuing)	
6.1	Recreational activities		Negligible	Restricted (11-30%)	Negligible (<1%)	High (Continuing)	Some boating, but not as much as in southern Ontario, negligible effect.
6.2	War, civil unrest & military exercises						
6.3	Work & other activities		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Researchers.
7	**Natural system modifications**	CD	Medium – Low	Large (31-70%)	Moderate - Slight (1-30%)	High (Continuing)	
7.1	Fire & fire suppression						
7.2	Dams & water management/use		Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	Dams, diversions, water removal for irrigation, water management to control flooding.
7.3	Other ecosystem modifications	CD	Medium - Low	Large (31-70%)	Moderate - Slight (1-30%)	High (Continuing)	Rip rap in the Red R. (Winnipeg and south of Winnipeg), Assiniboine R. banks are highly modified by diking and rip rap for flood control, which changes hydrology, Zebra Mussels have arrived and will modify the habitat.
8	**Invasive & other problematic species & genes**	BD	High-Low	Large (31-70%)	Serious - Slight (1-70%)	High (Continuing)	
8.1	Invasive non-native/alien species	BD	High-Low	Large (31-70%)	Serious - Slight (1-70%)	High (Continuing)	Zebra Mussels have arrived, we know there will be an impact, just don't know how severe. Based on Mississippi, s. Ontario, Detroit River etc., there is a wide range of possible effects.
8.2	Problematic native species						No predation beyond normal background predation.
8.3	Introduced genetic material						

	Threat	Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9	**Pollution**	CD	Medium-Low	Large (31-70%)	Moderate - Slight (1-30%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
9.1	Household sewage & urban waste water	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Brandon, Portage La Prairie, Winnipeg, Grand Forks, Fargo (ND).
9.2	Industrial & military effluents	CD	Medium – Low	Large (31-70%)	Moderate - Slight (1-30%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	Brandon meat packing plant, potential pipeline spills, industry in Winnipeg. Moderate timing based on possible pipeline spill.
9.3	Agricultural & forestry effluents	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Lots of agricultural effluent from Saskatchewan, Manitoba, North Dakota and Minnesota.
9.4	Garbage & solid waste						
9.5	Air-borne pollutants						
9.6	Excess energy						
10	**Geological events**						
10.1	Volcanoes						
10.2	Earthquakes/tsunamis						
10.3	Avalanches/landslides						
11	**Climate change & severe weather**		Unknown	Pervasive (71-100%)	Unknown	Moderate (Possibly in the short term, < 10 yrs/3 gen)	This DU is exposed to all of these influences (pervasive), but it may ultimately be neutral as the effects may be a benefit to the host fishes (thereby expanding the potential range). No current evidence that climate change is actually affecting the population.
11.1	Habitat shifting & alteration						
11.2	Droughts						
11.3	Temperature extremes						
11.4	Storms & flooding						Frequency of floods has increased, but severity unknown.

Natural system modifications (Threat 7: impact medium – low)

Much of the Red and Assiniboine river systems have been diked and/or had rip rap placed in the embankments to act as flood controls. Rip rap destroys mussel habitat by burying the clay and cobble with large boulders. Dikes and rip rap both can alter the hydrology in ways that are detrimental to mussel survival (Libois and Hallet-Libois 1987; Watters 1999). The arrival of Zebra Mussel not only has a direct effect on *Q. quadrula*, but also has indirect effects including outcompeting the native mussel species and altering the habitat (Ward and Ricciardi 2013).

Pollution (Threat 9: impact medium – low)

Elevated nutrients and pollutants in the water represent a present and ongoing threat to *Q. quadrula*. Point source inputs, such as household sewage and urban wastewater from Brandon, Portage La Prairie, Winnipeg, and Grand Forks and Fargo, North Dakota as well as industrial effluents associated with the Brandon meat packing plant, and industry in Winnipeg are sources of effluents that are demonstrated to cause harm to freshwater mussels (Gillis 2012; Gillis *et al.* 2014). Non-point source agricultural effluents from Saskatchewan, Manitoba, North Dakota, and Minnesota into the Red and Assiniboine river systems contribute nutrients and toxins that are major threats to unionid mussels (Strayer and Fetterman 1999). Phosphorus and nitrogen loads in these systems exceed legal standards (Environment Canada 2011). These elevated nutrient loads have been shown to be important factors that limit freshwater mussel populations (Augspurger *et al.* 2003; Bartsch *et al.* 2003; Mummert *et al.* 2003)

Limiting Factors

The major natural limitation to distribution and abundance of freshwater mussels is the availability, distribution, and abundance of the host fish required for successful completion of the life cycle. If the host fish is absent then there can be no recruitment. If a mussel species is long-lived, persistence of adult populations can lead to the illusion of a healthy mussel population despite the lack of recruitment due to a missing host fish. Because *Q*. *quadrula* is relatively long-lived, it is evidence of recruitment that would indicate a healthy viable population, not just the presence of adult mussels. The known host fishes for *Q*. *quadrula* include the Channel Catfish and Flathead Catfish. Channel Catfish is a common species in Ontario and in Manitoba and this should not limit the possibility for successful reproduction by *Q*. *quadrula*. However, fish populations should be monitored to ensure mussel reproduction is possible.

Number of Locations

Ontario

The major threats (Table 6) for the Great Lakes - Upper St. Lawrence population are: Pollution from agricultural, municipal, and industrial sources (Medium-Low impact), Natural system modifications (Medium-Low impact, including effects on the habitat caused by dreissenids), and Invasive species (Low impact – primarily dreissenid mussel infestation). A spill (agricultural, industrial, or other) is likely the most serious plausible event that could define the number of locations. All of the subpopulations, defined by water body (Table 1), are exposed to the ongoing threat of a toxic effluent spill, which suggests at least 21 locations. Only 11 (Thames River, Grand River, Jordan Harbour, Sixteen Mile Creek, Fifteen Mile Creek/Pond, Cootes Paradise, Coyle Creek, St. Clair Delta, Bayfield River, Lake Henry/Pelee Island, Rondeau Bay) of the 21 subpopulations are currently under the threat of infestation by dreissenid mussels. This is because the other ten subpopulations in streams and rivers lack any upstream source population (in a lake or impoundment) that would produce dreissenid veligers to infest downstream unionid populations.

Manitoba

The major threats (Table 7) for the Saskatchewan - Nelson Rivers population are: Invasive species (High-Low Impact, dreissenid mussel infestation), Natural system modifications (Medium-Low impact, dreissenid mussels and river bank hardening), and Pollution (Medium-Low impact, urban, agricultural, and industrial activities). These threats suggest that there are currently 7-11 locations in Manitoba (Table 2). The threat from non-point source pollution exists in the Red River (including the Seine River, La Salle River, and Cooks Creek tributaries), the Rat River (although it could be considered part of the Red River location as it is a tributary of the Red River), and the Assiniboine River (above and below the Portage Diversion dam) each representing single locations (n=3). Each of the Brokenhead, Wanipigow, Bloodvein, and Bradbury rivers (all drain into the eastern edge of Lake Winnipeg separate from the Red River) represent separate locations (n=4) because they are not subject to the same magnitude or sources of pollution. Therefore, there are seven locations based on the threats from pollution and Zebra Mussels. The threat associated solely with Zebra Mussels results in 11 locations, assuming each occupied waterbody will not be affected simultaneously by the infestation: Red River, La Salle River, Seine River, Rat River, Cooks Creek, Assiniboine River above the Portage Diversion, Assiniboine River below the Portage Diversion, Brokenhead River, Wanipigow River, Bloodvein River and Bradbury River. The tributaries of the Red are treated as different locations because they are upstream of the Red River, and the Assiniboine is counted as two locations, one upstream and one downstream of the Portage Diversion.

PROTECTION, STATUS AND RANKS

Legal Protection and Status

Quadrula quadrula in both Ontario (Great Lakes - Upper St. Lawrence DU) and Manitoba (Saskatchewan - Nelson Rivers DU) is listed under Schedule 1 of Canada's *Species at Risk Act* (SARA). The act prohibits killing or capturing listed Endangered or Threatened species, and protects critical habitat, when it is identified. A Recovery Strategy and Action Plan for the Ontario DU has been proposed (Fisheries and Oceans Canada 2016) and identifies critical habitat and key actions that will be implemented.

Ontario is one of six provinces that have stand-alone endangered species acts. Species designated as endangered are protected from willful destruction under these acts. *Quadrula quadrula* is currently listed as Threatened under Ontario's *Endangered Species Act*. Collection of live mussels is considered "fishing" and falls under the Ontario Fishery Regulations made under the federal *Fisheries Act*. This means that mussels cannot be collected in Ontario without an authorization from the Ontario MNRF. Threatened and endangered species in Ontario receive policy level protection from development and site alteration through the Provincial Policy Statement under the provincial *Planning Act*. The *Ontario Lakes and Rivers Improvement Act* (prohibiting the impoundment or diversion of watercourses that would lead to siltation) also protects mussel habitat, as can the Ontario *Endangered Species Act*. Stream-side development in Ontario is managed through flood plain regulations enforced by local conservation authorities.

Quadrula quadrula is listed as Endangered under Manitoba's *Endangered Species Act*. The purpose of this act is to designate indigenous species as endangered, threatened, extinct or extirpated, to protect and enhance survival of species considered endangered or threatened, and to permit the reintroduction of extirpated species. Under this act no person can cause harm, possess, disturb, or interfere with species that are recognized as endangered, threatened, or reintroduced. Furthermore, habitat or required resources of such species cannot be destroyed, disturbed, or interfered with. It is not permitted to kill, capture, collect, or hold alive such species. Exceptions to this require a permit and include reasons such as scientific investigations and purposes related to protection or reintroduction of such species. Another exception is ministerial discretion based on assurance of protection and preservation of the species, or appropriate measures being established to minimize impact of whatever the activity under consideration might be. Mussels are considered shellfish in Manitoba and fall under the jurisdiction of the Fisheries Branch. Currently, the collection of freshwater mussels in Manitoba requires a permit from the Fisheries Branch.

Non-Legal Status and Ranks

Quadrula quadrula is listed as Secure (G5) in North America; its national status is N5 in the United States (as of 11 May 2006) and Imperilled-Vulnerable (N2N3) in Canada (as of 14 May 2013) (NatureServe 2016). The IUCN Red List of Threatened Species categorizes the species as LR/lc as of August 1996, which means Lower Risk/least concern with the suggestion the rank needs updating (IUCN Species Survival Commission 2016). The national general status of freshwater mussels in Canada was completed in 2004 and updated in 2010 (CESCC 2010); *Q. quadrula* was ranked as 1 (At Risk) nationally and in both jurisdictions (Manitoba and Ontario) where it occurs. The species is provincially ranked as S2 (Imperilled) by Ontario's Natural Heritage Information Centre (Enns pers. comm. 2016) and S1 (Critically Imperilled) by the Manitoba Conservation Data Centre (Friesen pers. comm. 2016); NatureServe (2016) suggests it is S2 in both Ontario and Manitoba. Other NatureServe (2016) state ranks for *Q. quadrula* are: Alabama (S4: Apparently Secure), Arkansas (S5), Illinois (S5), Indiana (S4), Iowa (SNR), Kansas (S4), Kentucky (S4S5), Louisiana (S5), Michigan (SNR: Unranked), Minnesota (SNR), Mississippi (S5), Missouri (S4), Montana (SNA: Not Applicable), Nebraska (SNR), New York (SH: Possibly Extirpated / Historical), North Dakota (S3), Ohio (S5), Oklahoma (S5), Pennsylvania (S1S2), South Dakota (S2), Tennessee (S5), Texas (S3), West Virginia (S2) and Wisconsin (S3).

Habitat Protection and Ownership

<u>Ontario</u>

Land ownership along the reaches of the Sydenham, Thames, Ausable, and Grand rivers where *Q. quadrula* occurs is mainly private and in agricultural use. Only three small properties in the Sydenham River watershed, the 7 ha Shetland Conservation Area, the 20 ha Mosa Township forest, and the Moore Wildlife Management Area (on Bear Creek where *Q. quadrula* are present) are publicly owned and somewhat protected (Andreae pers. comm. 1998). There are 21 natural areas totalling 6,200 ha in the Thames River watershed, but only one – the 16 ha Big Bend Conservation Area – is located in the same reach as *Q. quadrula* (Thames River Background Study Research Team 1998). Also in this reach are four First Nations' reserves (Delaware of Moraviantown, Munsee Delaware, Oneida of the Thames, and Chippewa of the Thames) that occupy over 6,700 ha of land along approximately 45 km of the river. The Ausable Bayfield Conservation Authority owns a number of properties totalling 1,830 ha throughout the basin (Snell and Cecile Environmental Research 1995). Less than 3% of the land in the Grand River watershed is publicly owned (GRCA 1998). There are 11 conservation areas, only one of which (Byng Island) is located within *Q. quadrula*'s range in the river. Recovery strategies and action plans have been implemented for the aquatic ecosystems of the Ausable, Sydenham, and Thames rivers to protect and recover aquatic and semi-aquatic species at risk including fishes, mussels, turtles, and snakes (Ausable River Recovery Team 2005; Sydenham River Recovery Team 2002; Thames River Recovery Team 2004). Many landowners are participating in riparian rehabilitation projects and improved land use practices that will ultimately benefit all aquatic species.

Manitoba

Land ownership on the Assiniboine, Red, and Roseau rivers was determined using GIS from 1:500,000 base maps for the water layer. Land along these rivers is predominately privately owned and in agricultural use. Approximately 19% of the Red River could be considered urban, passing through Winnipeg and Selkirk. With the exception of small towns, the remainder is agricultural. There are no protected lands along the Red River or the Roseau River. Approximately 7% is Crown land, 9% is First Nations' Reserve land, and the remaining 84% is private land used mostly for agriculture. If the entire length of the Assiniboine River within Manitoba (approximately 1,000 km) is considered, then 84% of the surrounding land is privately held and agricultural, 6% is urban, and approximately 10% flows through either a park or a Wildlife Management Area (WMA). Approximately 60% of these parks or WMAs are designated as protected, meaning mining, logging, hydroelectric development, and other activities that affect wildlife habitat are prohibited. The non-protected parks and WMAs are designated Crown lands without a regulation or order in council specifying that land is to be protected. About half of these designated lands, whether protected or not, lie on one bank of the river, with the opposite bank being privately held. However, if just the stretch of the Assiniboine downstream from the Portage Diversion to the confluence with the Red River is considered, there is only 7% flowing through protected land (Beaudry Provincial Park). The remainder is 80% agricultural and 13% is urban, flowing through Winnipeg.

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BIOGRAPHICAL SUMMARY OF REPORT WRITERS

Dr. David Zanatta is an Associate Professor in the Biology Department at Central Michigan University. Dr. Zanatta has over 15 years of experience working on unionid mussels. He has a B.Sc. (Hons.) in Biology from Laurentian University (1998); an M.Sc. in Zoology from the University of Guelph (2000); a Ph.D. from the University of Toronto (2007) where he researched the evolution and population genetics of lampsiline mussels; and held an NSERC post-doctoral fellowship at Trent University in 2008 prior to starting a professorship at Central Michigan University. Dr. Zanatta has authored or co-authored numerous peer-reviewed papers on freshwater mussel biology, including research on the

Mapleleaf mussel. He has also written several COSEWIC status reports on Canadian freshwater mussel species and is a member of the Molluscs Specialist Subcommittee of COSEWIC. Dr. Zanatta is a member of the recovery teams for the Thames, Sydenham, and Ausable rivers as well as the Ontario Freshwater Mussel Recovery Team.

Jordan Hoffman is a graduate student in Biology at Central Michigan University. He received his BS from Oakland University (Rochester, Michigan) in 2011 and an MS in Ecology and Evolutionary Biology from Tulane University (New Orleans, Louisiana) in 2014. Jordan has diverse interests in biodiversity and conservation biology and has recently completed his MS Thesis investigating dispersal and genetic structure in Ontario populations of *Quadrula quadrula*. He is a member of the Freshwater Mollusk Conservation Society.

Dr. Joseph Carney is an associate professor at Lakehead University, Thunder Bay, Ontario. He received his Ph.D. from the University of Manitoba in 2000 investigating the evolution and community ecology of parasites of yellow perch (*Perca flavescens*). Since 2002 he has initiated a research program investigating the ecology and conservation of freshwater mussels (Mollusca: Unionidae) within the Red River drainage in Manitoba, Saskatchewan, and North Dakota. He has published several scientific papers and reports focusing on freshwater mussels. He is a member of the American Society of Parasitologists, Canadian Society of Zoology, and the Freshwater Mollusk Conservation Society. He has been a member of the COSEWIC Molluscs SSC since 2005 and is the current co-chair (beginning in 2015).

COLLECTIONS EXAMINED

Collections of freshwater mussels from Manitoba are limited. The Manitoba Museum of Man and Nature has a small collection deposited by Ernie Watson. This has been examined by William Watkins, one of the writers of the previous report. A larger research collection is maintained by J. Carney, report co-writer, and this collection is regularly examined. Vouchered specimens from the personal collection maintained by Dr. Eva Pip have been examined.

In 1996, all available historical and recent data on the occurrences of freshwater mussel species throughout the lower Great Lakes drainage basin were compiled into a computerized, GIS-linked database referred to as the Lower Great Lakes Unionid Database. The database is housed at the Fisheries and Oceans Canada offices in Burlington, Ontario. Data sources included the primary literature, natural history museums, federal, provincial, and municipal government agencies (and some American agencies), conservation authorities, Remedial Action Plans for the Great Lakes Areas of Concern, university theses, and environmental consulting firms. Mussel collections held by six natural history museums in the Great Lakes region (Canadian Museum of Nature, Ohio State University Museum of Zoology, Royal Ontario Museum, University of Michigan Museum of Zoology, Rochester Museum and Science Center, and Buffalo Museum of Science) were the primary sources of information, accounting for over two-thirds of the data acquired. J.L.

Metcalfe-Smith (co-writer of the 2006 status report) personally examined the collections held by the Royal Ontario Museum, University of Michigan Museum of Zoology, and Buffalo Museum of Science, as well as smaller collections held by the Ontario Ministry of Natural Resources. The database continues to be updated and contains over 10,000 records of unionids from Lake Ontario, Lake Erie, Lake St. Clair, and their drainage basins as well as several of the major tributaries to lower Lake Huron. The databased is currently managed by Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences.