COSEWIC Assessment and Status Report

on the

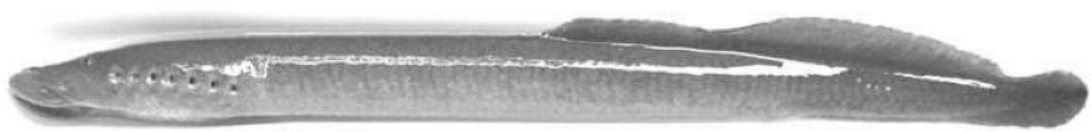
Northern Brook Lamprey
Ichthyomyzon fossor

Great Lakes - Upper St. Lawrence populations
Saskatchewan - Nelson River populations

and the

Silver Lamprey
Ichthyomyzon unicuspis

Great Lakes - Upper St. Lawrence populations
Saskatchewan - Nelson River populations
Southern Hudson Bay - James Bay populations



in Canada

Northern Brook Lamprey - Great Lakes - Upper St. Lawrence populations – SPECIAL CONCERN
Northern Brook Lamprey - Saskatchewan - Nelson River populations – ENDANGERED
Silver Lamprey - Great Lakes - Upper St. Lawrence populations – SPECIAL CONCERN
Silver Lamprey - Saskatchewan - Nelson River populations – SPECIAL CONCERN
Silver Lamprey - Southern Hudson Bay - James Bay populations – DATA DEFICIENT
2020

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. 2020. COSEWIC assessment and status report on the Northern Brook Lamprey *Ichthyomyzon fossor* (Great Lakes - Upper St. Lawrence populations and Saskatchewan - Nelson River populations) and the Silver Lamprey *Ichthyomyzon unicuspis* **(**Great Lakes - Upper St. Lawrence populations, Saskatchewan - Nelson River populations and Southern Hudson Bay - James Bay populations) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xxiv + 156 pp. (https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry.html).

Previous report(s):

COSEWIC 2007. COSEWIC assessment and update status report on the northern brook lamprey *Ichthyomyzon fossor* (Great Lakes – Upper St. Lawrence populations and Saskatchewan – Nelson population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 30 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Lanteigne, Jacqueline. 1991. COSEWIC status report on the northern brook lamprey *Ichthyomyzon fossor* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-21 pp.

Production note:
COSEWIC would like to acknowledge Margaret Docker, Justin Budyk, Doug Watkinson and Anthony Wightman for writing the status report on Northern Brook Lamprey, *Ichthyomyzon fossor*, and Silver Lamprey, *Ichthyomyzon unicuspis* in Canada, prepared under contract with Environment and Climate Change Canada. This report was overseen and edited by Nicholas Mandrak, Co-Chair of the COSEWIC Freshwater Fishes Specialist Subcommittee.

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Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur la Lamproie du Nord (*Ichthyomyzon fossor)* (populations des Grands Lacs et du haut Saint-Laurent et populations de la rivière Saskatchewan et du fleuve Nelson) et la Lamproie argentée (*Ichthyomyzon unicuspis*) (populations des Grands Lacs et du haut Saint-Laurent, populations de la rivière Saskatchewan et du fleuve Nelson et populations du sud de la baie d'Hudson et de la baie James) au Canada.

Cover illustration/photo:
Northern Brook Lamprey and Silver Lamprey — Photo credit: Fraser Neave.

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COSEWIC
Assessment Summary

Assessment Summary – November 2020

Common name
Northern Brook Lamprey - Great Lakes - Upper St. Lawrence River populations

Scientific name
Ichthyomyzon fossor

Status
Special Concern

Reason for designation
This small, nonparasitic lamprey is found in streams throughout the Laurentian Great Lakes basin and in southwestern Quebec. In the Great Lakes basin, most of its Canadian range, about half of the streams it is known to inhabit are subjected to ongoing chemical treatment for Sea Lamprey control, which causes significant mortality to larval lampreys. Barriers that exclude Sea Lamprey protect this species from exposure to lampricides in upper reaches of many tributaries, and it is still relatively abundant in untreated streams. The overall population is not known to be declining currently. However, it may be exposed to additional threats such as pollution from agricultural effluents and increased temperatures and decreased water flows related to climate change and water control structures. If these threats are not managed effectively, this species may become at greater risk of extinction.

Occurrence
Ontario, Quebec

Status history
The species was considered a single unit and designated Special Concern in April 1991. When the species was split into separate units in April 2007, the “Great Lakes - Upper St. Lawrence populations” unit was designated Special Concern. Status re-examined and confirmed in November 2020.

Assessment Summary – November 2020

Common name
Northern Brook Lamprey - Saskatchewan - Nelson River populations

Scientific name
Ichthyomyzon fossor

Status
Endangered

Reason for designation
This small, nonparasitic lamprey has a very limited distribution in the Winnipeg River watershed in southeastern Manitoba. The number of mature individuals is declining based on observed reductions in extent of occurrence, area of occupancy, and number of locations, and an inferred decline in quantity and quality of aquatic habitat. These populations are exposed to threats, such as decreases in stream flows under current and future climates, and are very susceptible to anticipated increases in water temperature. Substantial recent targeted sampling, using both conventional methods and environmental DNA (sampling water to confirm presence of DNA from the species), now provides sufficient data to conclude that this species is at risk of extinction.

Occurrence
Manitoba

Status history
The species was considered a single unit and designated Special Concern in April 1991. When the species was split into separate units in April 2007, the “Saskatchewan - Nelson River populations” unit was designated Data Deficient. Status re-examined and designated Endangered in November 2020.

Assessment Summary – November 2020

Common name
Silver Lamprey - Great Lakes - Upper St. Lawrence River populations

Scientific name
Ichthyomyzon unicuspis

Status
Special Concern

Reason for designation
This small parasitic lamprey is distributed in streams and lakes throughout the Laurentian Great Lakes basin and in southern Quebec. In the Great Lakes basin, a major part of its range, about half of the streams that it inhabits have barriers, or are subjected to ongoing chemical treatment for Sea Lamprey control. These control methods prevent migration to spawning areas or cause significant mortality to larval individuals, respectively. Throughout its range, it may be exposed to additional threats such as pollution from agricultural effluents, effects of water control structures, and increased temperatures and decreased water flows related to climate change. If these threats are not managed effectively, this species may become at greater risk of extinction.

Occurrence
Ontario, Quebec

Status history
This species was designated Special Concern in May 2011. Status re-examined and confirmed in November 2020.

Assessment Summary – November 2020

Common name
Silver Lamprey - Saskatchewan - Nelson River populations

Scientific name
Ichthyomyzon unicuspis

Status
Special Concern

Reason for designation
This small parasitic lamprey is found in widely disjunct, but limited, areas in streams and lakes in the Nelson and Winnipeg River basins of Manitoba and northwestern Ontario. The species is susceptible to fluctuating water levels as a result of water management and climate change. Recent sampling using conventional methods and environmental DNA (sampling water to confirm presence of DNA from the species) now provide sufficient data to conclude that populations of this species may be declining and may become at greater risk of extinction if these threats are not managed effectively.

Occurrence
Ontario, Manitoba

Status history
This species was considered in May 2011 and placed in the Data Deficient category. Status re-examined and designated Special Concern in November 2020.

Assessment Summary – November 2020

Common name
Silver Lamprey - Southern Hudson Bay - James Bay populations

Scientific name
Ichthyomyzon unicuspis

Status
Data Deficient

Reason for designation
This small parasitic lamprey has only recently been confirmed as present in the Southern Hudson Bay-James Bay basin based on the two specimens found on angled Northern Pike in the upper Hayes River system of northern Manitoba. There is insufficient information with which to assess the eligibility and status of this species in this system.

Occurrence
Manitoba

Status history
Species considered in November 2020 and placed in the Data Deficient category.

COSEWIC
Executive Summary

Northern Brook Lamprey
Ichthyomyzon fossor

Great Lakes - Upper St. Lawrence populations
Saskatchewan - Nelson River populations

and the

Silver Lamprey
Ichthyomyzon unicuspis

Great Lakes - Upper St. Lawrence populations
Saskatchewan - Nelson River populations
Southern Hudson Bay - James Bay populations

Wildlife Species Description and Significance

The Northern Brook Lamprey (*Ichthyomyzon fossor*) and Silver Lamprey (*Ichthyomyzon unicuspis*) are closely related “paired” species that are generally indistinguishable during their long larval phase, but they adopt very different lifestyles at metamorphosis and they are formally recognized as valid species. The Northern Brook Lamprey begins sexual maturation during metamorphosis and spawns and dies without feeding again. In contrast, the Silver Lamprey feeds parasitically on other fishes for approximately one year before initiating sexual maturation. Consequently, the Northern Brook Lamprey is only 120–150 mm in length at maturity, while the Silver Lamprey reaches at least 250–300 mm in length. Lampreys have special scientific significance as one of only two groups of jawless fishes that evolved more than 500 million years ago, and understanding the genetic mechanisms by which the parasitic feeding phase has been eliminated in the Northern Brook Lamprey could lead to new ways of controlling invasive Sea Lamprey (*Petromyzon marinus*) in the Great Lakes. Lampreys are also fed on by a variety of aquatic, aerial, and terrestrial predators.

Distribution

Northern Brook and Silver Lampreys are found in fresh water in eastern North America. In Canada, they occur in the Great Lakes - Upper St. Lawrence and Saskatchewan - Nelson River National Freshwater Biogeographic Zones (NFBZs) in Quebec, Ontario, and Manitoba. The Silver Lamprey has a slightly wider distribution than the Northern Brook Lamprey, and its occurrence has recently been confirmed in a third NFBZ, the Southern Hudson Bay - James Bay NFBZ.

Habitat

Larval Northern Brook and Silver lampreys burrow in silty substrate in rivers and streams. Northern Brook Lamprey adults remain within their home stream, moving only short distances upstream to spawn in relatively shallow areas with coarse gravel and a moderate current. In contrast, Silver Lamprey migrate downstream to large river or lake systems to feed as parasites; at maturity, they migrate upstream and spawn in similar habitats as Northern Brook Lamprey or, sometimes, in deeper rivers.

Biology

The larval stage in these species lasts for approximately 3–7 years, although it can be quite variable, and the Northern Brook Lamprey likely metamorphoses at older ages and larger sizes than Silver Lamprey. The larval stage likely averages just over 5 years in Northern Brook Lamprey (i.e., from spawning in late spring/early summer to metamorphosis in late summer/early fall) and just over 4 years in Silver Lamprey. The post-metamorphic lifespan of Northern Brook Lamprey is 6–8 months, while Silver Lamprey live for another year while feeding parasitically (and often non-lethally) on large-bodied fishes such as Lake Sturgeon (*Acipenser fulvescens*) and Northern Pike (*Esox lucius*). Like all lampreys, Northern Brook and Silver lampreys die after a single spawning season. Therefore, the average age at maturity and generation time is the same as the total lifespan, which is approximately 6 years for both species. Northern Brook Lamprey females produce an average of 1,200 eggs, while the larger-bodied Silver Lamprey produces approximately 19,000 eggs per female.

Population Sizes and Trends

Population estimates are not available, but changes in relative abundance can be inferred in the Great Lakes basin from incidental capture during Sea Lamprey control efforts (although this means that sampling is biased towards stream reaches with Sea Lamprey). Catch rates of larval Northern Brook and Silver lampreys (combined) have been relatively consistent over the last three generations, but they were lower in 2001–2018 than in 1989–2000. Catch rates of adult Silver Lamprey appear to have stabilized or increased over the last three generations, although they are low overall.

Threats and Limiting Factors

The key threat to Northern Brook and Silver lampreys in Great Lakes tributaries is the application of lampricides used to control the invasive Sea Lamprey. Dams and barriers that exclude Sea Lamprey from the upper reaches of tributaries occupied by the stream-resident Northern Brook Lamprey protect many populations of the latter species from exposure to lampricides, but these barriers block the upstream migration of Silver Lamprey so that their distribution often overlaps with that of Sea Lamprey. In the Saskatchewan - Nelson River populations, Northern Brook Lamprey may be susceptible to impacts from invasive species and climate change (e.g., increased temperatures, decreased water quantity). Silver Lamprey, being lower in the watershed, is likely less susceptible to the effects of climate change, but may be more impacted by lampricide treatments, large hydroelectric dams, and a broad array of other threats.

Protection, Status and Ranks

The Great Lakes - Upper St. Lawrence populations of both Northern Brook Lamprey and Silver Lamprey are listed under Schedule 1 of the *Species at Risk Act* (SARA) as Special Concern. The Saskatchewan - Nelson River populations of both species were assessed by COSEWIC as Data Deficient in 2007. The federal *Fisheries Act* and provincial legislation may provide indirect protection to both species. NatureServe ranked the global populations of Northern Brook and Silver lampreys as G4 (Apparently Secure) and G5 (Secure), respectively.

TECHNICAL SUMMARY – Great Lakes - Upper St. Lawrence River populations

Ichthyomyzon fossor

Northern Brook Lamprey

Lamproie du Nord

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

Demographic Information

Generation time	6 years
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Unknown
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Not applicable
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations]	Not applicable
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Not applicable
[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.	Not applicable
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	Not applicable
Are there extreme fluctuations in number of mature individuals?	Unknown

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	419,126 km^2
Index of area of occupancy (IAO) (Always report 2x2 grid value)	880 km^2 Continuous
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)	> 32
Is there an [observed, inferred, or projected] decline in extent of occurrence?	No

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

Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Yes, observed, although apparent decline may be due to differences in search effort and exclusion of populations with only unidentified larvae; largest decline > 3 generations ago
Is there an [observed, inferred, or projected] decline in number of subpopulations?	No
Is there an [observed, inferred, or projected] decline in number of “locations”*?	No; 36 locations reported for 1990–2006; any declines > 3 generations ago
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	No
Are there extreme fluctuations in number of subpopulations?	Not applicable.
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)	N Mature Individuals
Total	Unknown

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, or 10% within 100 years]?	Unknown

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

Was a threats calculator completed for this species? Yes
Overall threat is Very High.

i. Lampricide treatments of populations co-existing with Sea Lamprey larvae (High)
ii. Dams and water management/use (Medium-Low)
iii. Climate change and severe weather (Medium-Low)
iv. Invasive non-native species (Medium-Low)
v. Other pollution (especially agricultural effluent) (Low)

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	“Apparently Secure” in the United States
Is immigration known or possible?	Possible, but unlikely due to non-migratory behavior
Would immigrants be adapted to survive in Canada?	Probably yes

Is there sufficient habitat for immigrants in Canada?	Yes, but lampricide treatments ongoing
Are conditions deteriorating in Canada?+	Probably yes
Are conditions for the source (i.e., outside) population deteriorating?+	Variable
Is the Canadian population considered to be a sink?+	Unknown; lampricide treatments ongoing
Is rescue from outside populations likely?	No

Data Sensitive Species

Is this a data sensitive species?	No

Status History

COSEWIC Status History: The species was considered a single unit and designated Special Concern in April 1991. When the species was split into separate units in April 2007, the "Great Lakes - Upper St. Lawrence populations" unit was designated Special Concern. Status re-examined and confirmed in November 2020.

Status and Reasons for Designation:

Status: Special Concern	**Alpha-numeric codes:** Not applicable

Reason for Designation:

This small, nonparasitic lamprey is found in streams throughout the Laurentian Great Lakes basin and in southwestern Quebec. In the Great Lakes basin, most of its Canadian range, about half of the streams it is known to inhabit are subjected to ongoing chemical treatment for Sea Lamprey control, which causes significant mortality to larval lampreys. Barriers that exclude Sea Lamprey protect this species from exposure to lampricides in upper reaches of many tributaries, and it is still relatively abundant in untreated streams. The overall population is not known to be declining currently. However, it may be exposed to additional threats such as pollution from agricultural effluents and increased temperatures and decreased water flows related to climate change and water control structures. If these threats are not managed effectively, this species may become at greater risk of extinction.

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals):
Not applicable. No information available on population trends.

Criterion B (Small Distribution Range and Decline or Fluctuation):
Not applicable. IAO meets threshold for Threatened, B2, but not severely fragmented and >10 locations. No continuing decline (declines occurred > 3 generations ago), and fluctuations that are more recent are more likely related to variation in search effort.

Criterion C (Small and Declining Number of Mature Individuals):
Not applicable. No information available on population size.

Criterion D (Very Small or Restricted Population):
Not applicable. No information available on population size.

Criterion E (Quantitative Analysis):
Not applicable. Data not available.

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

TECHNICAL SUMMARY – Saskatchewan - Nelson River populations

Ichthyomyzon fossor

Northern Brook Lamprey

Lamproie du Nord

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

Demographic Information

Generation time	6 years
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Unknown
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Not applicable
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Not applicable
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Not applicable
[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.	Not applicable
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	Not applicable
Are there extreme fluctuations in number of mature individuals?	Unknown

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	162 km²
Index of area of occupancy (IAO) (Always report 2x2 grid value)	108 km² Continuous
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)	1
Is there an [observed, inferred, or projected] decline in extent of occurrence?	Yes, observed

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

Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Yes, observed
Is there an [observed, inferred, or projected] decline in number of subpopulations?	No
Is there an [observed, inferred, or projected] decline in number of "locations"*?	Yes; 3 locations for 1990–2006
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Yes, inferred decline in quality of habitat
Are there extreme fluctuations in number of subpopulations?	Not applicable
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)	**N Mature Individuals**
Total	Unknown

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, or 10% within 100 years]?	Unknown

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

Was a threats calculator completed for this species? Yes
Overall threat is High-Medium.

i. Climate change and severe weather (High-Low)
ii. Dams and other water use management (Low)
iii. Invasive non-native species (Low)

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	"Apparently Secure" in the United States
Is immigration known or possible?	Very unlikely
Would immigrants be adapted to survive in Canada?	Probably yes
Is there sufficient habitat for immigrants in Canada?	Unknown
Are conditions deteriorating in Canada?[+]	Yes, inferred
Are conditions for the source (i.e., outside) population deteriorating?[+]	Variable

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

Is the Canadian population considered to be a sink?[+]	No
Is rescue from outside populations likely?	No

Data Sensitive Species

Is this a data sensitive species?	No

Status History

COSEWIC Status History: The species was considered a single unit and designated Special Concern in April 1991. When the species was split into separate units in April 2007, the “Saskatchewan - Nelson River populations” unit was designated Data Deficient. Status re-examined and designated Endangered in November 2020.

Status and Reasons for Designation:

Status: Endangered	**Alpha-numeric codes:** B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v)
Reasons for designation: This small, nonparasitic lamprey has a very limited distribution in the Winnipeg River watershed in southeastern Manitoba. The number of mature individuals is declining based on observed reductions in extent of occurrence, area of occupancy, and number of locations, and an inferred decline in quantity and quality of aquatic habitat. These populations are exposed to threats, such as decreases in stream flows under current and future climates, and are very susceptible to anticipated increases in water temperature. Substantial recent targeted sampling, using both conventional methods and environmental DNA (sampling water to confirm presence of DNA from the species), now provides sufficient data to conclude that this species is at risk of extinction.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable. No information available on population trends.
Criterion B (Small Distribution Range and Decline or Fluctuation): Meets Endangered, B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v), with small EOO (162 km²) and IAO (108 km²), < 5 locations, and observed, projected or inferred continuing decline in (i) extent of occurrence; (ii) index of area of occupancy; (iii) extent and quality of habitat; (iv) number of locations; and (v) number of mature individuals.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable. EOO and IAO exceed thresholds.
Criterion D (Very Small or Restricted Population): Not applicable. No information available on population size.
Criterion E (Quantitative Analysis): Not applicable. Data not available.

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

TECHNICAL SUMMARY – Great Lakes - Upper St. Lawrence River populations

Ichthyomyzon unicuspis

Silver Lamprey

Lamproie argentée

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

Demographic Information

Generation time	6 years
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	No, catches in traps very low but appear to have stabilized or increased over the last 3 generations
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Not applicable
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[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.	Unknown
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	Not applicable
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	274,064 km^2
Index of area of occupancy (IAO) (Always report 2x2 grid value)	5,160 km^2 Continuous
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)	>22

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

Is there an [observed, inferred, or projected] decline in extent of occurrence?	Yes, observed
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Yes, observed
Is there an [observed, inferred, or projected] decline in number of subpopulations?	Not applicable
Is there an [observed, inferred, or projected] decline in number of “locations”*?	Yes, inferred; 41 locations in previous report
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	No
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)	**N Mature Individuals**
Total	Unknown

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, or 10% within 100 years]?	Unknown

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

Was a threats calculator completed for this species? Yes
Overall threat is Very High.

i. Lampricide treatments of populations co-occurring with Sea Lamprey larvae (High)
ii. Dams and water management/use (Medium-Low)
iii. Invasive non-native species (Medium-Low)
iv. Climate change and severe weather (Medium-Low)

What additional limiting factors are relevant? The migratory behaviour of Silver Lamprey means that its in-stream distribution overlaps considerably with Sea Lamprey in the Great Lakes, but its lower fecundity makes it a poor competitor to the invasive Sea Lamprey.

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	“Secure” in the United States
Is immigration known or possible?	Undocumented, but likely
Would immigrants be adapted to survive in Canada?	Yes

Is there sufficient habitat for immigrants in Canada?	Unknown; accessible habitat unaffected by lampricides may be insufficient
Are conditions deteriorating in Canada?+	Probably yes
Are conditions for the source (i.e., outside) population deteriorating?+	Variable
Is the Canadian population considered to be a sink?+	Unknown; lampricide treatments ongoing
Is rescue from outside populations likely?	No

Data Sensitive Species

Is this a data sensitive species?	No

Status History

COSEWIC Status History: This species was designated Special Concern in May 2011. Status re-examined and confirmed in November 2020.

Status and Reasons for Designation:

Status: Special Concern	**Alpha-numeric codes:** Not applicable
Reasons for designation: This small parasitic lamprey is distributed in streams and lakes throughout the Laurentian Great Lakes basin and in southern Quebec. In the Great Lakes basin, a major part of its range, about half of the streams that it inhabits have barriers, or are subjected to ongoing chemical treatment for Sea Lamprey control. These control methods prevent migration to spawning areas or cause significant mortality to larval individuals, respectively. Throughout its range, it may be exposed to additional threats such as pollution from agricultural effluents, effects of water control structures, and increased temperatures and decreased water flows related to climate change. If these threats are not managed effectively, this species may become at greater risk of extinction.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable. No information available on population trends.
Criterion B (Small Distribution Range and Decline or Fluctuation): Not applicable. EOO and IAO exceed thresholds.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable. No information available on population size.
Criterion D (Very Small or Restricted Population): Not applicable. No information available on population size.
Criterion E (Quantitative Analysis): Not applicable. No data available.

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

TECHNICAL SUMMARY – Saskatchewan - Nelson River populations

Ichthyomyzon unicuspis

Silver Lamprey

Lamproie argentée

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

Demographic Information

Generation time	6 years
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Unknown
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[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.	Unknown
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	Not applicable
Are there extreme fluctuations in number of mature individuals?	Unknown

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	157,656 km^2
Index of area of occupancy (IAO) (Always report 2x2 grid value)	954 km^2 Continuous
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)	2–10

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

Is there an [observed, inferred, or projected] decline in extent of occurrence?	Yes, observed although likely due to differences in search effort and uncertainty re: previous records of Silver Lamprey in Assiniboine and Red river systems.
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Yes, observed, although likely due to differences in search effort and uncertainty.
Is there an [observed, inferred, or projected] decline in number of subpopulations?	Not applicable
Is there an [observed, inferred, or projected] decline in number of "locations"*?	Yes, although likely due to differences in search effort and uncertainty.
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	No
Are there extreme fluctuations in number of subpopulations?	Not applicable
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)	**N Mature Individuals**
Total	Unknown

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, or 10% within 100 years]?	Unknown

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

Was a threats calculator completed for this species? Yes
Overall threat is High-Medium.

i. Dams and water management (Medium/Low)
ii. Climate change and severe weather (Low)
iii. Invasive non-native species (Low)
iv. Forestry effluents (Low)

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	"Secure" in the United States
Is immigration known or possible?	Possible, but very unlikely.
Would immigrants be adapted to survive in Canada?	Yes

Is there sufficient habitat for immigrants in Canada?	Yes
Are conditions deteriorating in Canada?[+]	No
Are conditions for the source (i.e., outside) population deteriorating?[+]	Variable
Is the Canadian population considered to be a sink?[+]	No
Is rescue from outside populations likely?	No

Data Sensitive Species

Is this a data sensitive species?	No

Status History

COSEWIC Status History: This species was considered in May 2011 and placed in the Data Deficient category. Status re-examined and designated Special Concern in November 2020.

Status and Reasons for Designation:

Status: Special Concern	**Alpha-numeric codes:** Not applicable
Reasons for designation: This small parasitic lamprey is found in widely disjunct, but limited, areas in streams and lakes in the Nelson and Winnipeg River basins of Manitoba and northwestern Ontario. The species is susceptible to fluctuating water levels as a result of water management and climate change. Recent sampling using conventional methods and environmental DNA (sampling water to confirm presence of DNA from the species) now provide sufficient data to conclude that populations of this species may be declining and may become at greater risk of extinction if these threats are not managed effectively.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable. No information available on population trends.
Criterion B (Small Distribution Range and Decline or Fluctuation): Not applicable. May meet Threatened, B2ab(i,ii,iv), with IAO (954 km²) and number of locations (2 to >10) lower than thresholds, but not severely fragmented, and declines in EOO, IAO and locations likely related to search effort. No decline in habitat quality or quality.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable. No information available on population size.
Criterion D (Very Small or Restricted Population): Not applicable. No information available on population size.
Criterion E (Quantitative Analysis): Not applicable. Data not available.

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

TECHNICAL SUMMARY – Southern Hudson Bay - James Bay populations

Ichthyomyzon unicuspis

Silver Lamprey

Lamproie argentée

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

Demographic Information

Generation time	6 years
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Unknown
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[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.	Unknown
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	Not applicable
Are there extreme fluctuations in number of mature individuals?	Unknown

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	4 km²; based on no search effort
Index of area of occupancy (IAO) (Always report 2x2 grid value)	4 km²; based on no search effort
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)	Unknown
Is there an [observed, inferred, or projected] decline in extent of occurrence?	Not applicable; first vouchered specimens from this National Freshwater Biogeographic Zone

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

Is there an [observed, inferred, or projected] decline in index of area of occupancy?	Not applicable
Is there an [observed, inferred, or projected] decline in number of subpopulations?	Not applicable
Is there an [observed, inferred, or projected] decline in number of “locations”*?	Not applicable
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Not applicable
Are there extreme fluctuations in number of subpopulations?	Not applicable
Are there extreme fluctuations in number of “locations”*?	Not applicable
Are there extreme fluctuations in extent of occurrence?	Not applicable
Are there extreme fluctuations in index of area of occupancy?	Not applicable

Number of Mature Individuals (in each subpopulation)

Subpopulations (give plausible ranges)	N Mature Individuals
Total	Unknown

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, or 10% within 100 years]?	Unknown

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

Was a threats calculator completed for this species? Yes Overall threat is unknown

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	“Secure” in the United States
Is immigration known or possible?	No
Would immigrants be adapted to survive in Canada?	Probably
Is there sufficient habitat for immigrants in Canada?	Yes
Are conditions deteriorating in Canada?+	No
Are conditions for the source (i.e., outside) population deteriorating?+	Variable

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

Is the Canadian population considered to be a sink?⁺	No
Is rescue from outside populations likely?	No

Data Sensitive Species

Is this a data sensitive species?	No

Status History

COSEWIC Status History: Species considered in November 2020 and placed in the Data Deficient category.

Recommended Status and Reasons for Designation:

Status: Data Deficient	**Alpha-numeric codes:** Not applicable
Reason for Designation: This small parasitic lamprey has only recently been confirmed as present in the Southern Hudson Bay-James Bay basin based on the two specimens found on angled Northern Pike in the upper Hayes River system of northern Manitoba. There is insufficient information with which to assess the eligibility and status of this species in this system.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable. Data not available.
Criterion B (Small Distribution Range and Decline or Fluctuation): Not applicable. Data not available.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable. Data not available.
Criterion D (Very Small or Restricted Population): Not applicable. Data not available.
Criterion E (Quantitative Analysis): Not applicable. Data not available.

PREFACE

In 2007 and 2011, COSEWIC assessed the status of Northern Brook Lamprey and Silver Lamprey, respectively, in Canada, dividing each species into two designatable units (DUs). The Saskatchewan - Nelson River DU of each species was designated Data Deficient. Directed surveys for distribution and abundance had not been conducted on either species in these DUs, and data on trends were unavailable. However, since 2010, more targeted sampling has been conducted in these DUs (including using environmental DNA assays), and there has been increased reporting of parasitic feeding phase Silver Lamprey caught incidentally by anglers or during surveys for other fish species.

Status assessment of each species was also hampered by the inability to distinguish Northern Brook and Silver lampreys from one another as larvae, which has confounded attempts to accurately assess the distribution of each species. Even in the Great Lakes - Upper St. Lawrence DU, where both species were designated Special Concern, larval assessment data are pooled for the two species and many occurrence records have been based only on larvae that could not be identified to species.

Therefore, because it is difficult or impossible to evaluate the Northern Brook Lamprey and Silver Lamprey entirely independently, the two species are being evaluated together in a single updated report. Furthermore, the species have largely overlapping distributions and similar threats in Canada. Genetic studies show that Northern Brook and Silver lampreys are very closely related and may experience some gene flow where they co-occur. Nevertheless, although the relationship between these paired species has yet to be fully resolved, Northern Brook and Silver lampreys are recognized as distinct species using conventional lamprey taxonomy, and they maintain distinct phenotypes even where they spawn sympatrically. Each should continue to be considered as a distinct species in the accepted sense of the taxonomic hierarchy.

Since 2011, Silver Lamprey presence has been confirmed in a third National Freshwater Biogeographic Zone, the Southern Hudson Bay-James Bay NFBZ. Silver Lamprey had been reported previously in this NFBZ, but no vouchered specimens with clear locational information were kept prior to 2011.

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
(2020)

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

Northern Brook Lamprey
Ichthyomyzon fossor

Great Lakes - Upper St. Lawrence populations
Saskatchewan - Nelson River populations

and the

Silver Lamprey
Ichthyomyzon unicuspis

Great Lakes - Upper St. Lawrence populations
Saskatchewan - Nelson River populations
Southern Hudson Bay - James Bay populations

in Canada

2020

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Kingdom: Animalia
Phylum: Chordata
Subphylum: Vertebrata
Class: Petromyzontida
Order: Petromyzontiformes
Family: Petromyzontidae

Scientific name: *Ichthyomyzon fossor* Reighard and Cummins 1917

Common names:
English: Northern Brook Lamprey
French: lamproie du nord

Scientific name: *Ichthyomyzon unicuspis* Hubbs and Trautman 1937

Common names:
English: Silver Lamprey
French: lamproie argentée

Ichthyomyzon, derived from Greek, translates to “fish” (ichthys) and “suckle” (myzo). The species epithet *fossor*, meaning “digger,” is in reference to the Northern Brook Lamprey’s main life stage where it burrows in substrate to filter feed, and *unicuspis* refers to the Silver Lamprey’s distinguishing feature of having single cusps on the circumoral teeth (Scott and Crossman 1998). Previous nomenclature of the Northern Brook Lamprey includes: *Ammocoetes unicolor* DeKay 1842, *Ammocoetes borealis* Agassiz 1850, and *Reighardina unicolor* (DeKay 1842). Previous nomenclature of the Silver Lamprey includes: *Petromyzon argenteus* Kirkland 1941, *Ammocoetes concolor* Kirkland 1941, *Ammocoetes borealis* Agassiz 1850, *Petromyzon hirudo* Jordan and Copeland 1876, *Ichthyomyzon castaneus* Provancher 1876, and other variations in use up until 1933, but which Hubbs and Trautman (1937) considered were referring to Silver Lamprey (Scott and Crossman 1998).

The Northern Brook Lamprey (*Ichthyomyzon fossor*) and Silver Lamprey (*Ichthyomyzon unicuspis*) are one of three closely related species pairs in the genus *Ichthyomyzon*. Such “paired” species exist in seven of the 10 extant lamprey genera. In each pair, the larvae (which are microphagous filter feeders) are morphologically similar or indistinguishable but, at metamorphosis, their life-history types diverge (*see* Potter 1980a; Docker 2009; Docker and Potter 2019). One member of the pair (in this case, the Northern Brook Lamprey) begins sexual maturation during metamorphosis and spawns and dies the following spring without ever feeding again; these non-parasitic and non-migratory lampreys are collectively called “brook lampreys.” The other member of the pair (in this case, the Silver Lamprey) remains sexually immature following metamorphosis, feeds parasitically on ray-finned fishes for several months to more than a year (either in its natal stream or after migrating to larger waterbodies) before initiating sexual maturation and embarking on its upstream migration to spawn and die.

Conspicuous morphological (e.g., smaller adult body size, relative eye and oral disc size) and histological (e.g., lack of a functional digestive tract following metamorphosis) differences distinguish non-parasitic adults from parasitic forms, and most lamprey taxonomists recognize feeding type as a species-specific characteristic (e.g., Potter *et al.* 2015) because size-assortative mating was thought to result in reproductive isolation between such differently sized parasitic and non-parasitic forms (Hardisty and Potter 1971). However, plasticity of feeding type (e.g., facultative parasitism) has been observed in some lamprey populations (Manion and Purvis 1971; Beamish 1987), and molecular data on a number of paired species show no genetic differentiation between species pairs where they co-occur and evidence of contemporary gene flow (e.g., Docker *et al.* 2012; Rougemont *et al.* 2015). Such findings have led to suggestions that lamprey paired species are different ecotypes of a single species and even that feeding type might not be genetically determined (*see* Docker 2009; Artamonova *et al.* 2011; Docker and Potter 2019).

Recent genomic studies on the European Brook Lamprey (*Lampetra planeri*) and European River Lamprey (*Lampetra fluviatilis*) demonstrated that feeding type in this pair did have a genetic basis (i.e., was not due to phenotypic plasticity). Rougemont *et al.* (2017) identified 40 single nucleotide polymorphisms (SNPs) that were highly differentiated between European River and Brook lampreys, even where they co-occurred and showed evidence of gene flow at neutral loci (i.e., not under selection). A total of 166 species-specific loci were found in a European River-European Brook lamprey pair from southern Portugal (Mateus *et al.* 2013), although a subsequent study by these authors showed that the two feeding types from this population could also be differentiated at neutral microsatellite loci (F_{ST} 0.317; Mateus *et al.* 2016), suggesting that not all of the 166 fixed loci were necessarily correlated with life-history type. Rougemont *et al.* (2015, 2017) have suggested that these European “species” are partially reproductively isolated ecotypes that maintain distinct phenotypes because regions of the genome involved in reproductive isolation and local adaptation resist the homogenizing effect of introgression, resulting in highly differentiated “genomic islands” amid a background or “sea” of less differentiated loci. The virtual absence of later-generation hybrids in the wild suggested some form of hybrid breakdown (Rougemont *et al.* 2017).

Similar genomic studies have not yet been performed in the Northern Brook and Silver lamprey pair. Hybridization experiments between Northern Brook Lamprey and Silver Lamprey showed that the survival of hybrids was equivalent to that of pure individuals for the first few weeks following fertilization (Piavis *et al.* 1970), but there is nothing known regarding possible selection against hybrids later in development (e.g., survival at metamorphosis when the two feeding types diverge or reproductive capacity at maturity). A long-term study investigating the heritability of feeding type of Northern Brook and Silver lamprey larvae transplanted into streams experiencing different environmental conditions was inconclusive given the high rates of mortality experienced during artificial propagation, but no larvae were shown to switch feeding type (Neave *et al.* 2019). Nevertheless, although it is clear that Silver and Northern Brook lampreys are closely related and may experience some gene flow, it is unlikely that they represent a single panmictic (i.e., freely interbreeding, with no apparent barriers to gene flow) species. The lack of differences observed to date in mitochondrial DNA (mtDNA) and microsatellite markers does not preclude differentiation at regions of the genome related to feeding type. Furthermore, although evidence of gene flow between paired species in sympatry suggests that they are only partially reproductively isolated, it is important to distinguish between true sympatry, where the paired species come into contact (e.g., overlapping in their spawning sites), and situations where they are found in the same basin or river systems but with no opportunity for contemporary gene flow (i.e., where they are parapatric). Although Docker *et al.* (2012) demonstrated a lack of significant genetic differentiation between Northern Brook and Silver lampreys where they were collected from the same rivers in the Lake Huron basin, the two species were significantly differentiated in the Lake Michigan basin where Northern Brook Lamprey were collected almost exclusively from the basin's eastern shore and Silver Lamprey were collected from the western shore. Similar patterns have been seen in other lamprey paired species (Bracken *et al.* 2015; Rougemont *et al.* 2015), where higher levels of differentiation are observed in parapatry than in sympatry. Northern Brook and Silver lampreys are not often collected from the same tributaries in Canadian waters (*see* **Distribution**), reducing the opportunity for gene flow between the species.

Thus, based on recent genomics results in other paired lamprey species and in keeping with conventional lamprey taxonomy (e.g., Renaud *et al.* 2009; Renaud 2011; Potter *et al.* 2015; Docker and Potter 2019), Northern Brook and Silver lampreys are considered distinct species here. However, given the potential for gene flow (suggesting that they may not always be entirely evolutionarily independent) and the inability to distinguish them during the long-lived larval stage (thus making it difficult or impossible to evaluate them entirely independently), the two species are being evaluated together in a combined status report. In each section, shared information on the two species will be combined and then, when warranted or possible, each species will be discussed separately in the order Northern Brook Lamprey and then Silver Lamprey.

Morphological Description

Lampreys are easily distinguished from most other fishes by their elongate body shape, jawless mouth (characterized by a toothed, oral disc in adults), lack of paired fins and scales, a single large, central nostril, and seven pairs of gill pores leading to internal gills (Figure 1). All lamprey species pass through a protracted larval phase that is spent burrowed in the soft substrata in the slower-flowing regions of streams and rivers (*see* **Biology**). The larva, termed an ammocoete, has a worm-like body shape and is blind and toothless, possessing an oral hood for filter feeding rather than the sucking oral disc.

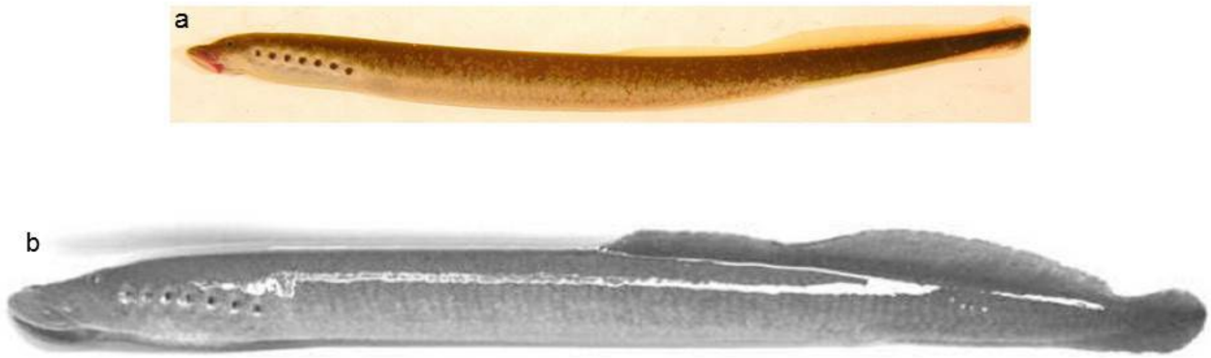

Figure 1. Adult (a) Northern Brook Lamprey (*Ichthyomyzon fossor*) and (b) Silver Lamprey (*Ichthyomyzon unicuspis*). Photos by Fraser Neave (used with permission).

The genus *Ichthyomyzon* can be distinguished from all other lamprey genera by possessing a single indented dorsal fin compared to the two distinct dorsal fins possessed by other genera. This trait allows identification of *Ichthyomyzon* spp. even during the larval stage. Thus, using this trait, Northern Brook and Silver lampreys can be distinguished from Sea Lamprey (*Petromyzon marinus*) and American Brook Lamprey (*Lethenteron appendix*), species with which they may occur in the Great Lakes basin (Renaud *et al.* 2009; Potter *et al.* 2015).

Distinguishing among congeneric lamprey species is more difficult. Of the six species in *Ichthyomyzon* genus, the parasitic Chestnut Lamprey (*Ichthyomyzon castaneus*) also occurs in Canada—in Saskatchewan and Manitoba, and possibly Ontario and Quebec (Renaud *et al.* 2009; COSEWIC 2010). In the juvenile (i.e., parasitic feeding phase following metamorphosis but prior to sexual maturation) and adult stages, Northern Brook and Silver lampreys are distinguished from the Chestnut Lamprey by the usual absence in their oral disc of bicuspid inner lateral (or circumoral) teeth (range 0–2; strong mode of 0) compared to typically 6–8 bicuspid inner lateral teeth (range 1–8; mode of 6) in the Chestnut Lamprey (Renaud 2011; Figure 2). Adult non-parasitic Northern Brook Lamprey are easily distinguished from Chestnut Lamprey by their smaller eye, oral disc, and body size, but variation in dentition patterns in the two parasitic species may result in some uncertainty regarding identification (*see* **Distribution**). Hubbs and Trautman (1937) showed that 98% of all Silver Lamprey had 0 bicuspid inner lateral teeth and 77% of all Chestnut Lamprey had 6–8 bicuspid inner lateral teeth. In Renaud *et al.* (1996), 81% of Silver Lamprey from Ontario had 0 bicuspid inner lateral teeth (the rest had 1 or 2 bicuspid inner lateral teeth). In contrast, four of the five Ontario Chestnut Lamprey specimens possessed 4 or 5 bicuspid inner lateral teeth, and the fifth possessed 3 or 4. However, Hall and Moore (1954) reported two Chestnut Lamprey specimens without any bicuspid inner lateral teeth; one specimen was from Oklahoma and the other was from Texas, where neither Northern Brook Lamprey nor Silver Lamprey have ever been reported. Furthermore, genetic analysis has been used to confirm the identity of one Chestnut Lamprey without any bicuspid inner lateral teeth (from the Rat River in Manitoba; Figure 3a) and one Silver Lamprey with one bicuspid inner lateral tooth (from the Winnipeg River near Kenora, Ontario; Figure 3b). In contrast to the subtle morphological differences, there are pronounced and diagnostic differences in mtDNA sequence (Lang *et al.* 2009; Docker *et al.* 2012) that have allowed for the development of easy, definitive genetic assays to distinguish Chestnut Lamprey from Silver and Northern Brook lampreys (Neave *et al.* 2007). This assay is applicable to all stages and sizes, and it has been used to test methods to distinguish Chestnut Lamprey from Northern Brook and Silver lampreys as larvae. According to Vladykov and Kott (1980) and Lanteigne (1981, 1988), Chestnut Lamprey larvae can be distinguished from Northern Brook and Silver lamprey larvae by their darkly pigmented lateral-line organs. Using genetic analysis, Neave *et al.* (2007) found that the lateral-line organs were not pigmented in any Chestnut Lamprey < 80 mm in total length (TL) but were darkly pigmented in 24% of those 81–104 mm, and all individuals ≥105 mm TL had pigmented lateral-line organs (Figure 4). Thus, although the absence of pigmented lateral-line organs does not definitively identify small Northern Brook and Silver lamprey larvae, their absence is thought to be diagnostic in larger larvae (≥105 mm TL) and their presence definitively identifies Chestnut Lamprey larvae of any size.

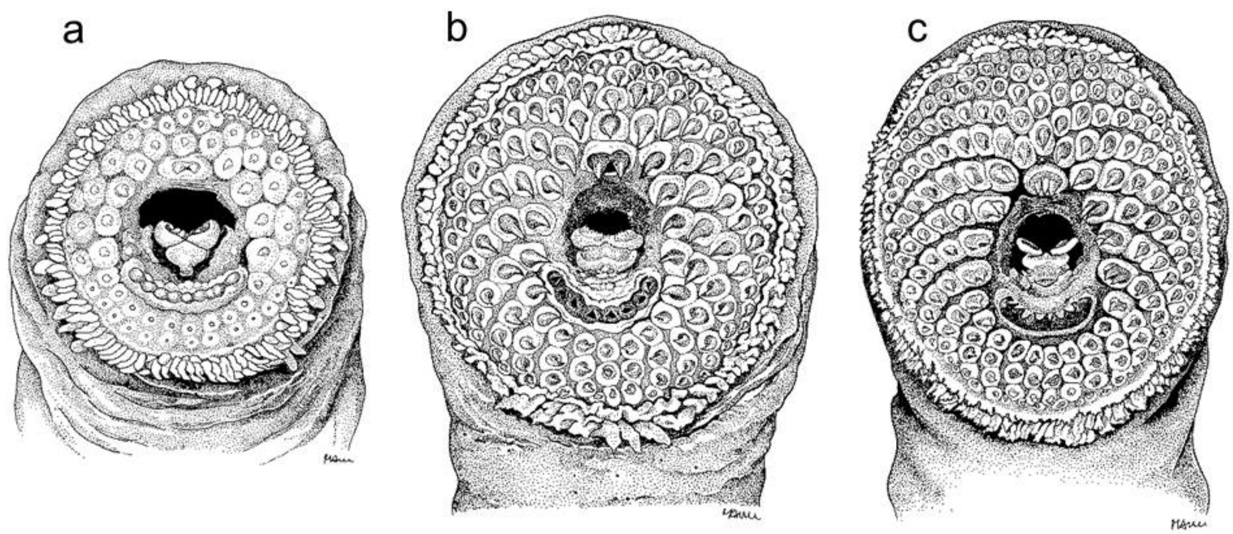

Figure 2. Oral disc of: a) Northern Brook Lamprey (*Ichthyomyzon fossor*); b) Silver Lamprey (*Ichthyomyzon unicuspis*); and, c) Chestnut Lamprey (*Ichthyomyzon castaneus*). Source: Food and Agriculture Organization of the United Nations, Original Scientific Illustrations Archive (reproduced with permission).

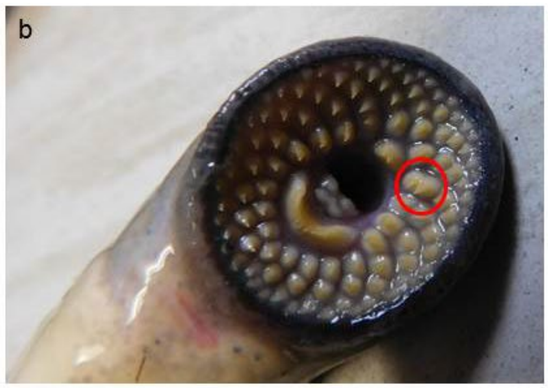

Figure 3. Atypical dentition in Chestnut and Silver lampreys: a) Chestnut Lamprey (left, as confirmed by genetic analysis) with unicuspid inner lateral teeth and normal bicuspid Chestnut Lamprey (right) collected from the Rat River, Manitoba, in 2011. Photo by Margaret Docker (used with permission); and, b) Silver Lamprey with one bicuspid inner lateral tooth (circled). Photo by Ontario Ministry of Natural Resources and Forestry, Kenora District (used with permission).

Figure 4. Chestnut Lamprey larva displaying pigmentation along its lateral line organs (circled); note that lateral line pigmentation was artificially darkened (in Microsoft Paint) to enhance visibility. Photo by Fraser Neave (used with permission).

The closely related Northern Brook and Silver lampreys are generally distinguishable from one another by mid- to late metamorphosis (Table 1). The non-parasitic Northern Brook Lamprey, which does not feed again after metamorphosis, can be distinguished from post-metamorphic Silver Lamprey by its relatively small eye, small oral disc (which is narrower than the width of the head or body), and poorly developed, knob-like teeth. Northern Brook Lamprey adults are significantly smaller than Silver Lamprey adults. TL at maturity averages 115–119 mm (Hubbs and Trautman 1937; Morman 1979; *see* Docker

2009). Northern Brook Lamprey also tend to be darker in colour (grey or brown) dorsally and switching to a silvery-white on the ventral surface (Vladykov 1949). It has been observed that during spawning, females can develop an orange tint on their ventral surface, where the eggs show through the body wall; after spawning, both sexes darken to black or a dark blue (Vladykov 1949; Becker 1983). They generally remain within their natal stream and stay burrowed until shortly before spawning (Dawson *et al.* 2015). Silver Lamprey, which feeds parasitically following metamorphosis, is recognizable by its relatively large eye, large oral disc (which is wider than the width of the head or body), and sharper, more prominent teeth. Silver Lamprey adults are considerably larger than Northern Brook Lamprey. Total length at maturity averages 224–248 mm (Hubbs and Trautman 1937; Vladykov 1951; Morman 1979; *see* Docker 2009), although individuals as large as 390–415 mm have been reported near the end of the parasitic feeding phase (Morman 1979; Cochran and Marks 1995; Cochran and Lyons 2004) prior to the shrinkage experienced during their non-trophic sexual maturation (*see* **Biology**). Silver Lamprey tend to reach smaller sizes in Canada compared to the United States (Scott and Crossman 1998). Vladykov and Roy (1948) reported maximum total length to be 318 mm, although a 331 mm Silver Lamprey was captured in the St. Lawrence River in October 2001 during a standardized survey conducted by the Ministère des Forêts, de la Faune et des Parcs (MFFP). Colouration of adult Silver Lamprey tends to be a tannish-yellow with a darker dorsal surface, and a lighter ventral surface (Hubbs and Trautman 1937). Despite its common name, Vladykov (1949) noted that no silvery colouration was observed in hundreds of adult Silver Lamprey specimens collected in Quebec. In both Northern Brook and Silver lamprey adults, females are generally larger than males (Scott and Crossman 1998; Docker 2009). Given the dramatic differences in size at maturity, Silver Lamprey females are considerably more fecund than Northern Brook Lamprey females (Table 1).

Table 1. Morphological and life-history traits in Northern Brook Lamprey and Silver Lamprey, compiled from Hubbs and Trautman (1937), Purvis (1970), Morman (1979), Scott and Crossman (1998), Docker (2009), Docker *et al.* (2019).

	Northern Brook Lamprey	**Silver Lamprey**
Size at maturity	Range: 86–170 mm Mean: 115–119 mm	Range: 157–415 mm Mean: 224–248 mm
Adult teeth	Small, blunt, and peg-like	Long, curved, and sharp
Eye size	Small	Moderately large
Diameter of sucking disc	Less than width of branchial region	Greater than width of branchial region
Number trunk myomeres	47–56	47–55
Juvenile–adult lifespan (i.e., post-metamorphosis)	6–8 months	18–20 months
Larval duration	3–7 years	3–7 years
Maximum larval size	182 mm	155 mm
Average fecundity	1,200	19,000

	Northern Brook Lamprey	Silver Lamprey
Migratory	No	Yes
Parasitic	No	Yes

Despite the pronounced morphological differences that emerge at metamorphosis, Northern Brook and Silver lampreys are not distinguishable as larvae. Although there appears to be a general trend in lampreys for fewer trunk myomeres in non-parasitic species relative to parasitic species (Vladykov and Kott 1979), the difference among paired species is rarely, if ever, diagnostic (Docker 2009). Not even subtle differences in myomere number have been observed between Northern Brook and Silver lampreys, where the myomere counts average 50.9 and 50.5, respectively, and the ranges overlap almost completely (Hubbs and Trautman 1937; Table 1). Some authors have described differences between the species in pigmentation patterns in the branchial region (Lanteigne 1981, 1988; Stewart and Watkinson 2004) and tail (Vladykov and Kott 1980; Fuiman 1982). However, some of these keys are contradictory (e.g., Vladykov and Kott 1980; Lanteigne 1988), and other authors have found that such differences in pigmentation or other external features are not reliable for diagnostic species identification, particularly when comparisons are made across a broader geographic area (Purvis 1970; Morman 1979; Becker 1983; Neave *et al.* 2007).

There are also no diagnostic genetic differences known to exist between Northern Brook and Silver lampreys. Studies using mtDNA sequence data show that Silver and Northern Brook lampreys are not reciprocally monophyletic and lack fixed species-specific differences (Lang *et al.* 2009; Docker *et al.* 2012; Ren *et al.* 2016). Allele frequency differences were observed between the species by Filcek *et al.* (2005), who were able to distinguish Northern Brook Lamprey from the Lake Superior basin and Silver Lamprey from tributaries to Lake Michigan using microsatellite markers developed for Sea Lamprey. However, as the two species were collected from different basins, observed species differences were likely confounded by geographic differences. Using microsatellite markers, Docker *et al.* (2012) found no evidence of genetic differentiation between Northern Brook and Silver lampreys where they occur sympatrically in the Lake Huron basin and, although the two species were significantly differentiated when collected from allopatric localities in the Lake Michigan basin, statistical differences in allele frequencies still do not allow for diagnostic identification of individuals. Future genomic analyses (e.g., using SNPs) may identify loci capable of species identification (*see* **Name and Classification**), but none exist at present.

Ecological or life-history characteristics are sometimes used to infer species identification, although these are also not conclusive. Location of capture can be an indication of species identity, because Northern Brook Lamprey is more likely to be found in smaller streams than Silver Lamprey (Scott and Crossman 1998). Likewise, Northern Brook Lamprey are more likely to be found above barrier dams, and migratory Silver Lamprey, not surprisingly, tend to be limited to the lower stretches of rivers (*see* **Habitat**). The presence of adults of one species or the other is also used sometimes to infer species identification of larvae collected from particular localities, but this is not always reliable, because both species occur together in some tributaries and the limited search effort expended at some localities or at times of the year when adults are present makes it impossible to rule out the presence of the other species. It has also been suggested that differences in the size at which metamorphosis occurs can help distinguish between parasitic and non-parasitic lampreys (*see* Docker 2009). In general, metamorphosing Northern Brook Lamprey are larger than metamorphosing Silver Lamprey (Table 1), but this only suggests that very large individuals might be Northern Brook Lamprey. Likewise, larvae of non-parasitic species tend to have a lower potential fecundity (e.g., number of oocytes per histological cross section), and individuals with very high oocyte counts (80–93 per cross section) are likely Silver Lamprey (Neave *et al.* 2007). However, in most individuals, the differences are likely not diagnostic and this approach requires lethal sampling and time-consuming histological preparation (Neave *et al.* 2007; Docker 2009; Spice and Docker 2014). Thus, in this report, most data and information on larval Northern Brook and Silver lampreys are pooled.

Population Spatial Structure and Variability

Across larger spatial scales (e.g., across their range within the Great Lakes or between National Freshwater Biogeographic Zones, NFBZs), genetic differences in Northern Brook and Silver lampreys are greater among regions (e.g., basins) than between species. For example, within the Great Lakes and Upper St. Lawrence River NFBZ, an east-to-west gradient was observed in both Northern Brook and Silver lampreys with respect to the distribution of the mtDNA haplotypes; variation among basins was significant, but there was no significant range-wide difference in haplotype frequency between Northern Brook and Silver lampreys (Docker *et al.* 2012). Of the five most common composite mitochondrial haplotypes, three (A1, A2, and A4) were widespread, occurring in 93% of the > 500 individuals surveyed across this region. However, the fourth haplotype (type A3) was found only in lampreys from Lake Erie and Lake Huron tributaries, and the frequency of the fifth haplotype (B1), which was found in 6% of all individuals, decreased from east to west. Type B1 was found in 75 and 21% of Northern Brook Lamprey from Lake Champlain and Lake Erie, respectively, and in 2–10% of Northern Brook and Silver lampreys from Lake Huron and Michigan, but it was not found among any of the 117 lampreys sampled in the Lake Superior basin. A Mississippian refugium during the most recent Wisconsinan glaciation has been suggested for these species (Mandrak and Crossman 1992), and it is possible that the two observed mitochondrial lineages represent different recolonization routes. Mandrak and Crossman (1992) suggested that Ontario populations of Northern Brook Lamprey re-colonized postglacially from either or both of the Warren or Brule-Portage routes, and they suggested that Silver Lamprey recolonized via the Brule-Portage or Chicago postglacial dispersal routes. Genetic variation among Great Lakes basins was likewise significant using microsatellite loci, although to a lesser extent than using mtDNA markers (e.g., AMOVA showed that 3.1% of the variation in microsatellite allele frequencies was among basins, while 27.9% of the mtDNA variation was among basins). In general, mtDNA retains historical patterns that are more quickly lost in microsatellites, especially with ongoing gene flow among populations (Avise 2000; Heckel *et al.* 2005; Spice *et al.* 2019).

Mitochondrial DNA variation has not been systematically examined between the Great Lakes-Upper St. Lawrence and Saskatchewan-Nelson River NFBZs. However, McFarlane (2009) found significant variation between Northern Brook and Silver lampreys from the Great Lakes basin and Silver Lamprey from the Winnipeg River using *Ichthyomyzon*-specific microsatellite loci. Genetic differentiation (F_{ST}) among the Great Lakes basins averaged 0.070, but comparison between Silver Lamprey from the Winnipeg River and Northern Brook and Silver lampreys from the Great Lakes yielded F_{ST} values averaging 0.213. Based on its distribution, Stewart and Watkinson (2004) hypothesized that Silver Lamprey entered the Red River mainstem via Big Stone Lake and Lake Traverse, or Red River tributaries from Mississippi River tributaries in Minnesota. Silver Lamprey also presumably entered Manitoba via the Winnipeg-Rainy River system from the Great Lakes, given its distribution in western Ontario and Minnesota. Stewart and Watkinson (2004) suggested that Northern Brook Lamprey entered Manitoba during postglacial times from the Great Lakes via the Winnipeg River, but Northern Brook Lamprey from the Saskatchewan-Nelson River NFBZ were not included in the genetic analyses by McFarlane (2009).

On smaller spatial scales (e.g., within each basin), species-specific differences in spatial structure are expected given the different adult life-history types between Northern Brook and Silver lampreys. In general, non-parasitic, non-migratory (brook) lampreys show more genetic differentiation among populations than do migratory parasitic lampreys, especially because it appears that migratory lampreys do not home to their natal streams (e.g., Goodman *et al.* 2008; Waldman *et al.* 2008; Bracken *et al.* 2015). For example, F_{ST} values in Western Brook Lamprey (*Lampetra richardsoni*) populations separated by < 570 km in the Columbia River basin were more than an order of magnitude greater than those for anadromous Pacific Lamprey (*Entosphenus tridentatus*) separated by up to 2,600 km (Spice *et al.* 2012, 2019). Although not studied as extensively in Northern Brook and Silver lampreys, this same pattern appears to be observed, as outlined below.

Northern Brook Lamprey disperse far less widely than Silver Lamprey (*see* **Dispersal and Migration**). Therefore, as expected, McFarlane (2009) found that genetic differentiation among Northern Brook Lamprey populations was greater than that of Silver Lamprey on the same spatial scale. For example, F_{ST} averaged 0.078 and 0.089 among Northern Brook Lamprey populations in Lake Huron and Michigan, respectively, and 0.056 and 0.038 among Silver Lamprey populations in these basins. However, given the evidence for contemporary gene flow between sympatric Northern Brook and Silver lampreys (Docker *et al.* 2012), Silver Lamprey may mediate gene flow among otherwise disjunct brook lamprey populations. Preliminary observations that genetic differentiation between Northern Brook Lamprey populations is higher in areas where Silver Lamprey do not occur is consistent with this suggestion (Docker unpubl. data), but further study is required.

In contrast, there is almost certainly gene flow among different Silver Lamprey streams within a region. Like in other parasitic lampreys, feeding juveniles can be transported large distances on host fishes, and they do not appear to home to their natal streams to spawn (*see* Spice *et al.* 2012). As a result, it is not likely that Silver Lamprey populations over moderate spatial scales (e.g., within basins) are geographically isolated.

However, movement between basins, especially those separated by salt water, may be restricted (but *see* **Designatable Units** re: proximity of the Nelson and Hayes river mouths). Unlike anadromous lampreys or freshwater forms that are recently derived from anadromous lampreys (e.g., landlocked Sea Lamprey), Silver Lamprey appears to have either evolved in fresh water or been freshwater resident for long periods of evolutionary time (Bartels *et al.* 2012). Furthermore, gene flow within some streams may be limited by physical impediments such as natural and artificial barriers (Schreiber and Engelhorn 1998; Spice *et al.* 2012).

Designatable Units

Although the relationship between these paired lamprey species has yet to be fully resolved, Northern Brook and Silver lampreys are recognized as distinct species using conventional lamprey taxonomy, and they maintain distinct phenotypes even with the potential for contemporary gene flow when they spawn sympatrically (*see* **Name and Classification**). Therefore, using “species” in the accepted sense of the taxonomic hierarchy, each should continue to be considered as a distinct species.

In both the Northern Brook Lamprey and Silver Lamprey, the previous COSEWIC reports identified two designatable units (DUs): the Great Lakes-Upper St. Lawrence populations (DU1) and the Saskatchewan-Nelson River populations (DU2) (COSEWIC 2007, 2011). These two DUs correspond with two NFBZs used, in part, by COSEWIC for recognition of discrete and evolutionarily significant units (COSEWIC 2015).

Results from mtDNA analysis are consistent with the lampreys within the Great Lakes-Upper St. Lawrence and Saskatchewan-Nelson River NFBZs representing discrete and evolutionarily significant units. Although Northern Brook Lamprey has not yet been analysed, Silver Lamprey from the two NFBZs differ significantly in the frequency of four mtDNA haplotypes; those from the Great Lakes-Upper St. Lawrence NFBZ (n = 155) exhibited four mtDNA haplotypes (A1, A2, A4, and B1), while Silver Lamprey (n = 15) from the Saskatchewan-Nelson River NFBZ was fixed for a single haplotype (A1; Docker unpubl. data).

Furthermore, the occupancy within two NFBZs reflects isolation within distinct geographic regions with different environmental conditions and distinct fish community assemblages. In Northern Brook Lamprey, the distribution gap between the most northwesterly occurrence record in DU1 and the easternmost locality in DU2 is substantial (Figure 5, 6), especially for a small-bodied species with limited dispersal capabilities. The distribution gap (in terms of overland distances) is smaller for the Silver Lamprey (Figure 7, 8), but natural dispersal between the different drainages in these two NFBZs is unlikely. Moreover, the ecological and environmental conditions experienced by Silver Lamprey in these two NFBZs that stretch from the lower Nelson River near Hudson Bay to the upper St. Lawrence River estuary are undoubtedly quite distinct. Thus, the Great Lakes-Upper St. Lawrence populations (DU1) and the Saskatchewan-Nelson River populations (DU2) are both important to the evolutionary legacy of the species as a whole and, if lost, would likely not be replaced through natural dispersal.

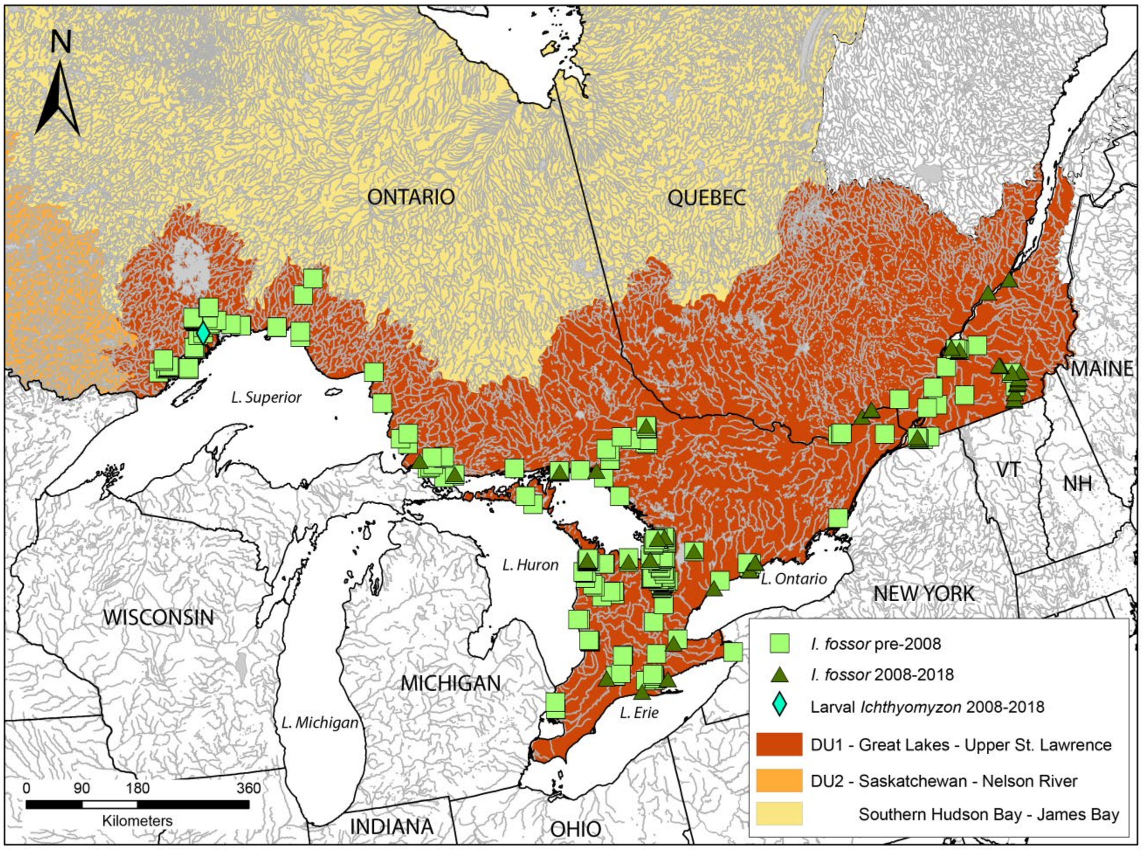

Figure 5. Collections of post-metamorphic Northern Brook Lamprey (*I. fossor*) in the Great Lakes-Upper St. Lawrence (DU1). Larval specimens (larval *Ichthyomyzon*) are included only where historical records strongly support the occurrence of only Northern Brook Lamprey (*see* Distribution); collections of *Ichthyomyzon* larvae that could not be confidently identified as Northern Brook or Silver Lamprey are shown in Figure 10.

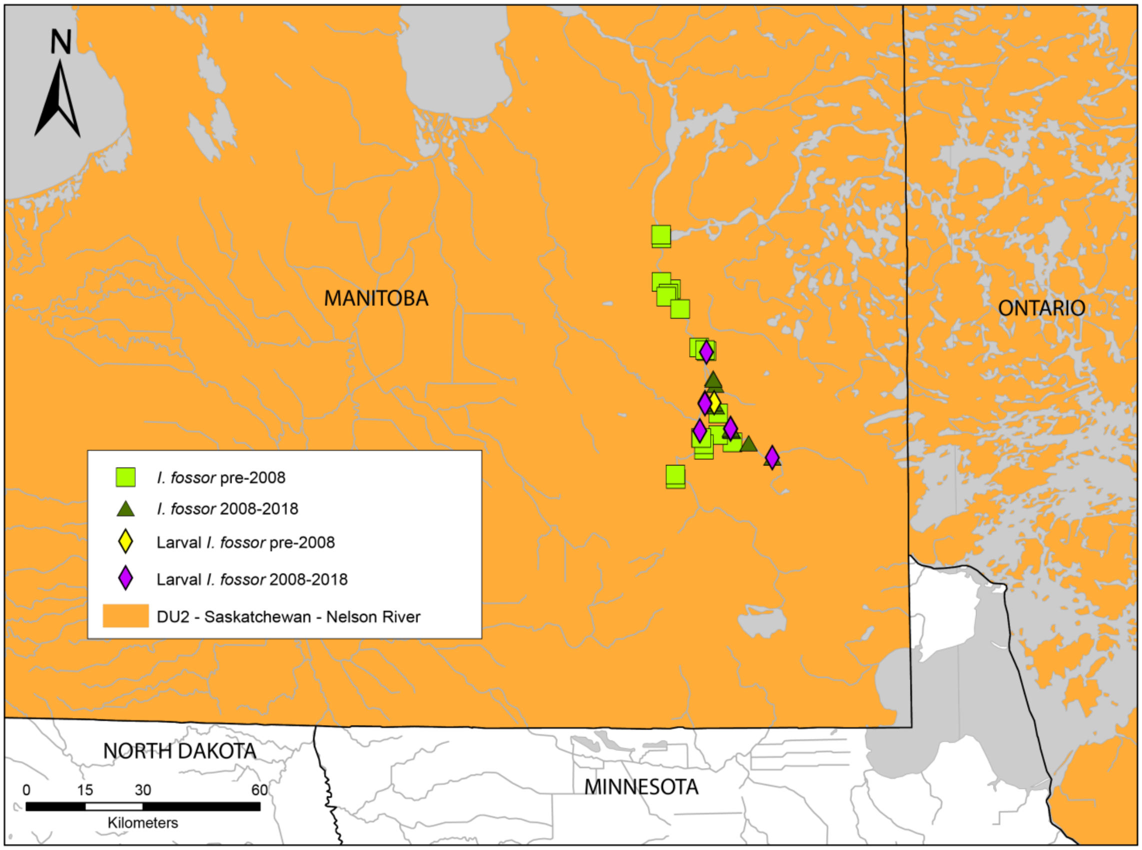

Figure 6. Collections of Northern Brook Lamprey in the Saskatchewan-Nelson River (DU2). Records include post-metamorphic specimens (*I. fossor*), as well as larval specimens (larval *I. fossor*) where recent and historical records suggest that no Silver Lamprey are present (*see* Distribution).

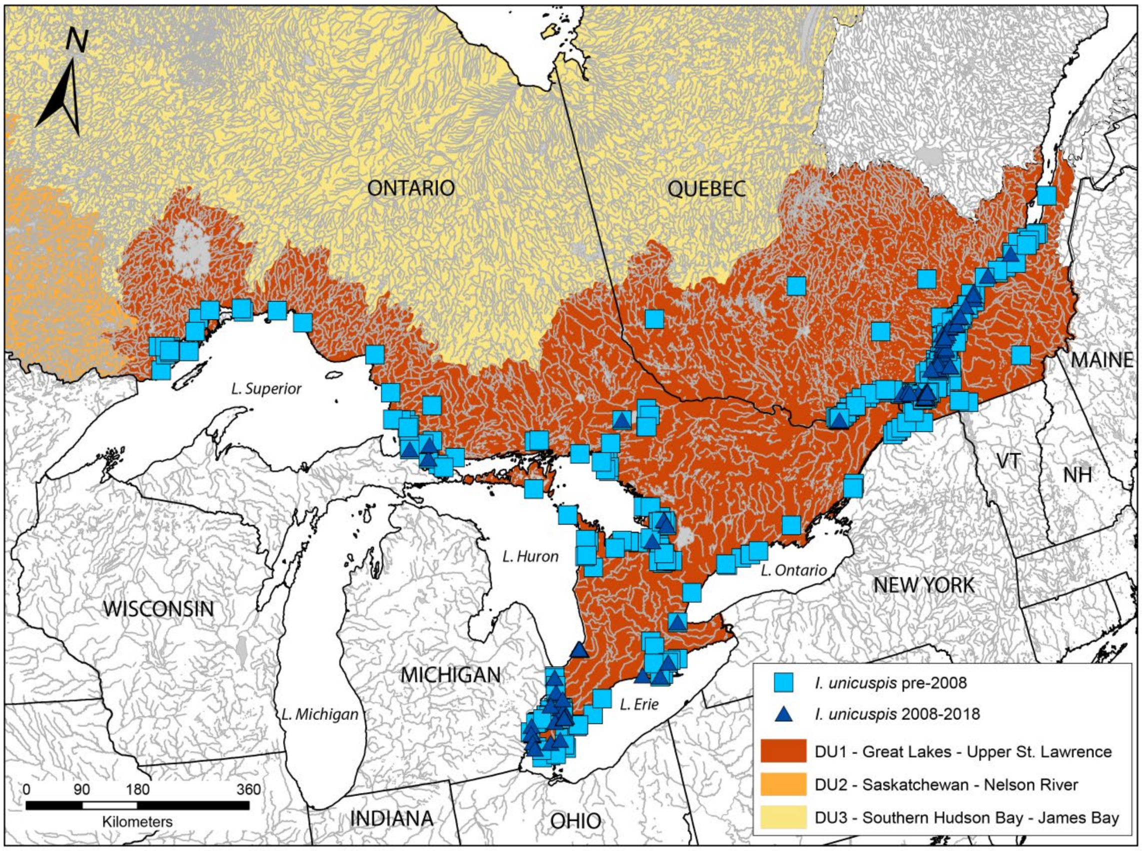

Figure 7. Collections of post-metamorphic Silver Lamprey (*I. unicuspis*) in the Great Lakes-Upper St. Lawrence (DU1); collections of *Ichthyomyzon* larvae that could not be confidently identified as Northern Brook or Silver Lamprey are shown in Figure 10.

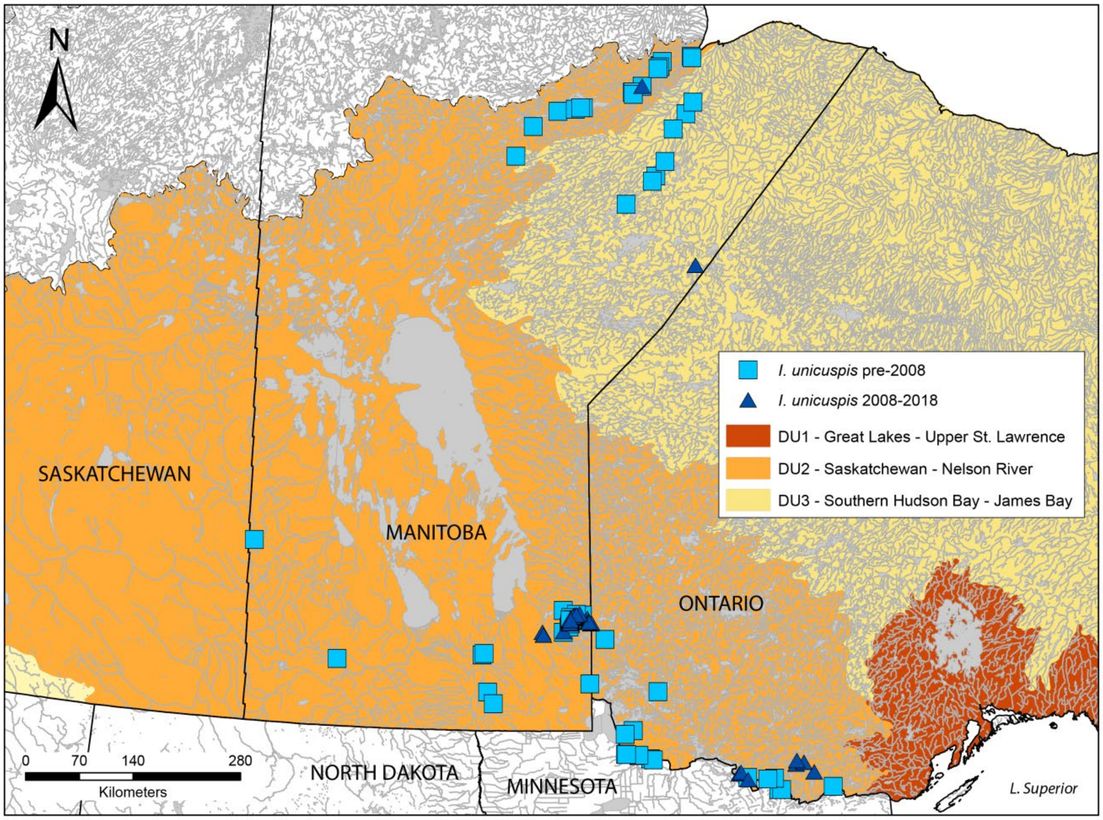

Figure 8. Collections of post-metamorphic Silver Lamprey (*I. unicuspis*) in the Saskatchewan-Nelson River (DU2) and Southern Hudson Bay-James Bay (DU3).

In addition to these two DUs described in the previous reports, Silver Lamprey presence has recently been confirmed in the upper Hayes River system in a third NFBZ, the Southern Hudson Bay-James Bay NFBZ (Tyson and Watkinson 2013; Figure 8). The proximity of the mouths of the Hayes River and the Nelson River (< 50 km), combined with our current understanding of postglacial dispersal routes, suggest a Nelson River origin for the Silver Lamprey in the Hayes River (Stewart and Lindsey 1983; Mandrak and Crossman 1992). Furthermore, potential host species such as Lake Sturgeon (*Acipenser fulvescens*), Lake Whitefish (*Coregonus clupeaformis*), and Brook Trout (*Salvelinus fontinalis*) are known to move back and forth between the Hayes and Nelson river systems (*see* Tyson and Watkinson 2013). However, unlike anadromous lampreys or freshwater forms that are recently derived from anadromous lampreys (e.g., landlocked Sea Lamprey), Silver Lamprey appears to have either evolved in fresh water or been freshwater resident for long periods of evolutionary time (Bartels *et al.* 2012). Although increased contribution of river water along the shore might provide a lower-salinity coastal conduit between the mouths of the Hayes and Nelson rivers (Granskog *et al.* 2009), movement between basins separated by salt water is likely restricted. In keeping with the recommendation of Tyson and Watkinson (2013), until more information is available, the Silver Lamprey in the Hayes River should be placed in a separate DU in order to maintain consistency with the delineation of the national freshwater biogeographical zones (COSEWIC 2015).

Thus, there are now three DUs for Silver Lamprey. No additional records of Northern Brook Lamprey have been reported in any other NFBZ.

Special Significance

Along with hagfishes, lampreys are the only extant jawless vertebrates, which diverged from the rest of the vertebrate lineage more than 500 million years ago (Kuraku and Kuratani 2006). As such, they provide important insights into the origins and early evolution of vertebrates (Docker *et al.* 2015; McCauley *et al.* 2015; York *et al.* 2019), and they also serve as important model organisms in biomedical research (Docker *et al.* 2015). Lampreys are also known to play important ecological roles. For example, larval lampreys are important in nutrient cycling, facilitating the conversion of nutrients derived from detritus and algae into stored biomass that serves as a food source for other animals. For example, Lake Sturgeon and American Eel (*Anguilla rostrata*), two fish species of commercial, recreational, and cultural importance in the Great Lakes-Upper St. Lawrence and Saskatchewan-Nelson River biogeographic zones, are able to detect and access buried prey and likely feed on larval lampreys. Siberian and White sturgeons (*Acipenser baeri* and *A. transmontanus*, respectively) have been observed feeding on other lamprey species (Cochran 2009), and American Eel were observed to capture and consume American Brook Lamprey larvae in laboratory experiments (Perlmutter 1951). Furthermore, during migration and spawning events, lampreys are fed on by a variety of aquatic, aerial, and terrestrial predators (*see* Scott and Crossman 1998; Docker *et al.* 2015). Lampreys are also ecosystem engineers, where the burrowing and feeding activities of larval lampreys significantly increase substrate oxygen levels (Shirakawa *et al.* 2013) and the nest-building activity of spawning lampreys increases streambed complexity in ways that appear to benefit other fishes and stream invertebrates (Sousa *et al.* 2012; Hogg *et al.* 2014). In addition, due to their sedentary nature, larval lampreys have been used as biomonitors of organochlorine contaminants in fresh water (Renaud *et al*. 1995, 1999).

Further study of paired Northern Brook and Silver lampreys will be of particular scientific value to provide insight into the evolution of alternative feeding strategies and speciation in lampreys. Recent population genomic studies in European River and Brook lampreys are already shedding light on the genetic architecture of life-history type (e.g., Rougemont *et al.* 2017; *see* **Name and Classification**), but, in this and many other lamprey species pairs, the parasitic member of the pair is also anadromous so that feeding and migratory transitions are confounded (i.e., genetic differences observed may be related to osmoregulation and not feeding type). In contrast, the Silver Lamprey has been resident in fresh water for long periods of evolutionary time (Bartels *et al.* 2012), so that differences observed in the genome between sympatric Northern Brook and Silver lampreys are more likely to represent genes specifically related to feeding type. Understanding the genetic mechanisms by which the parasitic feeding phase has been eliminated in the Northern Brook Lamprey could lead to new ways of controlling the invasive Sea Lamprey (McCauley *et al.* 2015).

DISTRIBUTION

Global Range

The distribution of Northern Brook and Silver lampreys is restricted to eastern North America (Figure 9). Both species are found in the Hudson Bay, Great Lakes, St. Lawrence River, and Mississippi River drainages (Potter *et al.* 2015). In Canada, these species are found in Manitoba, Ontario, and Quebec. In the United States, the Northern Brook Lamprey occurs in Illinois, Indiana, Kentucky, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, Vermont, West Virginia, and Wisconsin; the Silver Lamprey has been reported from these 12 states as well as from Iowa, Mississippi, Nebraska, North Dakota, and Tennessee (NatureServe Explorer 2018).

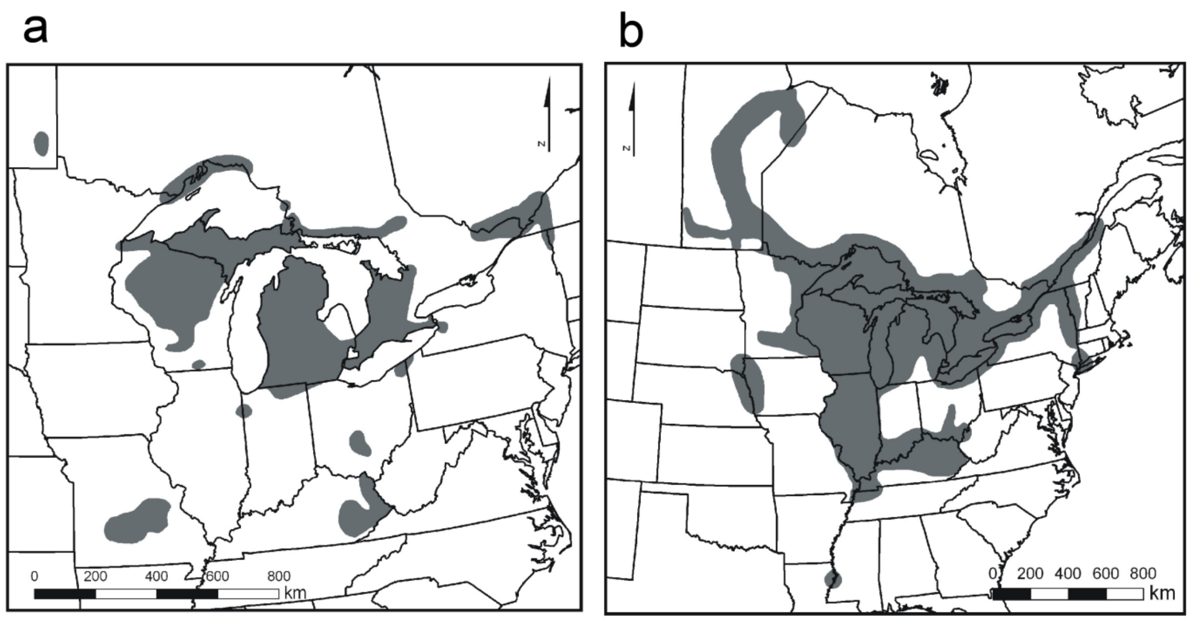

Figure 9. Global distribution of: a) Northern Brook Lamprey; and, b) Silver Lamprey (adapted from Renaud *et al.* 2009).

Search Effort

Northern Brook and Silver lampreys may be more widely distributed (globally and in Canada; *see* below) than indicated by existing records because the inability to distinguish Northern Brook and Silver lampreys from one another as larvae confounds our ability to accurately assess the distribution of each species, and Silver and Chestnut lampreys may sometimes be confused even as adults (*see* **Morphological Description**). Furthermore, the targeted sampling required to collect both species during their burrowed larval stage and Northern Brook Lamprey during their relatively brief (and also largely burrowed) post-metamorphic stages requires specialized equipment and techniques, which have generally not been used outside the Great Lakes basin. The widely used electrofishing surveys that target multiple species of fishes rarely collect larval lampreys, as they tend to become immobilized within their burrows. Pulsed DC electrical current is used in lamprey-specific electrofishing surveys because it is much more successful at influencing emergence of burrowed larvae (Weisser and Klar 1990; Bowen *et al.* 2003). However, even in the Great Lakes, survey activities are generally focused on streams that support Sea Lamprey and each stream is not necessarily sampled at regular intervals, and Sea Lamprey traps are ineffective in catching smaller adult brook lampreys (COSEWIC 2007). Nevertheless, the targeted larval lamprey sampling that was conducted in the Great Lakes basin (including Lake St. Clair) during Sea Lamprey Control Centre (SLCC) Sea Lamprey assessment surveys in 2008–2018 surveyed an average of 163 streams and 19,810 m^2 per year (SLCC unpubl. data). Targeted sampling for larval lampreys has been used more widely in recent years in Quebec and Manitoba, but search effort is variable. Parasitic feeding phase (juvenile) Silver Lamprey are taken as incidental catch by commercial and occasionally recreational fishing gear, but the potential for both capturing and reporting them is markedly lower than that of targeted species. Adult Silver Lamprey are occasionally collected in Sea Lamprey traps on their upstream (spawning) migration, although survey activities are normally restricted to assessment within streams that support Sea Lamprey (*see* **Sampling Effort and Methods**).

Search effort in DU2 has recently been augmented with the use of environmental DNA (eDNA) assays. Gingera *et al.* (2016) developed and tested end-point (conventional) eDNA assays to detect and diagnostically identify Sea Lamprey, American Brook Lamprey, Chestnut Lamprey, and Northern Brook and Silver lampreys; Northern Brook and Silver lampreys were treated as one species because they cannot be distinguished in sympatry by any known genetic methods (*see* **Name and Classification**). More sensitive quantitative or real-time PCR (qPCR) assays have since been developed for Chestnut Lamprey and Northern Brook Lamprey/Silver Lamprey. They amplify 167- and 159-base pair fragments, respectively, of the cytochrome *c* subunit I (COI) gene (Docker unpubl. data). In 2015–2017, these assays were used to test for the presence of Northern Brook Lamprey/Silver Lamprey in water samples collected from 29 tributaries of the Assiniboine, Red, and Winnipeg rivers and nine tributaries to lakes Winnipeg and Manitoba (*see* below). Water was collected at up to six sites within each tributary, over multiple time periods between May and November, resulting in a total of 115 sampling events. Three water samples were collected at each sampling event, and three PCRs were performed on each water sample. Further testing of the assays are required (e.g., to guard against false positives and to ensure sufficient sensitivity to reduce the chance of false negatives; *see* Docker and Hume 2019), but results to date have helped refine our understanding of these species in DU2 and have identified specific streams in need of follow-up sampling using traditional methods.

Canadian Range

In Canada, Northern Brook and Silver lampreys are found in Ontario, southern Quebec, and Manitoba. In total (i.e., dating from the first record of Silver Lamprey in 1882 to new records included in this report), post-metamorphic Northern Brook and Silver lampreys have been recorded in 104 and 152 waterbodies, respectively (Table 2-4). Other specimens (generally larvae) identified only as *Ichthyomyzon* sp. have been recorded in another 205 rivers and streams in which no adults of either species have been recorded.

Table 2. Summary of waterbodies in the Great Lakes-Upper St. Lawrence National Freshwater Biogeographic Zone (DU1) where Northern Brook Lamprey (NBL), Silver Lamprey, and *Ichthyomyzon* sp. have been recorded (*see* Appendices 1–3). Observations during the past three generations (since 2001) are shown in grey; records in light grey were taken from COSEWIC (2011) where the collected period is listed only as 1989–2007. Great Lakes tributaries subjected to Sea Lamprey Control are indicated according to information in Heinrich *et al.* (2003), Larson *et al.* (2003), Morse *et al.* (2003), and Sullivan *et al.* (2003): Category 1 streams are primary producers of Sea Lamprey in which treatment frequency is generally ≤ 5 years; Category 2 streams are treated less frequently; Category 3 streams produce relatively few Sea Lamprey and are treated even less frequently or not at all.

	NBL	Silver Lamprey	*Ichthyomyzon* sp.	Lampricide Category				Sea Lamprey Barrier
Lake Erie								
Big Cr	X	X	X		X			X
Big Otter Cr			X		X			
Black Cr		X						
Canard R		X						
Cedar Cr		X						
Conewango Cr			X					
Detroit R		X	X					
Grand R	X		X			X		
Hillman Marsh		X						
Horner Cr		X						
L Erie		X						
Little Otter Cr	X							X
NL Cr	X							
Normandale Cr			X			X		X
Point Pelee Marsh	X							
Silver Cr			X		X			
South Otter Cr	X	X	X			X		
Speed R	X							
Stoney Cr	X							
Waubuno Cr	X							

	NBL	Silver Lamprey	*Ichthy-omyzon* sp.	Lampricide Category				Sea Lamprey Barrier
Whitemans Cr	X							
Young's Cr	X	X	X		X			X
Lake Huron								
Ausable R		X	X					
Bannockburn R	X							
Bar R	X		X				X	
Bayfield R	X		X				X	
Bayne R	X							
Beatty Saugeen R	X							
Beaver R	X	X	X				X	
Bighead R		X	X				X	
Blackstone Cr			X					
Blind R			X				X	X
Blue Jay Cr			X		X			
Boyne R		X						
Browns Cr	X				X			X
Camp Cr	X							
Chikanishing R	X		X			X		
Coldwater R	X	X	X					
Echo R	X	X	X		X[1]	X[2]	X	X
French R	X	X	X					X
Garden R		X	X		X			
Georgian Bay		X						
Harris R		X						X
Hog Cr	X	X	X				X	
Indian Br			X					
Kagawong R		X	X				X	
Keenansville Cr			X					
Key R	X		X				X	
Koshkawong R		X			X			X
L Huron		X	X					
Lake 22		X						
Magnetawan R			X		X			
Manitou R	X	X	X		X			X
McKinnon Cr			X					
Mindemoya R	X				X			
Mississagi R			X		X			

	NBL	Silver Lamprey	*Ichthy-omyzon* sp.	Lampricide Category				Sea Lamprey Barrier
Musquash R		X	X			X		
Naiscoot R		X	X			X		
Nine Mile R	X		X					
Nottawasaga R	X	X	X			X		
Oxbow Cr	X							
Pine R/Cr	X				X			
Rankin R	X	X	X					
Root R	X		X		X			
Sauble R	X		X					
Saugeen R	X	X	X				X	X
Serpent R			X		X			
Shawanaga Landing Cr			X					
Shebeshekong R	X		X				X	
Silver Cr		X	X		X			
Simcoe/Severn System			X					
Spanish R	X	X	X			X		
Squaw L		X						
St Marys R	X	X			X			
Still R	X	X	X			X		X
Sturgeon R		X	X					
Styx R			X					
Sydenham R	X	X	X				X	
Thessalon R	X	X	X		X[2]	X[1]		
Tosorontio Cr	X							
Willow Cr	X	X						
Wye R	X		X					
Lake Ontario								
Bowmanville Cr		X			X			X
Cobourg Cr/Br	X	X				X		X
Credit R	X				X			X
Humber R		X						X
L Ontario	X		X					
Lynde Cr	X				X			
Niagara R	X		X					
Otonabee R		X						
Port Britain Cr		X			X			X
Royal Botanical Gardens Fishway		X						

	NBL	Silver Lamprey	*Ichthy-omyzon* sp.	Lampricide Category				Sea Lamprey Barrier
Salmon R	X	X			X			X
Shelter Valley Cr	X	X				X		X
Stokely Cr	X							
Sulphur Cr	X							
Lake Superior								
Agawa R		X				X		
Batchawana R	X	X	X		X			
Big Carp R		X	X			X		X
Big Pic R			X					
Big Trout Cr			X					
Black Cr			X					
Black Sturgeon R	X		X		X			X
Carp R		X			X			X
Cash Cr	X		X			X		X
Cedar Cr			X					
Chain Cr	X							
Chippewa Cr		X	X		X			
Cloud R		X	X			X		X
Cranberry Cr		X	X			X		X
D'Arcy Cr			X					
Digby Cr			X					
Downey Cr			X					
Goulais R		X	X		X			
Gravel R	X		X		X			
Harmony R		X	X			X		
Havilland Cr		X	X					
Hewitson Cr			X					
Horseshoe Cr			X					
Jackfish R	X		X		X			
Jones Landing Cr			X					
Kagiano R	X							
Kaministiquia R	X	X	X		X			
L Helen	X							
L Superior		X						
Little Carp R		X	X		X			
Little Gravel R			X		X			
Little Munroe Cr			X					

	NBL	Silver Lamprey	*Ichthy-omyzon* sp.	Lampricide Category				Sea Lamprey Barrier
Little Pic R			X			X		
Mackenzie R			X					
Michipicoten R	X	X	X		X			
Middle R			X					
Mignet Cr			X					
Neebing/McIntyre R	X	X	X			X		X
Nipigon R	X		X		X			
Nixon Cr			X					
Pancake R		X	X		X			
Pays Plat R	X	X	X			X		
Pearl R	X	X	X			X		
Pic R	X		X			X		
Pigeon R			X		X			
Prairie R	X	X	X			X		
Sable R		X	X					
Sawmill Cr			X					
Sibley Cr	X	X	X					
Squaw Lake	X							
Stillwater Cr			X		X			
Stokely Cr		X	X				X	X
Tiny Cr			X					
Unger Cr			X					
West Davignon Cr			X					
White R		X	X					
Wolf R	X	X	X		X			X
Lake St. Clair								
Jeanette's Cr		X						
L St. Clair		X						
Ruscom R		X						
St. Clair R	X	X	X					
Thames R	X	X	X					
Lake Nipissing								
Bear Cr	X		X					
Chippewa Cr	X	X						
L Nipissing	X	X						
South Cr	X	X	X					

	NBL	Silver Lamprey	*Ichthy-omyzon* sp.	Lampricide Category				Sea Lamprey Barrier
Wolseley R	X		X					
Ottawa-St. Lawrence River								
L Adrien			X					
L Allet			X					
L Anne			X					
L aux Araigneés			X					
L Argenté			X					
L'Assomption R		X						
L à la Barbotte			X					
L Barnes			X					
Batiscan R		X						
L Baumel			X					
L Bayette			X					
L Beaulieu			X					
Beauport R		X						
L Beauvais			X					
L Bécancour			X					
L Bertrand			X					
L Bessette			X					
L Bevin			X					
L Bidou			X					
L Blanc			X					
L Blondin			X					
L Bois Franc		X						
L Boitel		X						
Brewery Cr		X						
L Bouchette			X					
L Bourdeau			X					
L Bourque			X					
Bouthiller Pond			X					
L Bowker			X					
L du Brochet			X					
Petit L du Brochet			X					
Petit L Brompton			X					
L Brûlé			X					
L Brunet			X					
Bull Pond			X					

	NBL	Silver Lamprey	*Ichthy-omyzon* sp.	Lampricide Category				Sea Lamprey Barrier
L Caché			X					
L Capri			X					
L Caribou			X					
L Carman			X					
L Caron			X					
L Carré			X					
L Casgrain			X					
L Castor			X					
L Ceizur		X						
L Chabot			X					
L Champagne			X					
L Charbonneau			X					
L aux Chasseurs			X					
Châteauguay R	X	X						
L des Chats			X					
Chevreuil			X					
L Clair			X					
L Clément			X					
Coaticook R	X							
Petit L à Cochand			X					
L Comeau			X					
L à la Croix			X					
L Dame			X					
L Désert			X					
L Desroches			X					
Dorman Cr	X							
Dow’s L		X						
L Dumouchel			X					
L des Écorces			X					
L Edmond			X					
L Édouard			X					
Lac de l’Est			X					
Etchemin R			X					
Fairburn L			X					
Petit L Farley			X					
L Fer à Cheval			X					
Fiddler L			X					
L à Foin			X					

	NBL	Silver Lamprey	*Ichthy-omyzon* sp.	Lampricide Category				Sea Lamprey Barrier
L Fortier			X					
L Fortin			X					
L des Français			X					
Fraser L			X					
Gatineau R	X	X						
L Gauthier			X					
Gentilly R		X						
L Groulx			X					
Hamel L			X					
Hare R		X						
Hawkesbury Cr		X						
Hinchinbrooke R	X	X						
L à la Île			X					
L Jean			X					
Kingham R		X						
L Labelle			X					
L Lajeunesse			X					
L Lamoureux			X					
Petit L Lanthier			X					
Larose Br			X					
L Larouche			X					
L Laurel			X					
L des Lauriers			X					
L Lavallée			X					
L Leamy		X						
L Lefebvre			X					
L Lemay			X					
L Léonard			X					
Libby Pond			X					
Lièvre R			X					
Lindsay L			X					
L Lippé			X					
Litchfield			X					
Loaf Pond			X					
Long Lake			X					
Long Pond			X					
Petite R du Loup		X						
Étang du Loup (Pond)			X					

	NBL	Silver Lamprey	*Ichthy-omyzon* sp.	Lampricide Category				Sea Lamprey Barrier
L Loutre			X					
Madisson R			X					
Magog R			X					
L Marois			X					
L Marquis			X					
Mascouche R		X						
Massawippi R	X							
L Masson			X					
L Matley			X					
L Maxime			X					
McConge L			X					
McConnel L			X					
McDonald L			X					
McLeod L			X					
McRae L			X					
L Ménard			X					
L Michaudville			X					
Mitchel Br		X						
Nantel L			X					
Newman L			X					
Nick L			X					
Nicolet R	X	X						
Nicolet L			X					
L Noir			X					
L à Nymark			X					
Oak Br		X						
L Orford			X					
L à l'Orignal			X					
Ottawa R (Outaouais)	X	X						
Ouareau R		X						
Patterson L			X					
Peasley Pond			X					
L Pékan			X					
L Pelletier			X					
Perkins L			X					
Petite-Nation R	X							
L de la Pierre			X					
L Pierre-Paul			X					
R des Prairies	X	X						
L Raquette			X					

	NBL	Silver Lamprey	*Ichthy-omyzon* sp.	Lampricide Category				Sea Lamprey Barrier
Red R		X						
R de Renne			X					
Richelieu R	X	X						
L de Sables			X					
L Sainte-Adèle			X					
L Saint-Denis			X					
Saint-François R	X	X	X					
L Saint-François		X						
L Saint-François-Xavier			X					
L Saint-Joseph			X					
St. Lawrence R	X	X						
L Saint-Louis	X	X						
L Sainte-Marie			X					
L Saint-Pierre		X						
L Sainte-Rose			X					
Sally Pond			X					
L Sarrazin			X					
Saumon R	X							
R aux Saumons			X					
L Sauvage			X					
Schmidt L			X					
L des Seize Îles			X					
Serpentine R			X					
L Sim			X					
L Simard		X						
Simon R			X					
Sinclair L			X					
Sir John L			X					
L des Souris			X					
South Nation R		X						
Sparling L			X					
Spring L			X					
Stacey R	X	X						
Steele Cr	X							
Stevens L			X					
Stoke R			X					
L Taillefer			X					
L Tapani			X					

	NBL	Silver Lamprey	*Ichthy-omyzon* sp.	Lampricide Category				Sea Lamprey Barrier
Taylor L			X					
L Théodore			X					
L Thérien			X					
Thompson L			X					
Thurso R		X						
Lac à Ti-Lane			X					
Tomifobia R	X							
L Travers			X					
L des Trois Frères			X					
Trousers L			X					
Trout R	X							
L à la Truite			X					
L of Two Mountains (Deux Montagnes)		X	X					
L Valiquette			X					
L Vert			X					
L Vezeau			X					
Washington Cr	X							
L Wener			X					
William L			X					
Williams Cr	X							
Williams L			X					
Windigo L			X					
Woods L			X					
Yamaska R	X							
Lake Champlain								
Pike R			X					

Table 3. Summary of waterbodies in the Saskatchewan-Nelson River National Freshwater Biogeographic Zone (DU2) where Northern Brook Lamprey (NBL), Silver Lamprey, and *Ichthyomyzon* sp. have been recorded (see Appendices 1–3). Observations during the past three generations (since 2001) are shown in grey; records in light grey were taken from COSEWIC (2011) where the collected period is listed only as 1989–2007.

	NBL	Silver Lamprey	*Ichthyomyzon* sp.
Assiniboine River			
Assiniboine R		X	
Shell R		X	

	NBL	Silver Lamprey	*Ichthyomyzon* sp.
Nelson River			
Angling Cr		X	
Burntwood R		X	
Gull L		X	
Limestone R		X	
MacMillan Cr		X	
Nelson R		X	
Seagull		X	
Seal Cr		X	
Split L		X	
Stephens L		X	
Swift Cr		X	
Red River			
Joubert Cr		X	
Rat R		X	
Red R		X	
Seine R		X	
Winnipeg River			
Berry Cr		X	
Birch R	X		X
Bird R		X	
Crooked L		X	
Eaglenest L		X	
English R			X
Kawnipi L		X	
L of the Woods		X	
La Croix L		X	
Namakan L		X	
Nutimik L		X	
Olifaunt L		X	
Rainy R		X	
Saganaga L		X	
Sandpoint L		X	
Swan L		X	
Walter L		X	
Whitemouth R	X		X
Winnipeg R	X	X	X

Table 4. Summary of waterbodies in the Southern Hudson Bay-James Bay National Freshwater Biogeographic Zone (DU3) where Silver Lamprey has been recorded (see Appendices 1–3). Observations during the past three generations (since 2001) are shown in grey.

	Silver Lamprey	
Hayes R	X	
Seeber R	X	

In the Great Lakes-Upper St. Lawrence NFBZ, Northern Brook (DU1) and Silver (DU1) lamprey adults or post-metamorphic juveniles have been recorded in 101 and 116 waterbodies, respectively. Both species are found in the four Canadian Great Lakes watersheds (Erie, Huron, Ontario, and Superior), in Lake St. Clair (which connects lakes Erie and Huron) and Lake Nipissing (which drains into Lake Huron via Georgian Bay), and in the St. Lawrence River and its major tributary, the Ottawa River (Figure 5, 7; Appendix 1, 2). In the Saskatchewan-Nelson River NFBZ (DU2), the known distribution of Northern Brook Lamprey is more restricted than that of Silver Lamprey, with adults of the two species having been recorded in 3 and 34 waterbodies, respectively. Both species have been reported in the Winnipeg River system in the Hudson Bay watershed (although only Silver Lamprey extends into northwestern Ontario), and Silver Lamprey has been reported in other river systems within the Hudson Bay watershed (i.e., Nelson, Red, and Assiniboine rivers; Figure 6, 8; Appendix 1, 2). However, some confusion about Silver Lamprey distribution within the Red and Assiniboine rivers suggests that this species may be less widely distributed in southern Manitoba than previously thought, and Northern Brook Lamprey may occur in the Rat River, a tributary of the Red River (*see* below). Recent confirmed reports of Silver Lamprey in the Hayes River, which flows from Knee Lake in northern Manitoba to Hudson Bay, extend the confirmed range of this species (Tyson and Watkinson 2013) into the Southern Hudson Bay-James Bay NFBZ (DU3), where it has been recorded in two waterbodies to date (*see* below).

Details and trends related to the distribution of Northern Brook Lamprey and Silver Lamprey in each Canadian DU since the last status reports (since 2007) and over the past three generations (i.e., 18 years) are discussed below.

<u>Great Lakes-Upper St. Lawrence (DU1)</u>

Northern Brook Lamprey

In the time period since the last report (i.e., 2008–2018), Northern Brook Lamprey adults were recorded in 32 waterbodies in DU1: two, 12, and five in the Erie, Huron, and Ontario basins, respectively; one tributary to Lake Nipissing; and two and 10 rivers in the Ottawa and St. Lawrence river watersheds, respectively (Figure 5; Appendix 1). This includes 14 localities at which Northern Brook Lamprey adults had not been previously observed (eight in the Great Lakes basin and six in the St. Lawrence/Ottawa River basin). In the previous status report, Northern Brook Lamprey were reported from 36 stream systems since 1990, including a number of localities with previously unrecorded populations (COSEWIC 2007). These new records likely do not represent the presence of novel populations; rather they are likely the result of increased search effort. For example, in the Great Lakes, survey efforts have historically been focused on streams that support Sea Lamprey. However, in recent years, assessment staff at the Sea Lamprey Control Centre (SLCC) have conducted broader electrofishing surveys, leading to reports of previously unknown Northern Brook Lamprey localities (e.g., Bear Creek and Wolseley River in the Lake Nipissing drainage; COSEWIC 2007). Likewise, over the past four three-generation (18-year) time periods, there has been a steady increase in the number of streams with adult Northern Brook Lamprey (Table 5), but these new records are likely the result of a lack of earlier directed survey efforts and increased recent search effort.

Table 5. Number of tributaries within each watershed where Northern Brook Lamprey were detected in the past four three-generation (18-year) time periods and prior to 1947.

GREAT LAKES-UPPER ST. LAWRENCE (DU1)					
	2001–2018	**1983–2000**	**1965–1982**	**1947–1964**	**1946–1882**
Lake Erie	6	1	3	1	1
Lake Huron	20	10	13	8	0
Lake Ontario	7	2	1	0	1
Lake Superior	4	13	5	6	0
Lake St. Clair	0	1	0	0	1
Lake Nipissing	4	1	0	2	0
Ottawa-St. Lawrence River	15	8	3	4	1
	56	36	25	21	4
SASKATCHEWAN-NELSON RIVER (DU2)					
Winnipeg River	3	1	2	0	0
	3	1	2	0	0

Conversely, streams without recent Northern Brook Lamprey records may represent reduced effort at these localities or difficulty obtaining adult specimens rather than extirpation of previously existing populations. Unidentified *Ichthyomyzon* larvae were recorded in 55 streams in 2008–2018 (Figure 10; Appendix 3). Based on the historical presence of Northern Brook Lamprey adults in some of these streams and their location within the stream system (i.e., above barriers), many of these additional streams likely contain Northern Brook Lamprey (Schuldt and Goold 1980). In the previous COSEWIC status report, unidentified *Ichthyomyzon* larvae were observed in 66 streams since 1990, and unidentified *Ichthyomyzon* specimens (presumably larvae) were recorded from approximately 170 waterbodies in the St. Lawrence/Ottawa River basin in the 1930s, 1940s, and 1950s (Appendix 3). It is not known what proportion of these specimens would have been Northern Brook Lamprey, nor is it known which of these populations are still extant.

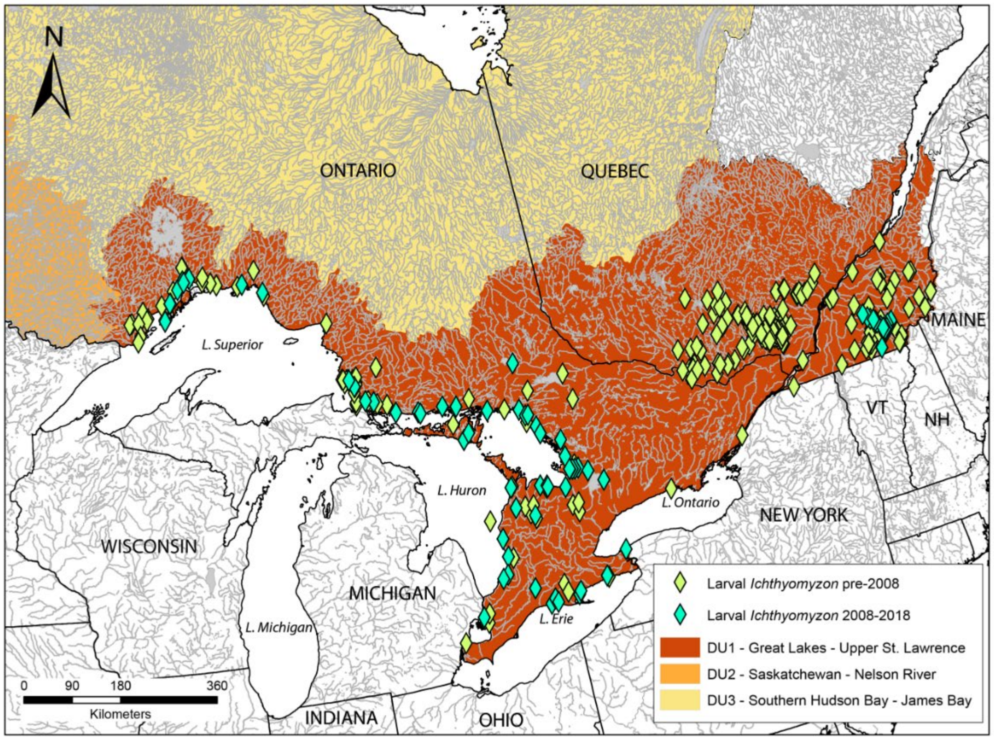

Figure 10. Collections of *Ichthyomyzon* sp. larvae that could not be identified as Northern Brook or Silver lamprey in the Great Lakes-Upper St. Lawrence (DU1).

Some of these populations may have been extirpated since these early sampling efforts, although not necessarily within the past three-generation time period. For example, Northern Brook Lamprey adults have not been observed in the Yamaska River in the St. Lawrence River watershed since 1959 (Renaud *et al*. 1995; see **Threats**). Likewise, some Northern Brook Lamprey populations in the Great Lakes basin may have been extirpated following initiation of Sea Lamprey control. Schuldt and Goold (1980) reported *Ichthyomyzon* larvae in 46 Canadian tributaries of Lake Superior in 1953–1972, a period which encompassed the initiation (in 1958) of lampricide treatments in this basin (Heinrich *et al*. 1980). Of these tributaries, 42 were resampled between 1973 and 1977, and only 17 were found with *Ichthyomyzon* larvae (see **Threats**). *Ichthyomyzon* larvae have subsequently been observed in six of the 24 named streams from which they appeared to have been extirpated (and Silver Lamprey adults have been observed in two other streams), suggesting either that native lampreys recolonized these eight tributaries or that they were not observed during resampling in 1973–1977. Northern Brook Lamprey adults have not been recorded in any Canadian tributaries of Lake Superior since 2007, although the *Ichthyomyzon* larvae collected at some localities (e.g., Black Sturgeon, Nipigon, and Pearl rivers) are thought to be Northern Brook Lamprey based on historical records (see Table 2; Neave *et al*. 2019). The total number of Canadian Great Lakes tributaries in which *Ichthyomyzon* larvae have been observed appears to have stabilized, likely as the result of many of these populations not being exposed to lampricide treatments (Table 2).

Silver Lamprey

Since the time period covered in the last report (i.e., 2008–2018), Silver Lamprey adults were recorded in 29 waterbodies in DU1: seven, six, one, and one in the Erie, Huron, Ontario, and Superior basins, respectively; five and one waterbodies in the Lake St. Clair and Lake Nipissing watersheds; and two and six waterbodies in the Ottawa and St. Lawrence watersheds, respectively (Figure 7; Appendix 2). This includes 10 localities at which Silver Lamprey adults had not been previously observed. In the previous report, Silver Lamprey were documented in 41 streams and seven lakes in the Great Lakes-Upper St. Lawrence DU from 1989–2007 (COSEWIC 2011). The number of waterbodies where Silver Lamprey adults have been reported has increased modestly over successive three-generation time periods (Table 6), likely because increased efforts have resulted in additional populations being documented recently. Unidentified *Ichthyomyzon* larvae were recorded in 52 rivers in 2008–2018 (Figure 10). Although many of these populations are thought to be Northern Brook Lamprey due to their upstream location within the stream systems, 34 of the larval records were from streams in which Silver Lamprey adults have been reported historically (Appendix 3).

Table 6. Number of tributaries within each watershed where Silver Lamprey were detected in the past four three-generation (18-year) time periods and prior to 1947.

GREAT LAKES-UPPER ST. LAWRENCE (DU1)					
	2001–2018	**1983–2000**	**1965–1982**	**1947–1964**	**1946–1882**
Lake Erie	8	3	1	3	1
Lake Huron	13	13	11	3	2
Lake Ontario	6	3	0	0	0
Lake Superior	1	10	2 (21)*	9 (23)*	1
Lake St. Clair	5	1	1	0	1
Lake Nipissing	3	0	0	1	1
Ottawa- St. Lawrence River	16	14	16	6	8
	52	44	31 (50)	22 (36)	14
SASKATCHEWAN-NELSON RIVER (DU2)					
Assiniboine River	1	1	0	0	0
Nelson River	10	2	0	1	1
Red River	0	1	2	2	0
Winnipeg River	12	3	8	0	0
	23	7	10	3	1
SOUTHERN HUDSON BAY-JAMES BAY (DU3)					
Hayes River	1	0	1	0	0

* Numbers in parentheses include the streams where Silver Lamprey were observed for an unspecified number of years during 1953–1972 (Schuldt and Goold 1980), placing them in both the 1965–1982 and 1947–1964 time periods

In the Great Lakes basin, some of these Silver Lamprey populations may have been extirpated following initiation of Sea Lamprey control. However, in other cases, the lack of more recent reports may be the result of decreased sampling effort or sampling that focuses on tributaries with Sea Lamprey. Schuldt and Goold (1980) reported that Silver Lamprey were captured at electric barriers, used to prevent upstream migration by Sea Lamprey, in 19 Canadian tributaries of Lake Superior in 1953–1972, but that none were captured in these tributaries in 1973–1977. However, Silver Lamprey were subsequently reported in seven of these 19 tributaries, indicating that this species either escaped detection in some of these rivers or recolonized since 1977. Nevertheless, since 1989, only five Silver Lamprey have been trapped in Lake Superior, all in the Big Carp River at the easternmost point of Lake Superior, and this is not entirely the result of poor search effort (see **Search Effort and Methods**). Although traps have been operated on only two tributaries to Lake Superior since 2015, trapping occurred on 5–6 tributaries in 2007–2014, and the Neebing-McIntyre Floodway in the western Canadian basin of Lake Superior has been monitored every year since 1994. Similarly, traps on the Wolf River, also in the western basin, were operated every year in 1981–1987 and 1991–2012. Admittedly, all the other trap sites that have been monitored in Lake Superior since 1989 are in the eastern basin (Big Carp and Carp rivers, and Stokely Creek), while earlier trapping efforts (e.g., 1953–1977, as reported by Schuldt and Goold 1980) included more sites from the western basin. Sampling efforts specifically targeting metamorphosed and adult Silver Lamprey are required to unequivocally determine which of these tributaries still have extant Silver Lamprey populations.

<u>Saskatchewan-Nelson River (DU2)</u>

Northern Brook Lamprey

In the time period since the last report (i.e., 2008–2018), Northern Brook Lamprey adults have been reported in two of the three waterbodies in DU2 from which they have been historically observed (the Birch and Whitemouth rivers in the Winnipeg River watershed), but not in the Winnipeg River itself (Table 3; Appendix 1). Unidentified *Ichthyomyzon* larvae were reported in the Winnipeg River in 2015 and 2017, and in the English River in 2015, but these larvae are suspected to be Silver Lamprey (*see* below). Spice and Docker (2014) suggested that three metamorphosing specimens collected from the Rat River were Northern Brook Lamprey based on histological analysis of the gonads. All three showed signs of sexual maturation (i.e., a non-parasitic life history type) and genetic analysis confirmed them to be either Northern Brook Lamprey or Silver Lamprey. Intact specimens were not retained as vouchers, and subsequent electrofishing and eDNA analysis has not confirmed presence of Northern Brook Lamprey in the Rat River (*see* below). More extensive sampling in the fall or spring (i.e., following metamorphosis but prior to or during spawning) is required.

Targeted electrofishing surveys in 2013–2015 failed to find Northern Brook Lamprey adults or *Ichthyomyzon* larvae identifiable as either Northern Brook or Silver lamprey in other waterbodies in Manitoba: Devils, Hazel, and Netley creeks and the La Salle, Morris, Pembina, Rat, and Roseau rivers in the Red River drainage or the Icelandic River in the Lake Winnipeg drainage (Collerone 2014; Docker unpubl. data). Environmental DNA (eDNA) surveys from 29 tributaries of the Assiniboine, Red, and Winnipeg rivers and nine tributaries to Lakes Winnipeg and Manitoba also indicate limited distribution of Northern Brook Lamprey in the Saskatchewan-Nelson River NFBZ (*see* **Search Effort**). However, eDNA from either Northern Brook or Silver lamprey has been detected at five sites outside the known range of Northern Brook Lamprey (Table 7). Five of 15 water samples detected Northern Brook or Silver lamprey eDNA in the Bird River, which could extend the known range of Northern Brook Lamprey within the Winnipeg River system. However, in the Seine and Whitemud rivers, only one of 12 and six water samples, respectively, tested positive for Northern Brook or Silver lamprey DNA (and in only one of three replicate PCRs), suggesting that these might represent false positives, either as a result of contamination with Northern Brook or Silver lamprey DNA from another source or cross-reactivity with Chestnut Lamprey DNA. Chestnut Lamprey is known to occur throughout many of these sites in southwestern Manitoba (Stewart and Watkinson 2004; COSEWIC 2010). There is also a 1974 record of Silver Lamprey in the Seine River, but some uncertainty exists regarding species identification (*see* **Morphological Description**). Two water samples tested positive for Northern Brook or Silver lamprey in the Little Saskatchewan and Souris rivers. Silver Lamprey has been reported from the Assiniboine River system (although not since 2002; *see* below), and follow-up sampling using traditional methods will be required for verification of lamprey presence and species identification.

Table 7. Tributaries in DU2 that have been sampled for environmental DNA (eDNA), with those showing detection (Y) of Northern Brook or Silver lampreys (which are genetically indistinguishable from one other) and Chestnut Lamprey indicated. Three water samples were collected at each sampling event (often at multiple sites and time periods), and the number of water samples testing positive is shown.

	Northern Brook or Silver lamprey		Chestnut Lamprey	
Stream	Detected?	Positive samples	Detected?	Positive samples
Assiniboine River				
Antler R		0/3		0/3
Birdtail Cr		0/9		0/3
Cypress R		0/3		0/3
Little Saskatchewan R	Y	3/48	Y	8/45
Oak Cr		0/6	Y	2/6
Plum Cr		0/3		0/3
Qu'Appelle R		0/3		0/3
Shell R		0/15	---	---
Souris R	Y	3/30		0/30
Willow Cr		0/3		0/3

Stream	Northern Brook or Silver lamprey		Chestnut Lamprey	
	Detected?	Positive samples	Detected?	Positive samples
Red River				
Devils Cr		0/3		0/3
Hazel Cr		0/12	Y	3/12
La Salle R		0/6		0/6
Netley Cr		0/6		0/6
Pembina R		0/9		0/9
Rat R		0/12	Y	6/12
Roseau R		0/6	Y	1/6*
Seine R	Y*	1/12		0/12
Winnipeg River				
Birch R	Y	6/12		0/9
Bird R	Y	5/15		0/15
Black R		0/6		0/6
Maple Cr		0/3		0/3
Peterson Cr		0/12		0/12
Pinawa Ch		0/21		0/21
Rabbit R		0/3		0/3
Rice Cr		0/3		0/3
Whitemouth R	Y	3/15		0/6
Whiteshell R		0/6		0/6
Lake Winnipeg				
Brokenhead R		0/63	Y	12/21
Fisher R		0/6		0/3
Gold Cr		0/3		0/3
Icelandic R		0/6		0/6
Manigotagan R		0/6		0/6
Moose R		0/3		0/3
O'Hanly R		0/3		0/3
Sandy R		0/3		0/3
Wanipigow R	---	---		0/3
Lake Manitoba				
Whitemud R	Y*	1/6		0/6

*3 PCRs were run per water sample; only one PCR out of 18 in total tested positive

Silver Lamprey

In the time period since the last report (i.e., 2008–2018), Silver Lamprey juveniles (i.e., captured during the parasitic feeding phase) have been reported in 10 waterbodies in DU2: in two rivers (the Nelson and Winnipeg rivers) and eight lakes (Table 3; Appendix 2). This includes six lakes where Silver Lamprey have not been previously recorded. Given the lack of targeted sampling in this DU, these new records likely do not represent a range expansion for the Silver Lamprey, but rather a range extension due to increased reporting. There has been a steady increase in the number of waterbodies in which Silver Lamprey has been reported over the past four three-generation (18-year) time periods, largely as the result of increased sampling and reporting in the Nelson and Winnipeg River watersheds.

In contrast, no Silver Lamprey were reported from either the Assiniboine or Red River systems since the last COSEWIC report, and the only record in the past three generations was a 2002 observation in the Assiniboine River. This may be partly attributable to less search effort in these areas, particularly efforts targeting feeding-phase juveniles. However, targeted electrofishing surveys in 2013–2015 also failed to find post-metamorphic Silver Lamprey or *Ichthyomyzon* larvae identifiable as either Northern Brook or Silver lamprey in eight tributaries to the Red River (Devils, Hazel, and Netley creeks and the La Salle, Morris, Pembina, Rat, and Roseau rivers) or in the Icelandic River, a Lake Winnipeg tributary (Collerone 2014; Docker unpubl. data). Nevertheless, in 2015–2017, eDNA assays were used to test for the presence of Northern Brook Lamprey or Silver Lamprey DNA in water samples collected from 29 tributaries of the Assiniboine, Red, and Winnipeg rivers and nine tributaries to Lakes Winnipeg and Manitoba (see **Search Effort**). Northern Brook Lamprey or Silver Lamprey DNA was detected in two Assiniboine River tributaries (the Little Saskatchewan and Souris rivers) and in one Red River tributary (the Seine River; Table 7). As discussed above, these preliminary results could represent false positives, especially in the Seine River where only one of 12 water samples (and only one of 36 replicate PCRs) tested positive for Northern Brook or Silver lamprey DNA. However, given the historical records of Silver Lamprey in these areas, follow-up sampling is required.

Follow-up sampling using conventional gear and genetic identification (see **Morphological Description**) are of particular importance given recent concerns regarding misidentification of some Silver and Chestnut lampreys even during the parasitic feeding phase. Although Silver Lamprey is generally distinguished from Chestnut Lamprey by only unicuspid inner lateral teeth compared to 6–8 bicuspid inner lateral teeth in the Chestnut Lamprey, some exceptions have been reported. For example, Hall and Moore (1954) reported two Chestnut Lamprey specimens without any bicuspid inner lateral teeth from regions where Silver Lamprey have never been reported. In Manitoba, genetic analysis has been used to confirm the identity of one Chestnut Lamprey without any bicuspid inner lateral teeth that was collected in spawning condition in the Rat River alongside two Chestnut Lamprey each with four inner lateral teeth (Docker unpubl. data; Figure 3a). Silver Lamprey specimens in the University of Manitoba Stewart-Hay Fish Museum (MZF) collection were confirmed to have unicuspid inner lateral teeth (Docker unpubl. data). However, it is possible that these represent unicuspid Chestnut Lamprey and that some or all of the historical Silver Lamprey records from the Red and Assiniboine river systems were actually Chestnut Lamprey.

All or most Silver Lamprey specimens recorded to date in this DU have been parasitic feeding phase individuals captured on host fish, during surveys or by anglers targeting other species. Other life-history stages have not been reported, despite more recent targeted sampling. In 2011, three-person crews spent 5–7 days electrofishing in all the apparently suitable tributaries throughout the Winnipeg River system, but no larval or spawning-phase Silver Lamprey were found. As described for Northern Brook Lamprey (*see* above), targeted electrofishing in 2013–2015 likewise failed to collect lamprey larvae or adults in Manitoba. However, in May 2012, biologists with North/South Consultants collected a putative larval Silver Lamprey in a drift trap just downstream of Pointe du Bois in the Winnipeg River (Appendix 3). Thus, although lampreys generally spawn in shallow streams (Johnson *et al.* 2015; *see* **Biology**), it appears that Silver Lamprey are likely spawning in deeper waters in the Winnipeg River, as has been observed for this species in other large river systems (Cochran and Lyons 2004). However, it is not yet clear if Silver Lamprey are spawning in deeper waters in the Winnipeg River due to modifications from damming (*see* **Threats**). Larvae assumed to be Silver Lamprey based on their location, were captured by electrofishing in the English River near Caribou Falls in northwestern Ontario in 2015 (Docker unpubl. data). It is important that more targeted sampling is completed; although parasitic feeding phase individuals are found widely throughout this DU, the distribution of the spawning and larval rearing habitat for this species is unknown.

<u>Southern Hudson Bay-James Bay (DU3)</u>

Silver Lamprey

In the time period since the last report (i.e., 2008–2018), two parasitic feeding phase Silver Lamprey were captured from Seeber River in the upper Hayes River system (Tyson and Watkinson 2013; Table 4; Figure 8). They were attached to Northern Pike (*Esox lucius*) that were collected by angling, and anglers at this same site observed two other lamprey attached to Northern Pike and one lamprey attached to a Walleye (*Sander vitreus*). Silver Lamprey had been reported previously in this NFBZ, but no vouchered specimens with clear locational information were kept prior to 2011. Hubbs and Trautman (1937) reported two vouchered specimens that were collected from the Hayes River (one prior to 1883 and one in 1900), but there is uncertainty in the collection localities of the specimens. Beck (1977) recorded capturing Silver Lamprey at three locations within the Hayes River in 1976, and also reported angler observations of lamprey attachments and scars on host fishes. He speculated that Silver Lamprey were fairly common in the lower Hayes River, but the two 2011 specimens from Seeber River are the first documented and vouchered specimens from the upper Hayes River system. However, these new records likely do not represent a range expansion for the Silver Lamprey, but rather increased search effort and reporting. Tyson and Watkinson (2013) suggested that the distribution of the Silver Lamprey likely extends throughout the Hayes River system in Manitoba and Ontario. Nevertheless, more targeted sampling is required and the distribution of the spawning and larval rearing habitat for this species is unknown.

Extent of Occurrence and Area of Occupancy

Estimated Extent of Occurrence (EOO) was calculated for each DU using the minimum convex polygon method, adjusted to contain only the EOO within Canada's jurisdiction (Appendix 4). The Index of Area of Occupancy (IAO) was calculated using a 2 x 2 km grid. For riverine organisms, IAO may be based on a continuous stretch of river between the observation records (Continuous IAO), or it may include only grids where an observation was found (Discrete IAO). Although suitable lamprey habitat is likely patchy (*see* **Habitat**) and Continuous IAO will overestimate area of occupancy to some degree (particularly when observation records are based on parasitic feeding-phase Silver Lamprey), we use Continuous IAO here for better comparison to previous IAO calculations and because Discrete IAO will underestimate area of occupancy. The current EOO and IAO of the species are based on distribution records for 2008–2018, and they are compared to the EOO and IAO calculated in the last status reports for Northern Brook Lamprey (1990–2006) and Silver Lamprey (1989–2007) (COSEWIC 2007 and 2011, respectively) and to the overall historical EOO and IAO (i.e., all records up to and including 2007). However, note that, although Silver Lamprey IAO in the last status report was calculated using the 2 x 2 km grid, Northern Brook Lamprey IAO was estimated in 2007 by multiplying the length of stream occupied by the mean width of the stream.

<u>Great Lakes-Upper St. Lawrence (DU1)</u>

Northern Brook Lamprey

Current EOO within Canada's jurisdiction, based only on post-metamorphic Northern Brook Lamprey records and one Lake Superior locality (Black Sturgeon River) where historical records strongly support the occurrence of only Northern Brook Lamprey, is 419,126 km^2 (Figure 5; Appendix 4). EOO in the last status report was 280,000 km^2, and historical EOO was 441,643 km^2. Therefore, EOO appears to be relatively stable over time, especially considering differences in search effort among time periods and the lack of adult specimens from several localities.

Current IAO (Continuous) is 880 km^2. IAO in the last status report was 1,284 km^2, and historical IAO was 4,700 km^2. IAO has declined over time, but this may be due (at least in part) to differences in search effort among time periods. Some Northern Brook Lamprey populations in the Great Lakes basin may have been extirpated following initiation of Sea Lamprey control (i.e., in the late 1950s and 1960s), but other populations (e.g., in the Lake Nipissing and St. Lawrence River basins) have been newly discovered (*see* above). The total number of Canadian tributaries with Northern Brook Lamprey or *Ichthyomyzon* larvae thought to be Northern Brook Lamprey appears to have stabilized (*see* **Number of Locations**).

Silver Lamprey

Current EOO within Canada's jurisdiction is 274,064 km^2. EOO in the last status report was 511,000 km^2, and historical EOO was 535,607 km^2 (Appendix 4). EOO appears to have declined over time, largely as a result of a lack of recent records from western Lake Superior. Big Carp River at the easternmost point of Lake Superior is the only locality at which Silver Lamprey adults have been recorded since 2007 (Figure 7). Unidentified *Ichthyomyzon* larvae have been reported from 11 Lake Superior tributaries since 2007, but many of these are suspected to be Northern Brook Lamprey (e.g., due to their location above impassable barriers or lack of any Silver Lamprey records in the system). The most recent collection of Silver Lamprey adults from the western Canadian basin of Lake Superior is 1998.

Current IAO (Continuous) is 5,160 km^2. IAO in the last status report was 1,750 km^2, but historical IAO was 12,236 km^2. Therefore, IAO has declined. Note that Continuous IAO overestimates area of occupancy, particularly when observation records are based on parasitic feeding-phase Silver Lamprey, but Discrete IAO (432 km^2) underestimates area of occupancy.

<u>Saskatchewan-Nelson River (DU2)</u>

Northern Brook Lamprey

Current EOO is 162 km^2. The EOO in the last status report was 5,000 km^2, and historical EOO was 596 km^2 (Appendix 4). Fluctuation in EOO over time is largely the result of Northern Brook Lamprey being reported in the Winnipeg River in 2003 only. There has been a lack of recent records of Northern Brook Lamprey in the Winnipeg River despite targeted sampling, indicating that EOO has declined.

Current IAO is 108 km^2. IAO in the last status report was 44 km^2 (estimated by multiplying the length of stream occupied by the mean width of the stream), but historical IAO was 264 km^2. Therefore, IAO appears to have declined.

Silver Lamprey

Current EOO is 157,656 km^2. The EOO in the last status report was 256,000 km^2, and the historical EOO was 452,509 km^2 (Appendix 4). The apparent decline in EOO over time is likely the result of a combination of differences in search effort (i.e., less extensive sampling in the Nelson River watershed) and lack of current records or uncertainty regarding the occurrence of Silver Lamprey in the Assiniboine and Red river systems (i.e., whether some of these earlier records may have been Chestnut Lamprey with entirely unicuspid inner laterals; see **Distribution**).

Current IAO is 954 km^2. IAO in the last status report was 2,076 km^2, and historical IAO was 5,016 km^2. The apparent fluctuation in IAO is likely the result of a combination of more extensive sampling in the Nelson River watershed prior to the last status report and lack of current records or uncertainty regarding the occurrence of Silver Lamprey in the Assiniboine and Red river systems. Discrete IAO was 120 km^2.

<u>Southern Hudson Bay-James Bay (DU3)</u>

Silver Lamprey

Current and historical EOO and IAO are both 4 km^2, based on only one record in each time period.

HABITAT

Habitat Requirements

<u>Larval Northern Brook and Silver Lampreys</u>

Larval lampreys, which require depositional areas with soft sediment for burrowing, are typically found in slower-flowing sections of streams (*see* Dawson *et al.* 2015). Substrate particle size is one of the most important factors limiting the distribution of larval lampreys. If sediment is too fine (e.g., clay), larvae are unable to penetrate, while sediment that is too coarse is too heavy for them to move (Becker 1983; Beamish and Lowartz 1996). Larval Sea Lamprey and European Brook Lamprey (*Lampetra planeri*) were found to be most abundant where particle size was < 0.5 mm in diameter. Northern Brook Lamprey larvae have been reported in fine sand or silt/sand (Reighard and Cummins 1916; Leach 1940). Although there may be subtle differences in preferred substrate particle size among species, substrate requirements appear similar among species, and multiple species are often found at the same sites (Dawson *et al.* 2015). Particle-size preferences for Silver Lamprey larvae have not been determined, but they are thought to be similar. However, Collerone (2014) found that Northern Brook Lamprey larvae in Manitoba were more likely to be found in finer sediment (fine/very fine sand on the Wentworth scale) than Chestnut Lamprey.

In terms of other habitat requirements for the larvae, Leach (1940) and Bowen and Yap (2003) found that organic detritus is an important component of Northern Brook Lamprey larval habitats. In other species, organic matter, chlorophyll *a*, macrophyte roots, and low-angle shading are important habitat characteristics for larvae (*see* Dawson *et al.* 2015).

The size of the tributaries where Northern Brook and Silver lampreys are found is variable, but it is generally recognized that Northern Brook Lamprey prefer smaller, shallower, slower-moving water than their parasitic counterparts (Becker 1983; Scott and Crossman 1998). However, this may be related more to the habitat requirements of the spawning adults than of the larvae (*see* below). Becker (1983) reported that Northern Brook Lamprey were found in streams that were 19 m wide and 0.7 m deep on average. Northern Brook Lamprey larvae have been reported in streams with a wide range of summer flow rates: 0.3–8.3 m^3/s by Schuldt and Goold (1980) and 0.2–71 m^3/s (average12.2 m^3/s according to unpublished SLCC data; COSEWIC 2007). Stream-flow rates recorded for Silver Lamprey are: 0.03–28 m^3/s in tributaries to Lake Superior (Schuldt and Goold 1980), 0.06–34 m^3/s in Michigan (Morman 1979), and 0.1–72 m^3/s (average 8 m^3/s) for Canadian Great Lakes tributaries (COSEWIC 2011). However, it should be noted that Silver Lamprey larvae are also found in the St. Marys and St. Clair rivers where average discharge rates are 2,100 and 5,097 m^3/s, respectively (Edsall and Charlton 1997).

Northern Brook and Silver lampreys tend to inhabit different sections of tributaries, with a general trend for Northern Brook Lamprey to be found in more upstream reaches (upstream of barrier dams if they are present), while Silver Lamprey are found in lower reaches of rivers (below barriers if they are present) (Morman 1979). However, Schuldt and Goold (1980) have also reported finding Northern Brook Lamprey restricted to creek mouths in the Chocolay River system in Michigan, and it is not uncommon for Northern Brook and Silver lampreys to overlap with each other as well as with other lamprey species (e.g., Sea Lamprey) (*see* **Interspecific Interactions**).

<u>Juvenile (Feeding Phase) Silver Lamprey</u>

After metamorphosis, Silver Lamprey migrate downstream to larger bodies of water to parasitize host fishes (*see* **Life Cycle and Reproduction**). These waterbodies are typically lakes, but given a suitable host population, large rivers and bays are also used (Vladykov 1949; *see* **Distribution**). Schuldt and Goold (1980) reported that Silver Lamprey were often found in rivers that were associated with bays. Cochran and Lyons (2004) found that Silver Lamprey were likely restricted to Green Bay and did not disperse widely into Lake Michigan, and Silver Lamprey also appear to be reasonably abundant in Lake St. Clair. As parasitic juveniles, they require clear water to locate suitable host fishes and are found at an average depth of 21.5 m (Trautman 1981; Scott and Crossman 1998). One of the most important requirements for this stage is connectivity between the spawning and larval habitat and the juvenile feeding habitat.

Spawning (Adult) Northern Brook and Silver Lampreys

Breeding adults of both species need gravel substrate to create nests where fertilization of the eggs occurs and some sand for the eggs to adhere to (Manion and Hanson 1980; Scott and Crossman 1998; Johnson *et al.* 2015; *see* **Life Cycle and Reproduction**). Spawning lampreys either avoid a substrate of fine particles (< 2 mm diameter; Gardner *et al.* 2012) or the nest-building activities themselves reduce the amount of silt. Therefore, appropriate rivers for spawning must have gravel substrate upstream of the silty depositional areas required for subsequent larval rearing (Dawson *et al.* 2015). Both Northern Brook and Silver lampreys require a unidirectional current and suitable water temperatures. Preferred spawning temperature for Silver Lamprey is 18°C, with water velocity between 0.5 and 1.5 m/s (Smith *et al.* 1968; Morman 1979; Manion and Hanson 1980). Northern Brook Lamprey nests have been found in interstices beneath large (18–36 cm in diameter) stones (Lanteigne 1991), usually in gravel shallows just above riffles (Hankinson 1932). Both Northern Brook and Silver lampreys spawn in relatively shallow water (i.e., generally < 0.5 m deep; Morman 1979). In Manitoba, Northern Brook Lamprey adults were collected at water depths averaging 0.6 m (Watkinson unpubl. data; Docker unpubl. data), but Silver Lamprey in large river systems may spawn in deeper water (Cochran and Lyons 2004). Spawning aggregations can occur under cover (e.g., woody debris, boulders, and vegetation), which can reduce the risk of predation (Cochran and Gripentrog 1992). In such cases, spawning appears to occur at greater depths than when conducted in open areas.

Habitat Trends

No studies exist that quantify changes in lamprey habitat over time (e.g., net gain or loss of area or quality of habitat change over the last three generations) or explicitly project future changes. However, Northern Brook Lamprey and Silver Lamprey in both DU1 and DU2 occur in areas that have been exposed to pollution (e.g., agricultural runoff; e.g., Schuldt and Goold 1980; Renaud *et al.* 1995; Clarke 1998) and where their habitats have undergone deforestation due to logging and agriculture (e.g., with destruction of riparian vegetation and tree cover), commercial development (which may decrease the extent and quality of spawning habitat and destroy silt beds; e.g., Starrett *et al.* 1960; Fortin *et al.* 2007; Becker and Hamel 2017), and construction of impoundments and barriers that remove access to spawning areas (resulting in habitat fragmentation) and irreversibly alter the hydrologic characteristics of spawning areas (e.g., Maitland *et al.* 2015; Becker and Hamel 2017) (*see* **Threats**). In the Great Lakes portion of DU1, the effect of these factors has been overshadowed by the loss of habitat or decline in habitat quality resulting from barrier dams and lampricide treatments, respectively (Schuldt and Goold 1980). However, at least in DU1, the rate of habitat change likely has not increased over the last three generations, and the decline in habitat quality due to some factors (e.g., industrial and urban waste water pollution) may be reversing. Declines in habitat quality may be ongoing in DU2 due to established and emerging invasive species (e.g., in the Whitemouth River Watershed; Becker and Hamel 2017) and large hydroelectric projects in the Winnipeg and Nelson rivers (*see* Threats), but they have not been quantified.

BIOLOGY

The general biology of the one or both of these species has been studied by various authors, including Hubbs and Trautman (1937) in Michigan, Leach (1940) in Michigan, Churchill (1945) in Wisconsin, Vladykov (1949, 1952) in Quebec, Purvis (1970) on the south shore of Lake Superior, Schuldt *et al.* (1987) in the Lake Michigan basin, and Cochran and colleagues (e.g., Cochran and Marks 1995; Cochran *et al.* 2003; Cochran and Lyons 2004) in Wisconsin. Scott and Crossman (1998) also provide reviews of the biology of these species, and the general ecology of larval lampreys and lamprey reproduction are reviewed by Dawson *et al.* (2015) and Johnson *et al.* (2015). These and additional sources are cited below. In the sections below, a general overview is presented for both species (i.e., summarizing relevant information that is common to both or highlighting important differences). Thereafter, additional details, when relevant, are given for each species.

Life Cycle and Reproduction

Like all lampreys, Northern Brook and Silver lampreys are oviparous and semelparous, and they invest a considerable amount of resources in their one and only spawning event (Scott and Crossman 1998; Docker *et al.* 2019). The lamprey life cycle includes an embryonic period, a larval period ending with metamorphosis, a parasitic or non-parasitic juvenile period (i.e., following metamorphosis but prior to sexual maturation), and an adult reproductive period. The larvae (termed ammocoetes) have a worm-like body shape and are blind and toothless. They spend most of their time burrowed in soft sediments in the slower-flowing regions of streams and rivers (*see* **Habitat**), feeding on organic detritus, algae (mostly diatoms), protozoans, and bacteria that they extract from the water overlying their burrows (Churchill 1945; Moore and Mallatt 1980; Yap and Bowen 2003; Dawson *et al.* 2015). In optimal habitats, larval densities can be very high (e.g., up to 126 Northern Brook Lamprey larvae per m^2 in the Brule River in Wisconsin (Churchill 1945) although, when density is averaged over larger areas, < 1 to about 20 larvae per m^2 is more typical (e.g., Hansen and Hayne 1962; Kainua and Valtonen 1980; Malmqvist 1980). Growth during this filter-feeding stage is slow. For example, Purvis (1970) documented annual growth increments of 37 mm, 28 mm, and 15 mm for the first three years of growth, respectively, in a Lake Superior tributary.

The larval stage in these species is thought to last for approximately 3–7 years (Purvis 1970; Scott and Crossman 1998). In lampreys, age at metamorphosis is sometimes determined using statolith banding patterns (structures analogous to teleost otoliths), but it is more commonly estimated from length at metamorphosis (*see* Dawson *et al.* 2015). These estimates are imprecise, due to significant differences in growth rate among individuals (e.g., Murdoch *et al.* 1992) and populations (Dawson *et al.* 2015), and due to a possible "arrested growth phase" or "rest period" prior to metamorphosis, during which time larvae may increase in mass but not length (Leach 1940; Lowe *et al.* 1973). In studies where known-age individuals have been monitored, age at metamorphosis varied widely. For example, Manion and Smith (1978) monitored a single year class of Sea Lamprey larvae in the Big Garlic River after it was isolated above a barrier dam, and they recovered metamorphosing individuals each year for 6–12 years afterwards. Similarly, size at metamorphosis has been shown to be an unreliable indicator of age at metamorphosis. Hess *et al.* (2015) used genetic analysis to identify the offspring of Pacific Lamprey released into a stream in 2007. Many of the offspring were recovered as downstream-migrating juveniles 5 years later, although they ranged in size from 74 to 145 mm TL. Without parentage analysis to place them in single year class, we would likely have assumed that they represented a large range of ages. In Northern Brook Lamprey, Purvis (1970) demonstrated that metamorphosis occurred in individuals as young as 3 years old by monitoring a single age class re-established after lampricide treatment. He also demonstrated that male Northern Brook Lamprey metamorphosed at earlier ages than females (i.e., 97% of these 3-year old transformers were male), a pattern that has been observed in many other lamprey species (*see* Dawson *et al.* 2015; Manzon *et al.* 2015; Docker *et al.* 2019). In general, non-parasitic species appear to be older and larger at metamorphosis than parasitic species, at least when comparing paired parasitic and non-parasitic lampreys (*see* Docker 2009; Dawson *et al.* 2015). It is hypothesized that the reduction in the length of post-larval life in non-parasitic lampreys (i.e., as a result of bypassing the parasitic feeding phase) is generally accompanied by an increase in the length of the larval period, so that the evolution of non-parasitism appears to have occurred without a change in the overall life span. Based on this general pattern and length at metamorphosis in these two species, the larval stage likely averages just over 5 years in Northern Brook Lamprey (i.e., from spawning in late spring or early summer to metamorphosis in late summer) and just over 4 years in Silver Lamprey (*see* below).

Metamorphosis in most Northern Hemisphere lamprey species begins in early to mid-summer, and is a 2- to 3-month process (Leach 1940; Manzon *et al.* 2015). It is influenced by endogenous and exogenous factors, most significantly a rise in spring water temperature and the accumulation of sufficient lipid reserves for the non-trophic metamorphic phase (Manzon *et al.* 2015). Metamorphosis involves a dramatic transformation leading to the development of functional eyes, a suctorial oral disc and protrusible tongue-like piston; restructuring of the branchial region; and changes in the fins and body colouration. Internal changes include major modifications to the digestive system (e.g., a remodeled esophagus and intestine) and a shift from the unidirectional, flow-through ventilation of the filter-feeding larva to the tidal, pumping ventilation of the adult. The life cycle of Northern Brook and Silver lampreys diverges considerably during metamorphosis. The Northern Brook Lamprey begins sexual maturation during metamorphosis, and spawns and dies within 6–8 months without ever feeding again, while the Silver Lamprey delays sexual maturation until completion of the parasitic feeding phase, and spawns and dies 18–20 months following metamorphosis (*see* below). Therefore, as suggested for lamprey species pairs in general, it appears that the overall life span (or generation time) of Northern Brook and Silver lampreys is similar, at approximately 6 years for both species.

Non-parasitic (brook) lampreys remain within their natal stream following metamorphosis, and undergo only short upstream migrations (not more than a few kilometers) to their spawning grounds (Malmqvist 1980). In contrast, parasitic lampreys, which generally migrate out of the stream after metamorphosis, typically embark upon longer spawning migrations (although they do not necessarily return to their natal streams to spawn; *see* Moser *et al.* 2015). For both Northern Brook and Silver lampreys, spawning occurs in tributaries, generally in May or June once water temperatures reach approximately 13°C (Vladykov 1949; Manion and Hanson 1980).

It is not uncommon for both species to be seen spawning in communal groups (Morman 1979; Cochran and Pettinelli 1987), and their mating system is described as polygynandrous (i.e., with both males and females having multiple mating partners during a breeding season; *see* Johnson *et al.* 2015). Both species have also been observed spawning in nests with other lamprey species: the Silver Lamprey has been observed in nests with Northern Brook Lamprey, American Brook Lamprey, and Sea Lamprey; and Northern Brook Lamprey have been observed in nests with Silver and Sea lampreys (Morman 1979). Experimental crosses in the laboratory indicate that hybrids between Northern Brook or Silver lampreys and either Sea Lamprey or American Brook Lamprey would be inviable (Piavis *et al.* 1970). However, Northern Brook-Silver lamprey hybrids showed survival rates equivalent to that of pure individuals (at least for the first few weeks following fertilization, when the experiment was terminated). Therefore, it appears that even accidental hybridization as the result of external fertilization will produce viable hybrids between Northern Brook and Silver lampreys, although long-term survival and fertility of hybrids is unknown (*see* **Name and Classification**). Northern Brook or Silver lampreys have not been observed spawning in the same nest as Chestnut Lamprey (Johnson *et al.* 2015), and Piavis *et al.* (1970) found 0% survival in experimental hybrids between these species. Hubbs and Trautman (1937) suggested that one adult specimen from Green Bay in the Lake Michigan basin might be a hybrid between Silver Lamprey and Chestnut Lamprey, and Starrett *et al.* (1960) reported a potential hybrid from the Mississippi River in Illinois. In the latter case, the specimen had eight bicuspid inner lateral teeth, but a low myomere count and a deeply bilobed transverse lingual lamina. However, hybridization between Northern Brook or Silver lampreys and the Chestnut Lamprey is likely limited.

In virtually all lamprey species studied, adult sex ratios (i.e., during the upstream migration or at spawning) show a small but consistent excess of males, but larval sex ratios are generally at parity or with an excess of females (*see* Docker *et al.* 2019). Sex ratios in Northern Brook and Silver lampreys follow this pattern. Adult sex ratios are reported to range from 54 to 75% male in Northern Brook Lamprey (Churchill 1945; Purvis 1970; Schuldt *et al.* 1987) and from 49 to 59% male in Silver Lamprey (Schuldt *et al.* 1987). In Northern Brook Lamprey, only 49% of larvae were male (Purvis 1970). In lampreys in general, it appears that females suffer higher mortality just prior to or during sexual maturation (e.g., due to the higher energetic demands of ovarian maturation relative to testicular maturation; *see* Docker *et al.* 2019).

In all lamprey species, fecundity increases approximately with the cubic power of total length (see Docker *et al.* 2019). Therefore, given their smaller size at maturity, Northern Brook Lamprey are considerably less fecund than Silver Lamprey, producing an average of 1,200 eggs per female versus 19,000 eggs in Silver Lamprey (*see* below). There is presumably a fitness trade-off between fecundity and mortality in the Northern Brook Lamprey relative to the parasitic Silver Lamprey.

Mortality through predation (and other sources of mortality associated with the longer and more exposed feeding and migratory phase in parasitic species) is presumably much higher in Silver Lamprey than that experienced by Northern Brook Lamprey with their shorter, more protected adult stage (Docker 2009). Mortality rates have not been quantified in these species, but they are thought to be comparable to rates observed in other lamprey species during the same stages. Under optimal laboratory conditions, Piavis (1961) found 78% survival to the burrowing stage in Sea Lamprey. However, lamprey eggs appear to be preyed upon by a number of fish species (Cochran 2009; *see* **Interspecific Interactions**), and eggs dislodged from the nest seem to be particularly vulnerable (Smith and Marsden 2009). Mortality is also thought to be high immediately following hatching, but it is relatively low and uniform throughout the remainder of the larval stage in other species (e.g., with annual survival rates estimated at 47–77%; see Dawson *et al.* 2015). Mortality rates typically increase again during the vulnerable period of metamorphosis (in both species), and, as indicated above, mortality is relatively high in migratory parasitic lampreys during their downstream migration following metamorphosis and their upstream (spawning) migration (e.g., due to predation by aquatic and avian predators; *see* Docker *et al.* 2015). In both species, predation by aquatic, avian, and terrestrial predators can be high during spawning, which generally occurs in daytime hours and in shallow water (*see* **Interspecific Interactions**).

<u>Northern Brook Lamprey</u>

As discussed above, duration of the larval stage is approximately 3–7 years in the Northern Brook Lamprey (Purvis 1970; Scott and Crossman 1998). Age at metamorphosis in other lamprey species appears to be largely dependent on size and will therefore vary with growth rate. For example, metamorphosis is observed at younger ages in Sea Lamprey from more productive streams (e.g., with higher water temperatures and food availability; Morman 1987; Quintella *et al.* 2003). High growth rates are also seen at lower larval densities (Murdoch *et al.* 1992). Purvis (1970) observed that male Northern Brook Lamprey metamorphosed at ages as young as 3 years old in a tributary of southern Lake Superior following re-establishment after lampricide treatment. Acceleration of growth rates after larval densities were dramatically reduced following lampricide treatment has been observed in Sea Lamprey (*see* Dawson *et al.* 2015). Nevertheless, size at metamorphosis also varies among individuals. Purvis (1970) observed Northern Brook Lamprey transformers to range in length from 97 to 127 mm (averaging 114 mm) and Morman (1979) found transformers ranging from 84 to 182 mm (averaging 126 mm). Female Northern Brook Lamprey typically undergo metamorphosis at older ages and larger sizes than males (Purvis 1970).

In general, lampreys going through the process of metamorphosis tend to move to coarser substrates with better oxygenated water where flows are higher, and, as a result of downstream drift, they may accumulate in more downstream reaches of the stream (*see* Dawson *et al.* 2015). Even after completion of metamorphosis, Northern Brook Lamprey tend to remain burrowed in the sediment until January or February (at least in Wisconsin), when they begin to emerge from their burrows and swim periodically (Becker 1983). They overwinter in or near the substrate, and full sexual maturity is reached in May or June, just before spawning (*see* Docker *et al.* 2019).

The time of spawning is determined by water temperature (Scott and Crossman 1998; Johnson *et al.* 2015), and Reighard and Cummins (1916) reported that the optimal spawning temperature for Northern Brook Lamprey was 20–22°C. However, spawning temperatures may vary by region. In Quebec, spawning occurs in May, when water temperature is between 13 and 16°C (Vladykov 1949). In Michigan, adults were observed spawning in June, at 16.5–20.5°C (Morman 1979). Spawning usually takes place in a shallow (20.3–45.7 cm deep), pool-riffle, high-gradient stretch of the stream (Scott and Crossman 1998). Male Northern Brook Lamprey initiate nest building, and the nests measure approximately 7.6–10.2 cm in diameter (Scott and Crossman 1998). Spawners are usually concentrated in a small area, and nests are inconspicuously located in spaces between large stones (Morman 1979) or, occasionally, under different types of cover (Cooper 1983; Cochran and Gripentrog 1992). Groups of 3–13 Northern Brook Lamprey have been observed in a single nest (Morman 1979; Cochran and Pettinelli 1987), and Northern Brook Lamprey have been observed spawning in nests with other native lamprey species (*see* above). While in the nest, the male attaches to the female, but he apparently does not wrap around her, as is observed in most lamprey species. Vigorous vibration accompanies spawning (Scott and Crossman 1998), and after fertilization, the eggs are sometimes covered with the substrate surrounding the nest (Johnson *et al.* 2015).

Mean fecundity estimates for different Northern Brook Lamprey populations range from 1,095 (Leach 1940) to 1,475–1,668 (Vladykov 1951; Schuldt *et al.* 1987), with an overall mean of 1,200 (Docker *et al.* 2019). The number of eggs increases with the size of the female, and the maximum reported fecundity is 1,979 (Vladykov 1951). The average egg size ranges from 1.0 to 1.2 mm (Vladykov 1951; Schuldt *et al.* 1987), and eggs hatch in 2–4 weeks (Leach 1940). Although not documented in Northern Brook Lamprey, in other species, female and male lampreys generally die within 1 week and 1 month of spawning, respectively (Pletcher 1963; *see* Docker *et al.* 2019).

Silver Lamprey

Size at metamorphosis in Silver Lamprey varies among individuals and may vary geographically. Recently metamorphosed Silver Lamprey measured 91–155 mm (average 114 mm) in Michigan (Morman 1979), 103–139 mm in Wisconsin (Becker 1983), and averaged 108 and 113 mm in males and females, respectively, in Quebec (Vladykov and Roy 1948). Age at metamorphosis has not been determined independently but, based on length at metamorphosis, ages likely range from approximately 3 to 7 years; however, the average age is likely younger, approximately 4 years (*see* above). Their weight at this stage is approximately 1–6 g (Vladykov and Roy 1948; Becker 1983; Scott and Crossman 1998).

Metamorphosed Silver Lamprey emerge from their burrows in early spring and migrate downstream to a lake (e.g., Lake St. Clair) or large river (e.g., the St. Lawrence, Winnipeg, and Nelson rivers), where the juveniles feed parasitically on a variety of host fishes (*see* **Interspecific Interactions**). The exact duration of the parasitic feeding phase is not known, but Silver Lamprey juveniles likely feed for approximately 7 months to 1 year. The active parasitic feeding phase for the closely related and ecologically similar Chestnut Lamprey was observed by Hall (1963) to last for 7 months (from April to October) in Michigan, followed by a largely inactive period from November through April. However, in Wisconsin, Cochran *et al.* (2003) found Chestnut Lamprey attached to host fishes during the winter, and their observation that Silver Lamprey gained significant mass between October and March suggests that the parasitic feeding phase (at least in some individuals or populations) extends for the entire year. Nevertheless, the greatest growth and highest feeding activity occurs between June and September (Becker 1983). In the laboratory, Roy (1973) found that female juvenile Silver Lamprey grew faster than males, and they attained a larger maximum length. Cochran and Lyons (2004) likewise found that female Silver Lamprey (during both the parasitic feeding and spawning phases) were larger than males. Feeding activity diminishes as sexual maturation approaches (Roy 1973). Therefore, the total post-metamorphic life span of Silver Lamprey is approximately 18–20 months (i.e., from the completion of metamorphosis in the early fall, followed by approximately 1 year of parasitic feeding, and sexual maturation and spawning the following spring). Vladykov and Roy (1948) documented the adult life span of Silver Lamprey as 12–13 months, but Roy (1973) found that lamprey grew more rapidly and reached maturity earlier in captivity than in their natural habitat. As discussed above, the average larval life span is approximately 4 years and 3–4 months (i.e., between spawning in spring and metamorphosis in late summer or early fall), yielding a total average life span of 6 years.

At the onset of sexual maturation (and depending on water temperatures and other factors; *see* Moser *et al.* 2015), Silver Lamprey begin the upstream migration to their spawning grounds. Unlike many other migratory fishes, lampreys do not appear to home to their natal streams (Bergstedt and Seelye 1995; Waldman *et al.* 2008); instead, they are attracted to bile acids ("migratory pheromones") released by the stream-resident larval lampreys (Sorensen and Vrieze 2003). Mature Silver Lamprey are attracted to bile acids released by Silver Lamprey larvae, as well as larvae of other species such as the Sea Lamprey (Fine *et al.* 2004). Silver Lamprey migration has been best studied in the Fox River in Wisconsin, where upstream migrants have been captured from early April to early

June (Cochran and Marks 1995; Cochran and Lyons 2004). Between 1979 and 1999, annual mean water temperature at capture ranged from 7.3 to 16.9°C. The mean date of capture did not differ between males and females, although larger individuals were generally caught earlier in the season. Sexual maturation continues during the upstream migration (e.g., with gonadosomatic index in females reaching up to 34% and averaging 14–19% by April–May; Vladykov 1951; Schuldt *et al.* 1987), the intestine becomes progressively less functional, and a decrease in length and weight is observed (Scott and Crossman 1998; Cochran and Marks 1995; Docker *et al.* 2019).

The time of spawning is determined by water temperature. The mean temperature at which Silver Lamprey have been observed spawning is 18.3°C (range 13–23°C) in Michigan (Morman 1979) and 18.2°C in Wisconsin (Cochran and Lyons 2004). A temperature of 18.4°C was considered optimal for rearing eggs to the prolarval stage (Smith *et al.* 1968). Silver Lamprey have been observed spawning in water as shallow as 13 cm (Manion and Hanson 1980), and Morman (1979) reported spawning at depths of 23–78 cm (mean 38 cm). Cochran and Lyons (2004) suggested that Silver Lamprey may be able to spawn in swifter, deeper water than other *Ichthyomyzon* species, and observed Silver Lamprey in spawning aggregations with Sea Lamprey at depths of 47–68 cm. Lamsa *et al.* (1980) reported that scuba divers have observed numerous Silver Lamprey spawning near the inlet to the St. Clair River in water as deep as 5 m, and Silver Lamprey may be spawning in deeper waters in the Winnipeg River as well (*see* **Distribution**). Manion and Hanson (1980) found that Silver Lamprey construct nests in gravel substrate 0.4–3.0 cm in diameter, and the nests average 8 cm in depth and are 33–122 cm in diameter (Morman 1979). Nests have been found to contain up to 15 Silver Lamprey each (Morman 1979; Cochran and Lyons 2004), indicating communal spawning (*see* above).

Mean fecundity estimates for different Silver Lamprey populations range from 13,403 to 22,820 (Vladykov 1951; Schuldt *et al.* 1987), with an overall mean of 19,000 (Docker *et al.* 2019). The lowest and highest recorded values are 12,006 and 29,412, respectively (Vladykov 1951). Egg diameter in females approaching maturity ranges from 0.8 to 1.0 mm (Vladykov 1951; Schuldt *et al.* 1987), and eggs hatch in 2–3 weeks, which is similar to that of the other four lamprey species in the upper Great Lakes (Smith *et al.* 1968).

Physiology and Adaptability

Both Northern Brook and Silver lampreys have been resident in fresh water for long periods of evolutionary time (Bartels *et al.* 2012). They do not develop seawater-type mitochondria-rich cells (SW-MRCs, formerly known as chloride cells) in their gills during metamorphosis and are unable to osmoregulate in salt water. However, both species (especially Silver Lamprey) have a relatively wide geographic distribution (Figure 9) and survive in a variety of hydrological, water chemistry, and temperature conditions (*see* **Habitat**). Although little is known about the physiology of Northern Brook and Silver lampreys specifically, inferences can be made from other lamprey species. This is particularly true of the conserved larval stage (*see* Dawson *et al.* 2015). The egg and embryo stages are most sensitive (e.g., to high temperatures), but larger larvae are generally more tolerant. For example, Sea Lamprey eggs are very sensitive to temperature and hatch only between 15.5 and 21.1°C, and newly hatched larvae show marked increases in mortality at 22°C (Piavis 1961). In contrast, in larger larvae (60–173 mm), Potter and Beamish (1975) determined that incipient lethal temperature for Northern Brook Lamprey acclimated to 15°C was 30.5°C, which was similar to that observed for two other Great Lakes species (30 and 29.5°C in Sea Lamprey and American Brook Lamprey, respectively). Thermal tolerance of Silver Lamprey larvae is likely similar. At 30.5°C, Northern Brook Lamprey larvae emerged from their burrows and died on top of the sediment.

Larval lampreys are able to tolerate relatively low oxygen tensions for up to 4 days, particularly at low temperatures (i.e., 7–10 mmHg at 5°C, 12–16 mmHg at 15.5°C, and 13–21 mmHg at 22.5°C; Potter *et al.* 1970). This is likely because the rate of oxygen consumption is lower in lamprey larvae than that observed in teleost fishes of similar weight (Hill and Potter 1970). In Mountain Brook Lamprey (*Ichthyomyzon greeleyi*), larval oxygen consumption at 3.5°C (8.1 µl/g/h) was less than one-tenth that observed at 22.5°C (90.1 µl/g/h) (Hill and Potter 1970). The low oxygen consumption of lamprey larvae allows them to burrow in silty regions in slow-flowing areas of streams. Nevertheless, oxygen concentrations could be limiting to larval lampreys during the summer months. Furthermore, the rate of oxygen consumption increases during metamorphosis, although it appears to increase less dramatically in non-parasitic species compared to parasitic species (*see* Manzon *et al.* 2015).

<u>Northern Brook Lamprey</u>

As metamorphosis progresses, Northern Brook Lamprey may be more tolerant of low oxygen levels than Silver Lamprey. In a European lamprey species pair, the non-parasitic species appears to remain in silty areas typical of the larvae until just prior to spawning, while the parasitic species moves into faster-flowing areas with more oxygenated sediments during metamorphosis, presumably as a result of differences in their oxygen requirements (Potter and Brown 1975). However, although it was not unusual for Mountain Brook Lamprey adults and larvae to occur in the same areas, Beamish and Medland (1988) still observed a tendency for the species to shift to coarser substrates and higher water flows during metamorphosis.

Although not studied specifically, adult Northern Brook Lamprey are likely sensitive to poor environmental conditions (e.g., high temperatures and low oxygen). During the non-trophic period of metamorphosis and sexual maturation, Leach (1940) found that female and male Northern Brook Lamprey lost 16 and 12% of their body weight, respectively, just between early September (i.e., during the early stages of metamorphosis) and late March or April. Weight loss between metamorphosis and spawning in late May or early June would have been even greater. One particularly small female, which was 92 mm at sexual maturity, died in mid-May as “little more than a swollen bag of eggs” (Leach 1940).

Although Northern Brook Lamprey has a relatively wide geographic distribution, its restricted mobility means that different populations are likely to be more adapted to local conditions compared to Silver Lamprey and other migratory species (*see* **Dispersal and Migration**). Furthermore, without gene flow among disjunct localities, isolated populations will tend to have smaller effective population sizes. When effective population size is high, a population has a high capacity to respond via selection, but when effective population size is low, the random process of drift becomes more powerful than selection (Kimura *et al.* 1963; Willi *et al.* 2013). However, given that the American Brook Lamprey has established well following accidental introduction into other Great Lakes streams (COSEWIC 2007), it is likely that Northern Brook Lamprey possesses some degree of adaptability to new areas on relatively short times scales.

<u>Silver Lamprey</u>

As mentioned above, relative to non-parasitic lampreys, parasitic species appear to require more oxygenated waters as metamorphosis progresses. This presumably continues during the free-swimming parasitic feeding phase. Nevertheless, the variety of habitats and conditions in which Silver Lamprey have been collected during the parasitic feeding phase (i.e., small and large lakes and rivers) across a wide latitudinal range suggests a considerable level of adaptability. Silver Lamprey has been reported to feed on more than 20 native and non-native fish species (*see* **Interspecific Interactions**), and Morman (1979) found that some populations of Silver Lamprey can persist upstream of barriers if a suitable forage-fish base is available. In three large rivers in Michigan, he reported that "remnant" Silver Lamprey populations were present in reaches upstream from dams established in the early 1900s. Each of these reaches was associated with inland lakes or impoundments capable of providing host fishes. Metamorphosed Silver Lamprey have been found upstream of dams in the Fox River, Wisconsin (SLCC unpubl. data). This system also is associated with a series of large inland lakes. In addition to apparent adaptability during the parasitic feeding phase, Silver Lamprey spawning has been observed in a variety of habitats and conditions (*see* **Life Cycle and Reproduction**).

Silver Lamprey occupies an even wider latitudinal range than Northern Brook Lamprey and, as a result of its dispersal on host fishes and presumed lack of natal homing, it is less likely to show local adaptation over moderate spatial scales (*see* **Dispersal and Migration**). Nevertheless, there are presumably limits to its dispersal capabilities and physiological differences (e.g., related to thermal preferences) at broader spatial scales (e.g., between the more northern and southern extremes and NFBZs).

Dispersal and Migration

In lampreys in general, most movement during the larval phase is the result of passive drifting with the current, although tagging studies in Sea Lamprey have shown that larvae are capable of moving short distances upstream (*see* Dawson *et al.* 2015). Furthermore, the degree to which lampreys drift downstream during their prolonged larval stage will be influenced by factors such as stream gradient, stream discharge levels, and water temperature (Potter 1980b). Following metamorphosis, dispersal capabilities differ considerably between the Northern Brook Lamprey and Silver Lamprey, although neither has the capacity to disperse via saltwater routes (*see* **Designatable Units**).

<u>Northern Brook Lamprey</u>

The Northern Brook Lamprey generally completes its entire life cycle in its natal stream (Leach 1940). Following metamorphosis, Northern Brook Lamprey will largely remain burrowed in the substrate, and movement even within a river system will likely be limited. Because they do not feed after metamorphosis, dispersal in brook lampreys does not occur via host fishes, and the small-bodied adults are capable of upstream migrations of only a few kilometers (*see* Moser *et al.* 2015).

<u>Silver Lamprey</u>

Metamorphosed Silver Lamprey migrate downstream to a lake or disperse within the river to begin their parasitic feeding phase. Feeding juveniles can be transported large distances on host fishes, although dispersal distances will still be limited by movement of the hosts and duration of Silver Lamprey attachment (*see* Spice *et al.* 2012). Cochran and Lyons (2004) found that Silver Lamprey in the Green Bay region of Lake Michigan were likely restricted to Green Bay itself and did not disperse widely into Lake Michigan.

Like other lampreys, Silver Lamprey does not appear to return to its natal streams to spawn (*see* **Life Cycle and Reproduction**). The upstream spawning migration is largely active, although Cochran *et al.* (2003) suggested that Silver Lamprey might be transported upstream, at least partially, while attached to Lake Sturgeon. Migration distances vary depending on the stream and presence of barriers but, in general, spawning appears to be restricted to the lower portions of rivers (Schuldt and Goold 1980). In the Rifle River in Michigan, Morman (1979) reported observing one Silver Lamprey in a nest 73 km above the river mouth, but spawners were most common in the lower 30–50 km of the main stream, and no spawners were found in otherwise suitable headwaters or tributaries.

Interspecific Interactions

In lampreys in general, predation by other fishes appears to be high during the egg stage. For example, cyprinids have been observed in the vicinity of spawning lampreys, presumably feeding on eggs, and Cochran (2009) found juvenile Hornyhead Chub (*Nocomis biguttatus*) eating the eggs of Southern Brook Lamprey (*Ichthyomyzon gagei*). Predation on Northern Brook Lamprey eggs could be particularly detrimental given low fecundity. Predation is likely lower during the burrowed larval stage, although some fishes (e.g., sturgeons, American Eel) appear able to detect and access them (*see* **Special Significance**), and larval lampreys may be susceptible to predation if they are dislodged from the substrate during scouring events (Cochran 2009; Docker *et al.* 2015). Post-metamorphic Northern Brook Lamprey remain relatively protected from predators, while Silver Lamprey are exposed to predators during their downstream migration, parasitic feeding phase, and subsequent upstream migration (*see* below). Both species are again vulnerable to predation during spawning in shallow water, when they are active during the daytime and found in higher densities (Manion and Hanson 1980; Cochran and Gripentrog 1992). Only the Silver Lamprey feeds on other fishes (*see* below). In terms of parasites, Appy and Anderson (1981) listed 70 distinct parasite species that have been found in larval and adult lampreys, although none were identified specifically in Northern Brook or Silver lamprey. In general, fewer parasites are found in non-parasitic lampreys because they feed only on microscopic organisms and do not acquire certain types of parasites (e.g., acanthocephalan parasites) from fish hosts.

In terms of interspecific competition, Northern Brook and Silver lampreys in the Great Lakes basin likely experience competition with the highly fecund Sea Lamprey (which produces an average of 70,000 eggs per female; Docker *et al.* 2019). Schuldt and Goold (1980) collected an average of nine Sea Lamprey adults for each Silver Lamprey in 12 Lake Superior tributaries in 1959, even before the effects of lampricide treatment were being noticed in adult returns, suggesting that the invading Sea Lamprey had already established a competitive advantage. Interspecific competition with Sea Lamprey (and perhaps the American Brook Lamprey; *see* **Threats**) might be acting during the larval stage. Larval growth is reduced under conditions of high density (Murdoch *et al.* 1991, 1992; Dawson *et al.* 2015), which might be the result of physical crowding rather than direct competition. Bowen and Yap (2018) found that when Northern Brook Lamprey occurred at 10 larvae/m^2, they contained 36% less food in their guts and were less efficient at assimilating organic detritus and amino acids from their diets than those held at 1 larva/m^2.

It is not clear how much interspecific competition there might be among adult lampreys for spawning habitat. Species-specific habitat preferences may reduce overlap, but Northern Brook and Silver lampreys have also been observed spawning communally with other species and, in fact, using the nests built by other lamprey species (*see* below). Experimental evidence suggests that viable hybrids would be produced only between Northern Brook and Silver lampreys (*see* **Life Cycle and Reproduction**). Nevertheless, producing inviable hybrids under these circumstances would result in gamete wastage, which could be significant in the Northern Brook Lamprey given its low fecundity.

Northern Brook Lamprey

Documented predators on adult Northern Brook Lamprey include Rock Bass (*Ambloplites rupestris*), and non-native Rainbow Trout (*Oncorhynchus mykiss*) and Brown Trout (*Salmo trutta*) (*see* Cochran 2009). Cochran *et al.* (1992) noted that stocked, non-native, predatory fishes could contribute to the decline and limit the dispersal of native lampreys. In southeastern Minnesota, the establishment of Brown Trout in streams with Northern Brook Lamprey and American Brook Lamprey might help explain the limited distribution of these species because relatively few native fishes in these streams were capable of feeding on large larvae or adult lampreys, particularly in streams too warm for Brook Trout (Cochran 2009).

In terms of interspecific competition, Churchill (1945) found that the burrows of Northern Brook Lamprey in the Brule River in Wisconsin are often close to burrowing mayfly nymphs and small mussels. All three of these organisms feed directly on microscopic aquatic organisms, but Churchill (1945) concluded that food competition was minimal because all three co-exist in substantial numbers.

In contrast, competition with other lamprey species may be significant. Northern Brook Lamprey co-exist in the same stream system with Silver and Sea lampreys and occasionally with American Brook Lamprey (COSEWIC 2007). Where their ranges overlap, generally only one species is common (Becker 1983), but whether this is purely the result of different habitat preferences or the result of competitive exclusion is not clear. In the Chocolay River system in Michigan, on the south shore of Lake Superior, Schuldt and Goold (1980) found that American Brook Lamprey predominated in the small, cold tributaries to the main stream and that Northern Brook Lamprey were restricted to the mouths of four creeks. Northern Brook Lamprey have been observed in nests with Silver and Sea lampreys (Morman 1979).

Silver Lamprey

At least 22 host fish species for the Silver Lamprey have been documented (Renaud and Cochran 2019). Of these 22 species, 19 and 15 are native to DU1 and DU2, respectively, and the non-native Common Carp (*Cyprinus carpio*) and Goldfish (*Carassius auratus*) are also found in these NFBZs; nine of these host species are found in DU3 (Scott and Crossman 1998). The preferred hosts for Silver Lamprey are likely a subset of these 22 species. In the laboratory, Silver Lamprey fed on seven of the 23 fish species presented to them (Roy 1973), and the average weight of the hosts selected was directly proportional to the average length of the lamprey. Other observations similarly suggest a preference (at least among large Silver Lamprey) for large-bodied hosts. Renaud (2002) found that Silver Lamprey parasitizing Muskellunge (*Esox masquinongy*) in the Ottawa River preferred larger fish. Other common large hosts for Silver Lamprey in Canada include Northern Pike, Channel Catfish (*Ictalurus punctatus*), Walleye, and Lake Sturgeon. Vladykov (1985) reported 61 Silver Lamprey on a single Lake Sturgeon caught in the St. Lawrence River. Cochran and Lyons (2004) expressed some reservations regarding the ability of Silver Lamprey to feed on heavily scaled non-native Common Carp, especially when they seem unable to form well-defined puncture wounds in the laboratory. These authors reported that a commercial fisher on the Mississippi River frequently observed Silver Lamprey associated with Paddlefish (*Polyodon spathula*), which is largely naked, and Common Carp. Interestingly, in the field observations, Silver Lamprey appeared to penetrate between Common Carp scales, and Cochran and Lyons (2004) thought that larger individuals are likely more able to do this.

On large hosts, Silver Lamprey parasitism is often not lethal. Unlike the invasive Sea Lamprey, Silver Lamprey has co-evolved with their hosts (Cochran and Lyons 2016). Renaud (2002) found that Silver Lamprey parasitizing Muskellunge often fed on blood rather than flesh, and no deep wounds were found. Eighty percent of the host fish had multiple marks, and 27% had healed injuries, indicating non-lethal past events of parasitism. In his laboratory study, Roy (1973) found that only about 30% of wounds resulted in the death of the host, and the lethality of the attack was dependent on the lamprey's stage of maturity (with growing lamprey being more detrimental to the host than those that had finished growing) and the location of the wounds (with the most vulnerable regions being the head and abdomen).

The host fishes of Sea Lamprey are also diverse (Renaud and Cochran 2019) and, therefore, there is some potential for competition between Sea and Silver lampreys in the Great Lakes during the parasitic feeding phase. However, in freshwater systems, the preferred prey of Sea Lamprey are small-scaled salmonids, primarily Lake Trout (*Salvelinus namaycush*) and Atlantic Salmon (*Salmo salar*), which share their preferred temperature range (15–20°C; Farmer 1980). During the parasitic phase, Sea Lamprey are more associated with cool water than Silver Lamprey, and display a pattern of more pronounced growth later into the fall that presumably reflects a tendency to feed more actively at lower temperatures. By comparison, Silver Lamprey achieves much of its growth during the summer months. According to Cochran and Marks (1995), Silver Lamprey prefer habitats such as that found in the Green Bay region of Lake Michigan that provide a combination of suitable warmer water temperatures and sufficient host population densities. The differences in bioenergetics and habitat preferences of different lamprey species may promote coexistence (Cochran and Marks 1995).

Predation on Silver Lamprey during the parasitic feeding stage is thought to be relatively low, because the adults are well dispersed. However, Cochran (2009) cautioned that predation on lampreys will often go undetected (e.g., in fish stomach contents) due to their lack of bone and other hard structures (with the exception of their keratinized teeth) that would be resistant to digestion. Nevertheless, Silver Lamprey have been found in the stomachs of Walleye in the St. Clair River in Michigan and Mississippi River in Minnesota (Cochran 2009). During spawning, predators of adult Silver Lamprey include mudpuppies and gulls (Cochran 2009), although predation is likely lower when Silver Lamprey spawn in deeper water or under cover (*see* **Habitat**).

As indicated above, interactions are observed among lamprey species at spawning, but they may represent a combination of direct competition, competitive exclusion, and cooperation. Silver Lamprey co-exist with Sea Lamprey in the Great Lakes basin, but Silver Lamprey tend to avoid stream localities where Sea Lamprey spawn in large numbers (Morman 1979). Silver Lamprey also co-exist in stream systems with Northern Brook Lamprey and, occasionally, American Brook Lamprey (SLCC unpubl. data). However, due to their preference for large, fast-flowing rivers, spawning Silver Lamprey do not often overlap with many brook lamprey species, which typically prefer smaller streams for spawning (Scott and Crossman 1998). Scott and Crossman (1998) speculated that where Silver and Chestnut lampreys occur together, they probably compete for spawning grounds and food, but they suggested that stream size and temperature selection, and the absence of Chestnut Lamprey from most Canadian waters, reduce this possibility of competition. Morman (1979) found that Silver Lamprey and Chestnut Lamprey were typically more common in the lower sections of main streams and comparatively large tributaries, and diminished progressively upstream, where they were displaced by Northern Brook Lamprey, American Brook Lamprey, and Sea Lamprey.

However, where they do spawn sympatrically, Silver Lamprey may spawn in the same nests with these other species (Johnson *et al.* 2015). Morman (1979) found that of 31 Silver Lamprey nests, 81% had other lamprey species present. Of the shared nests reported by Morman (1979), there were no incidences of antagonistic or territorial behaviour between species. The shared nests displayed physical characteristics typical of Sea Lamprey nests (Morman 1979), suggesting that the nest-building activity of larger-bodied Sea Lamprey may benefit Silver Lamprey. Cochran and Lyons (2004) found that Silver Lamprey spawned in deeper waters when in a nest with at least one Sea Lamprey. Interspecific mating was not observed, but the possibility of cross fertilization exists, which would likely be more detrimental to the Silver Lamprey relative to the Sea Lamprey given that Silver Lamprey females produce only about 25% the number of eggs as Sea Lamprey females (*see* above).

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

Targeted sampling for lampreys in recent decades has largely been concentrated in the Great Lakes basin, with native lamprey species usually being captured only incidentally during assessment efforts in support of Sea Lamprey control. In the Great Lakes basin, search effort has been quantified, permitting trends in relative abundance to be identified. However, it is important to acknowledge that changes to sampling techniques and sampling efficiency might confound comparisons over time. Furthermore, because larval Northern Brook and Silver lampreys cannot be distinguished morphologically or genetically (*see* **Morphological Description**), larval abundance estimates (e.g., during electrofishing surveys) are possible only for the two species combined; estimates for each species individually must depend on the post-metamorphic stages. In Northern Brook Lamprey, this is a relatively short portion of their life cycle, and sampling relies on collections of transformers in the late summer/early fall or of spawning adults in the spring. Silver Lamprey bycatch in Sea Lamprey traps operated by the SLCC provides an estimate of changes in adult abundance of this species, but Sea Lamprey traps are ineffective in catching upstream-migrating brook lampreys. Extensive lamprey sampling was conducted in Quebec in the 1930s, 1940s, and 1950s, although the majority of records are identified only as *Ichthyomyzon* sp. and most of these approximately 170 waterbodies in the St. Lawrence/Ottawa River basin have not been sampled since (Appendices 1–3). There has been a recent increase in the amount of targeted sampling in Quebec and Manitoba, but most of the information from these regions is still largely a mixture of bycatch data (e.g., of parasitic-phase Silver Lamprey attached to host fishes) and sporadic observations, and there is little quantification of sampling effort. Details of the sampling effort and methods are described for each DU below.

<u>Great Lakes-Upper St. Lawrence (DU1)</u>

In 2008–2018, electrofishing surveys in the Great Lakes basin (including Lake St. Clair) were conducted in 126–223 (mean 163) streams per year (SLCC unpubl. data). Sea Lamprey larvae were the target, but *Ichthyomyzon* spp. and American Brook Lamprey were also collected. A total of 217,900 m^2 of stream habitat was surveyed during this 11-year period using electrofishing, or 19,810 m^2 per year. Streams were also assessed using application of granular Bayluscide (gB), a bottom-release formulation that produces a high concentration of the pesticide niclosamide near the bottom in a limited area for a short period of time (Scholefield *et al.* 2003); in 2008–2018, 34–56 (average 42) streams per year were assessed using gB. A total of 162,965 m^2 of stream habitat was surveyed using gB, or 14,815 m^2 per year (SLCC unpubl. data). Comparisons to earlier survey results (COSEWIC 2011) permit changes in relative abundance to be identified, and population sizes can be inferred from the mean number of larvae collected per m^2 x total area of available habitat. However, these surveys are biased towards streams with known Sea Lamprey populations. More recent efforts by the SLCC have conducted targeted electrofishing surveys explicitly to identify undocumented localities of Northern Brook and Silver lampreys, and they have found that *Ichthyomyzon* larval densities are much higher in streams that are not treated with lampricides (SLCC unpubl. data).

Silver Lamprey bycatch in Sea Lamprey traps is also specific to the Great Lakes portion of DU1. The SLCC operates these traps with the primary purpose being assessment of Sea Lamprey spawner abundance, but Silver Lamprey captures are also recorded (COSEWIC 2011). Thus, although trapping techniques and trap efficiencies have not been consistent over time (COSEWIC 2011), the number of Silver Lamprey captured each year per trap and per trap-day (i.e., accounting for the number of days per year that each trap was in operation) provides some measure of relative abundance of upstream-migrating Silver Lamprey (catch per unit effort, CPUE). In 2008–2018, traps were operated on three tributaries to Lake Erie (Big and Young's creeks in each of the 11 years, and Big Otter Creek since 2012), eight tributaries to Lake Huron (Echo, St. Marys, and Thessalon rivers in all 11 years, and Beaver, Bighead, Koshkawong, Mississagi, and Nottawasaga rivers in 2–7 years), eight tributaries to Lake Ontario (Bowmanville and Duffins creek, Cobourg Brook, and Humber and Salmon rivers in all 11 years, and Grafton, Graham, and

Port Britain creeks in 1–7 years), and seven tributaries to Lake Superior (Big Carp River and Neebing-McIntyre Floodway in all 11 years, and Carp, Little Carp, Pancake rivers and Stokely Creek in 1–7 years) (SLCC unpubl. data). Overall, an average of 2.6, 4.6, 5.8, and 4.0 traps per year were operated in Lakes Erie, Huron, Ontario, and Superior in 2008–2018. For comparison, an average of 1.8, 5.6, 7.6, and 5.2 traps were operated in Lakes Erie, Huron, Ontario, and Superior in 1989–2007 (SLCC unpubl. data). Each trap was operated for 28–126 days per year (average 74 days) in 2007–2018 (SLCC unpubl. data), permitting calculation of the number of Silver Lamprey captured per trap-day. The number of Silver Lamprey captured per trap-day (CPUE) prior to 2007 was taken from the previous status report (COSEWIC 2011).

In Quebec, counts of upstream-migrating Silver Lamprey collected at a trap at St. Nicolas on the St. Lawrence River between 1975 and 2004 were used to infer a decline in abundance (COSEWIC 2011). Recent trap counts (MFFP unpubl. data) appear not to be entirely comparable (i.e., likely representing only a portion of the individuals collected), but comparable data from 2000 to 2019 may allow for recent trends to be inferred. In Lake St. Clair, the average number of lamprey scars (assumed to be inflicted by Silver Lamprey based on mark characteristics) documented on Lake Sturgeon between 1996 and 2005 were used to roughly infer an increase in Silver Lamprey abundance during this time period (COSEWIC 2011), but no comparable data were available recently. Standardized governmental surveys in the St. Lawrence River (i.e., Réseau de Suivi Ichtyologique, RSI, operated annually by MFFP since 1995, and Lampsilis, run by MFFP and the Université du Quebec à Trois-Rivières; *see* La Violette *et al.* 2003; Morissette *et al.* 2018) have captured parasitic phase Silver Lamprey in different sectors of the system (including Lake Saint-François, Lake Saint-Louis, and Lake Saint-Pierre). All sectors were not sampled each year, thus preventing interannual comparisons of relative abundance, but capture location, gear type, and usually total length were recorded (MFFP unpubl. data).

<u>Saskatchewan-Nelson River (DU2)</u>

Targeted sampling for Northern Brook and Silver lampreys has increased in recent years, but little or no information is available regarding population sizes or trends. One electrofishing survey estimated catch per unit effort (CPUE) as the number of *Ichthyomyzon* larvae collected per unit of time (Collerone 2014), but temporal comparisons are not available. All the Silver Lamprey data available in DU2 comes from parasitic feeding phase individuals that were captured during traditional fisheries surveys or by anglers, and effort was not standardized.

<u>Southern Hudson Bay-James Bay (DU3)</u>

The two specimens collected in this DU since 2008 were found attached to angled Northern Pike. There have been no targeted surveys of lampreys.

Abundance

Great Lakes-Upper St. Lawrence (DU1)

Ichthyomyzon sp. Larvae

In general, total population abundances have not been calculated for *Ichthyomyzon* larvae. One notable exception is in the Black Sturgeon River on the north shore of Lake Superior, where the population size was estimated at almost 14.6 million larvae in 2006 (Fisheries and Oceans Canada 2018). Because of its location above an impassable dam, the presence of metamorphosed Northern Brook Lamprey (*see* Table 1), and the lack of Silver Lamprey records in the system, it is suspected that all or most of these larvae are Northern Brook Lamprey (COSEWIC 2011). In the period 2008–2018, a total of 10,342 *Ichthyomyzon* lampreys were incidentally caught through larval Sea Lamprey assessment in Canadian tributaries to the Great Lakes (SLCC unpubl. data). The majority of these were larvae, although transformers (both Northern Brook and Silver lamprey) and Northern Brook Lamprey adults were also included. However, it should be noted that efforts targeted specifically at native lampreys (i.e., not restricted to streams or stream reaches with Sea Lamprey or subjected to Sea Lamprey control) have resulted in collection of significant numbers of *Ichthyomyzon* spp. During the above-mentioned survey of the Black Sturgeon River in 2006, approximately 900 Northern Brook Lamprey larvae were collected by electrofishing, and approximately 1,400 *Ichthyomyzon* larvae were collected in the Saugeen and Nottawasaga rivers upstream of the distribution of sea lamprey (SLCC unpubl. data). These numbers would be equivalent to 9,900 and 15,400 over an 11-year time period.

In areas surveyed during Sea Lamprey control efforts where *Ichthyomyzon* larvae occurred, mean and maximum densities in 2008–2018 were 0.7 and 8.2 larvae/m^2, respectively (derived from electrofishing), and 0.07 and 0.8 larvae/m^2, respectively (derived from gB surveys). For comparison, a total of 54,402 American Brook Lamprey were incidentally caught during larval Sea Lamprey assessment, although often not in the same tributaries as those containing *Ichthyomyzon* spp. Density of American Brook Lamprey was consistently higher than *Ichthyomyzon* densities; mean and maximum American Brook Lamprey densities were 2.4 and 15.0 larvae/m^2, respectively (electrofishing), and 0.2 and 2.4 larvae/m^2 (gB surveys; SLCC unpubl. data).

Northern Brook Lamprey

Between 2008 and 2018, a total of 147 metamorphosing and adult Northern Brook Lamprey were collected in the Great Lakes basin by SLCC through electrofishing and gB surveys (SLCC unpubl. data). During this time period, only one Northern Brook and four American Brook lampreys were captured in SLCC Sea Lamprey traps. In Quebec, not enough data have been collected to generate any population estimates for the species (Fortin *et al*. 2007). In 2011 and 2018, six and 10 Northern Brook Lamprey adults, respectively, were recorded in the St. Lawrence River watershed (MFFP unpubl. data).

Silver Lamprey

Between 2008 and 2018, only seven post-metamorphic Silver Lamprey were collected in tributaries to the Great Lakes during larval assessment (electrofishing and gB) surveys (SLCC unpubl. data). A total of 92 and 90 upstream-migrating Silver Lamprey were captured in 2008–2018 in SLCC Sea Lamprey traps operated on tributaries to Lake Erie and Lake Huron, respectively, or an average of 3.3 (Erie) and 1.7 (Huron) Silver Lamprey per trap-year (see **Sampling Effort and Methods**). Only one upstream-migrating Silver Lamprey was trapped in the Lake Superior basin during this 11-year period (0.02 Silver Lamprey per trap-year), and no Silver Lamprey were trapped in tributaries to Lake Ontario since 2006. In comparison to this total catch of 183 Silver Lamprey, 162,254 upstream-migrating Sea Lamprey were collected in SLCC Sea Lamprey traps over the same time period; that is, 887 Sea Lamprey were captured for every one Silver Lamprey (SLCC unpubl. data).

Schuldt and Goold (1980) reported that Silver Lamprey were uncommon in Canadian tributaries to Lake Superior even before lampricide treatments were initiated. In 1959, only 40 Silver Lamprey were collected at 16 electric barriers (2.5 Silver Lamprey per barrier) on the northern shore of Lake Superior, compared to a total of 4,278 collected at 35 American trap locations. Even in 1956, 2 years prior to the first lampricide treatment in the Lake Superior basin (see Table 2), only 97 Silver Lamprey (the maximum number for one year) were collected from Canadian traps. Scott and Crossman (1998) stated that the abundance of this species in Lake Ontario is likewise low, possibly as a result of the long presence of Sea Lamprey in the lake.

In Quebec, 110 parasitic feeding-phase Silver Lamprey were captured in 2008–2018 in the St. Lawrence River during RSI and Lampsilis surveys, including 18 lamprey from the Lake Saint-Louis sector, and 15 from Lake Saint-Pierre and the Saint-Pierre Lake archipelago (MFFP unpubl. data).

<u>Saskatchewan-Nelson River (DU2)</u>

Ichthyomyzon sp. Larvae

No population estimates or density data are available for larval lampreys in DU2, but an electroshocking survey collected 22 and 45 *Ichthyomyzon* larvae from the Whitemouth River in 2011 and 2013, respectively, and 23 and 10 from the Winnipeg River in these same years (Docker unpubl. data). Based on their distribution, these larvae are presumed to be Northern Brook Lamprey.

Northern Brook Lamprey

Since 2008, 15 metamorphosing and adult Northern Brook Lamprey have been recorded in DU2 (Docker unpubl. data).

Silver Lamprey

At least 78 parasitic-phase Silver Lamprey have been recorded in DU2 since 2008; more individuals may have been collected, but count information was not always included with collection records. In the Winnipeg River, Silver Lamprey are routinely found attached to Lake Sturgeon, Northern Pike, Channel Catfish, and suckers (*Catostomus* spp.) during fisheries surveys conducted by Manitoba Sustainable Development (Kroeker pers. comm. 2017). In one instance, an angler who caught 23 Lake Sturgeon on the Winnipeg River downstream of Point du Bois observed that at least half of them had one or two Silver Lamprey attached (Doyon pers. comm. 2017). Common host fishes are also frequently observed with healed lamprey scars (Kroeker pers. comm. 2017).

<u>Southern Hudson Bay-James Bay (DU3)</u>

Silver Lamprey

Only two Silver Lamprey have been observed in the Hayes River watershed since 2008, but no targeted surveys have been conducted.

Fluctuations and Trends

Changes in relative abundance over time can be inferred only for unidentified *Ichthyomyzon* larvae and Silver Lamprey in DU1.

<u>Great Lakes-Upper St. Lawrence (DU1)</u>

Ichthyomyzon sp. Larvae

Total catches of *Ichthyomyzon* larvae (and a small number of post-metamorphic Northern Brook and Silver lampreys; *see* above) from SLCC electrofishing surveys in the Great Lakes have been relatively consistent over the last three generations (i.e., 2001–2018). The total number of individuals captured incidentally during Sea Lamprey control efforts was 8,129 in 2001–2006; 4,891 in 2007–2012; and 6,050 in 2013–2018 (SLCC unpubl. data). However, average CPUE (as larvae/m^2) during this 18-year time period is lower than average CPUE for the previous three-generation period (Figure 11). On average, 0.145 larvae/m^2 were collected in 1989–2000 compared to only 0.073 larvae/m^2 in 2001–2018. Catch rates prior to 1989 were not available, but the most dramatic declines in abundance (in some cases > 95%) have been reported immediately following the initiation of Sea Lamprey control (Schuldt and Goold 1980; *see* **Threats**).

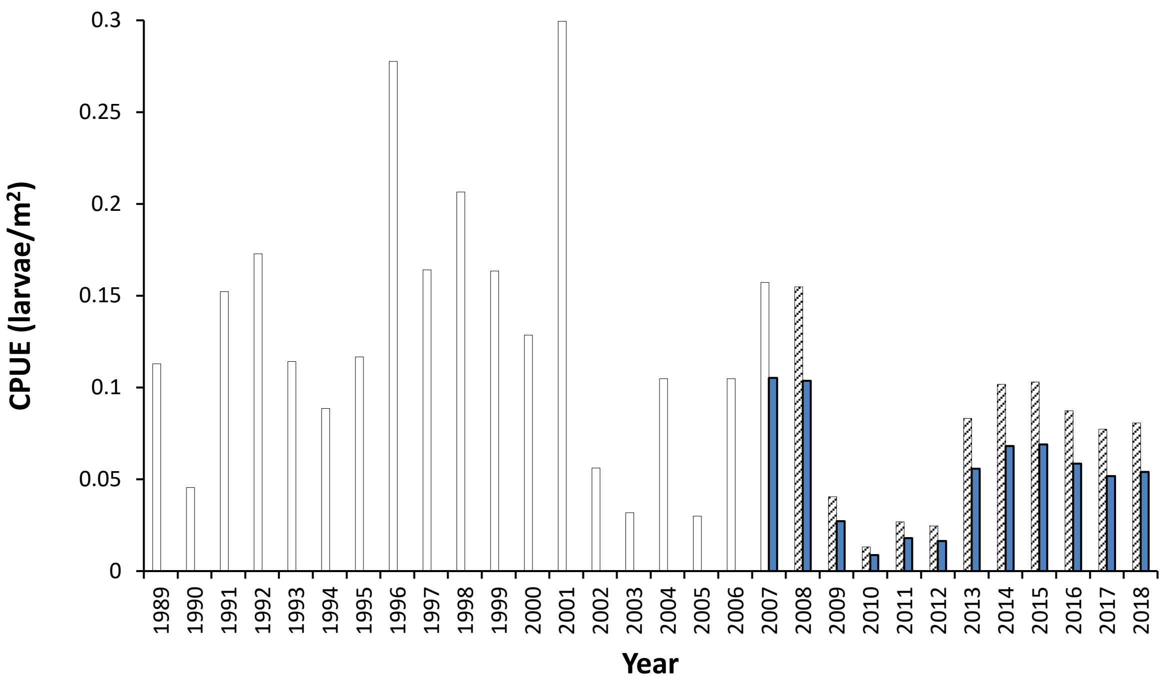

Figure 11. Sea Lamprey Control Centre (SLCC) electrofishing bycatch rates (catch per unit effort, CPUE) of *Ichthyomyzon* sp. larvae in Canadian Great Lakes tributaries (DU1) during Sea Lamprey assessment surveys, 1989–2018. Closed bars represent mean larvae/m^2 calculated using raw data for 2007–2018 (SLCC unpubl. data); open bars represent means estimated from Figure 3 in the previous Silver Lamprey status report (COSEWIC 2011) for 1989–2007; hatched bars represent 2008–2018 means adjusted using both values for 2007.

Northern Brook Lamprey

There are not enough data available for Northern Brook Lamprey in DU1 to infer trends in abundance. Only 147 metamorphosing and adult Northern Brook Lamprey were collected in the Great Lakes basin in 2008–2018 (see above), and historical records were not available for comparison.

Silver Lamprey

Overall, catch rates of upstream-migrating Silver Lamprey in the Great Lakes portion of DU1 appear to have stabilized or increased over the last three generations (Figure 12; SLCC unpubl. data). In 1989–2000, Silver Lamprey were captured in 39% of the Sea Lamprey traps operated on tributaries to Lake Erie (at an average of 1.6 per trap-year); in 2001–2018, Silver Lamprey were captured in 55% of traps, at an average of 2.6 per trap-year. In tributaries to Lake Huron, Silver Lamprey were captured in 31% of traps (at an average of 1.3 per trap-year) in 1989–2000, and in 29% of traps (at an average of 1.5 per trap-year) in 2001–2018. Silver Lamprey catches in traps have been consistently low in both Lake Ontario and Lake Superior, averaging only 0.1 and 0.03 per trap-year, respectively, between 1989 and 2018. Silver Lamprey are thought to have been historically uncommon in Canadian tributaries to Lake Superior, although it should be noted that 2.5

Silver Lamprey were collected per electric barrier in 1959 (Schuldt and Goold 1980; *see* **Abundance**).

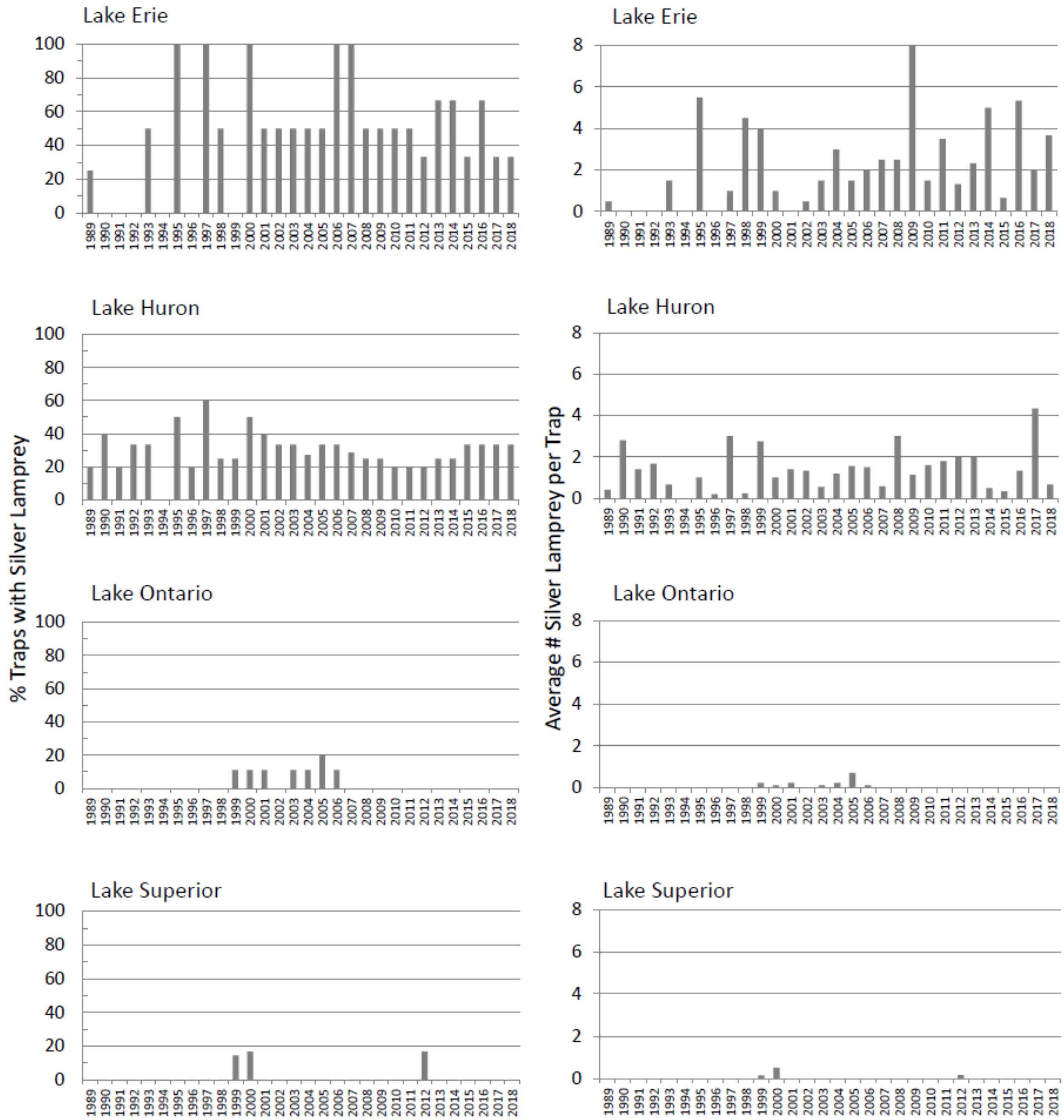

Figure 12. Catch per unit effort (CPUE) data for upstream-migrating Silver Lamprey collected in Sea Lamprey traps (percentage of traps where Silver Lamprey were recorded and average number of Silver Lamprey per trap) in Canadian tributaries for each Great Lakes basin (1989–2018). An average of 2.1, 5.2, 7.0, and 4.7 traps were operated per year in Lakes Erie, Huron, Ontario, and Superior, respectively.

Trends in catch rates over a longer time series can be made using the number of Silver Lamprey captured per trap-day because this measure of CPUE is available from the previous status report (*see* **Sampling Effort and Methods**). In general, catch rates declined dramatically after lampricide treatments were initiated (Figure 13). Although they have not returned to their historical levels, they appear to have stabilized or increased over the last three generations in Lake Erie and Lake Huron. CPUE peaked at 0.64 and 0.29 (in 1981 and 1968) in Lake Erie and Lake Huron, respectively, but averaged only 0.01 lamprey/trap-day in 1983–2000 (Erie and Huron); average CPUE increased to 0.03 (Erie) and 0.02 (Huron) lamprey/trap-day in 2001–2018. CPUE in Lake Superior peaked in 1956 (at 0.15 lamprey/trap-day), but it has been between 0 and 0.02 lamprey/trap-day for the past 50 years.

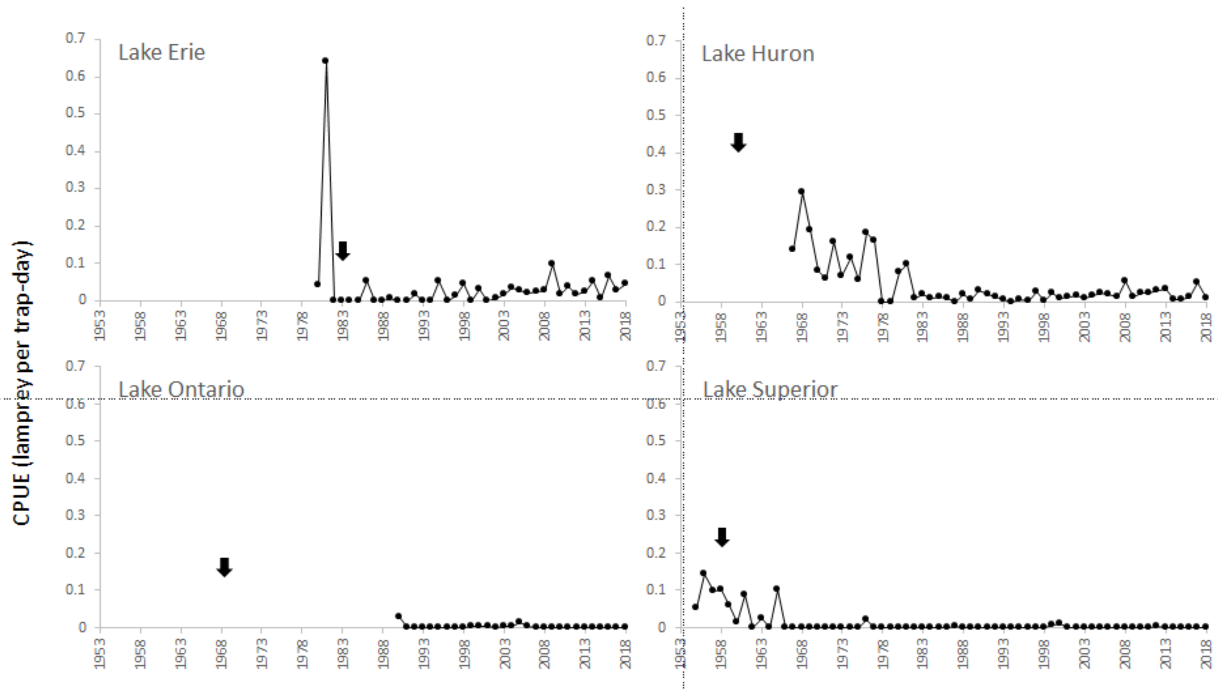

Figure 13. Catch per unit effort (CPUE) data for upstream-migrating Silver Lamprey collected in Sea Lamprey traps in monitored Canadian tributaries for each Great Lakes basin (1953–2018). Arrows denote when lampricide (TFM) treatment started in each basin (Sullivan *et al.* 2003; Morse *et al.* 2003; Pearce *et al.* 1980; Heinrich *et al.* 1980).

In the last status report, a substantial decrease in Silver Lamprey captures was noted at a trap at St. Nicolas on the St. Lawrence River between 1975 and 2004. An average of 68.2 Silver Lamprey was caught per year in 1975–1984, but annual catches averaged only 8.6 lamprey in 1995–2004 (COSEWIC 2011). Recently available trap records appear to represent only a portion of the individuals collected, but they suggest that the number of Silver Lamprey collected in this trap has remained low but stable. These records report annual catches averaging 2.9 lamprey per year in 1995–2004 and 2.5 lamprey per year in 2005–2019 (MFFP unpubl. data).

In Lake St. Clair, biologists and anglers witnessed an increase in the number of Silver Lamprey attachments to Lake Sturgeon and Muskellunge between 1996 and 2005 (COSEWIC 2011). The average number of presumed Silver Lamprey scars per Lake Sturgeon increased from 0.3 in 1996 to 6.0 in 2005, with an average of 2.3 over the 10-year period. The maximum number of scars per sturgeon also showed a general upward trend, ranging from 3 in 1996 to 73 in 2005 (n = 1,649 Lake Sturgeon). This apparent resurgence of Silver Lamprey in Lake St. Clair may have been due to rehabilitation of stream habitat in the Huron-Erie corridor, which has been hypothesized as the cause for re-establishment of other fish species in this area (e.g., Caswell *et al.* 2004; Roseman *et al.* 2007; *see* **Threats**). Recent scarring data were not available.

Rescue Effect

Northern Brook Lamprey

The non-migratory nature of Northern Brook Lamprey suggests that dispersal from populations in the United States is unlikely to allow successful repopulation of Canadian tributaries should this species disappear or experience a decline. Rescue from American populations is therefore unlikely in DU1 and even more unlikely in DU2.

Silver Lamprey

The dispersal capabilities of Silver Lamprey and their non-homing tendencies (*see* **Dispersal and Migration**) suggest that there is potential for rescue effect from one stream to another or one region of a lake to another. In fact, of the 19 Canadian tributaries of Lake Superior from which Silver Lamprey appeared to have been extirpated between 1953–1972 and 1973–1977 (Schuldt and Goold 1980), Silver Lamprey have subsequently been reported in seven (*see* **Distribution**). Therefore, the rescue effect from the United States could be significant for the Great Lakes populations in DU1. The number of adult Silver Lamprey caught in Sea Lamprey traps over the past 50 years in the United States (over 28,000 individuals, most from southern Lake Superior and western Lake Michigan (United States Fish and Wildlife Service unpubl. data) is much higher than the total number of Silver Lamprey collected in Canadian traps over the same time period (around 1,800 individuals; SLCC unpubl. data). Schuldt and Goold (1980) stated that rescue of Silver Lamprey from the American side of Lake Superior was highly likely. Rescue from American populations is less likely in DU2 and not possible in DU3.

THREATS AND LIMITING FACTORS

Threats

Ongoing and potential threats to Northern Brook and Silver lampreys are discussed below by DU and species. They are presented in the approximate order of most to least significant threats. To identify the nature and magnitude of threats to the Northern Brook and Silver lampreys, a threats calculator was completed based on the IUCN-CMP (World Conservation Union-Conservation Measures Partnership) unified threats classification system (IUCN and CMP 2006; Salafsky *et al*. 2008). The corresponding entry in the Threats Assessment Worksheet is identified for each in parentheses (Appendix 5). Threats common to more than one DU or species are discussed in full on first mention, with any relevant differences among DUs or species highlighted in subsequent sections.

<u>Great Lakes-Upper St. Lawrence (DU1)</u>

Northern Brook Lamprey

Based on the threats calculator, the overall threat impact is Very High (Appendix 5).

(9) Pollution – Lampricides (High)

The primary threat for native lamprey populations in the Great Lakes portion of DU1 are the ongoing lampricide applications conducted by Canadian and American agents of the Sea Lamprey Control (SLC) program (Fisheries and Oceans Canada 2018). The two main lampricides, which kill larvae while they are resident in the tributary streams, are 3-trifluoromethyl-4-nitrophenol (TFM) and niclosamide (2',5-dichloro-4'-nitrosalicylanilide, Bayer-73 or Bayluscide). TFM is largely lamprey-specific, and niclosamide is used in small quantities (1–2%) with TFM to reduce the amount of TFM required for a given target mortality (*see* Marsden and Siefkes 2019; Wilkie *et al.* 2019). Addition of 1% niclosamide can reduce the amount of TFM required by 40% (Wilkie *et al.* 2019). TFM treatments were initiated in 1958 in tributaries to Lake Superior (Heinrich *et al.* 1980), in 1960 in the Lake Huron basin (Morse *et al.* 2003), in 1971 in Canadian tributaries to Lake Ontario (Pearce *et al.* 1980), and in 1986 in Lake Erie (Sullivan *et al.* 2003). Due to their protracted larval stage, periodic lampricide treatments will eliminate multiple generations. TFM is administered at approximately 1.5 times the Minimum Lethal Concentration (MLC, defined as the concentration of TFM required to produce 99.9% mortality in a 9-hr exposure; Marsden and Siefkes 2019). TFM is largely lamprey-specific, but it is not specific to Sea Lamprey. Although larval *Ichthyomyzon* appear slightly less susceptible to TFM than Sea Lamprey larvae (King and Gabel 1985), the difference is insufficient to allow for selective control of Sea Lamprey without also killing native lampreys. Likewise, there are only small differences in the toxicity of niclosamide to Sea Lamprey and native lamprey larvae (Scholefield and Seelye 1992).

As a result, significant reductions or extirpations have been observed in larval populations of *Ichthyomyzon* lampreys in streams that were invaded by Sea Lamprey and subsequently treated with lampricides. For example, population declines of 94–98% were observed in several tributaries to Lake Superior after only one or two TFM treatments, and *Ichthyomyzon* larvae may have been extirpated from more than half of the 46 Canadian tributaries that were monitored between 1953 and 1977 (Schuldt and Goold 1980; *see* **Distribution**). *Ichthyomyzon* larvae were readily eliminated from watersheds where they were confined to short stretches and where few sources of recruitment were available. Native larvae disappeared from most streams unless they inhabited areas above barriers, lentic environments, tributaries in which Sea Lamprey did not spawn, or areas difficult to treat (e.g., oxbows, beaver ponds, long estuaries, and springs) (Schuldt and Goold 1980). *Ichthyomyzon* larvae have subsequently been observed in some of these rivers, but they are less abundant in treated areas than untreated areas (COSEWIC 2007).

Thus, the susceptibility of native lampreys to lampricides is dependent on whether they co-occur with Sea Lamprey. Of the 143 Great Lakes rivers in Canada where *Ichthyomyzon* lampreys have been reported, approximately half (76) have been or are currently treated with lampricides: 40 are Category 1 streams that are treated approximately every 2–5 years; 23 are Category 2 streams that are treated less frequently; and 13 are Category 3 streams that produce relatively few Sea Lamprey and are treated even less frequently or not at all (Table 2). Post-metamorphic Northern Brook Lamprey have been confirmed in 46 of these streams, 17 of these in the last three generations.

The non-migratory Northern Brook Lamprey can inhabit headwaters that are farther upstream than Sea Lamprey generally occur (Morman 1979; *see* **Habitat**) and can complete their life cycle in areas where Sea Lamprey have been excluded by dams or barriers constructed to prevent their upstream migration. Therefore, unless there is a dramatic change in Sea Lamprey distribution, it is unlikely that lampricide treatments will impact Northern Brook Lamprey populations beyond current levels (Fisheries and Oceans 2018). In untreated streams, the species is still abundant.

Northern Brook Lamprey in the Quebec portion of DU1 are not subjected to lampricide treatments. The anadromous Sea Lamprey in Quebec is native (Renaud *et al.* 2009) and, although parasitic-phase Sea Lamprey are sometimes attached to fish in the St. Lawrence River (Pearce *et al.* 1980), no significant impacts on freshwater fish populations have been documented. Landlocked Sea Lamprey occur in Quebec in tributaries to Lake Champlain, but lampricides are not used in Quebec (*see* Marsden and Siefkes 2019).

(9) Pollution – Other (Low)

Various types of pollution, either alone or in combination with other factors, appear to limit lamprey distribution. For example, Morman *et al.* (1980) reported that streams in the southern half of Michigan's Lower Peninsula that were subject to pollution from urbanization, agriculture, and industry had fewer and more isolated larval Sea Lamprey populations than streams in the less-developed northern half of the peninsula where water quality is relatively high. Stream pollution has also been thought to limit distribution in the Lake Erie basin and along the southwestern shore of Lake Ontario (Morman *et al.* 1980; *see* Maitland *et al.* 2015). The relative vulnerability of lampreys to different forms of chemical contamination in the water and underlying sediments is largely unknown.

(9.1) Household Sewage & Urban Waste Water

Although household sewage and urban waste water (in combination with industrial waste) were serious threats to fish health in the mid-19th century (e.g., in the Huron-to-Erie corridor), pollution-abatement efforts have significantly improved water quality throughout much of DU1. There are indications that such improvements can lead to the recovery of larval lampreys. For example, Sea Lamprey recolonized one Lake Michigan tributary and increased in abundance in two Lake Erie tributaries after water quality improved (Morman *et al.* 1980). Morman *et al.* (1980) reported substantial numbers of larval lampreys in a lagoon heavily contaminated with raw untreated municipal sewage, suggesting that they are reasonably tolerant of household sewage, although anoxic sediment or urban waste outflow during embryonic development are likely harmful.

(9.2) Industrial & Military Effluents

Andersen *et al.* (2010) found that Pacific Lamprey larvae showed high sensitivity (relative to other fishes) to pentachlorophenol. This chemical is used in paper mills and has other industrial applications (e.g., as an ingredient in anti-fouling paint), although its use has declined in recent years. Renaud *et al.* (1998) reported high levels of mercury in larval Northern Brook Lamprey (relative to mussels or teleost fishes) in the Châteauguay River in Quebec. Therefore, industrial effluents in some parts of DU1 (e.g., southwestern Ontario and the St. Lawrence River) may have a negative impact on Northern Brook Lamprey.

(9.3) Agricultural & Forestry Effluents

Agricultural activity in DU1 (e.g., in southwestern Ontario, and the St. Lawrence and Ottawa river watersheds) may pose a threat to Northern Brook Lamprey. In other lamprey species, an input of contaminated sediments, usually from agriculture and residential effluent, has resulted in decreased hatching success and larval feeding ability (Mundahl *et al.* 2006). Renaud *et al.* (1995) concluded that the apparent extirpation of Northern Brook Lamprey from the upper Yamaska River in Quebec was due in part to the herbicide atrazine leaching into the river from extensive corn fields during rain events. Northern Brook Lamprey were found in high abundance in this river in the 1940s but, atrazine, which was first introduced in the early 1960s, is suspected to have affected Northern Brook Lamprey by destroying its phytoplankton food source. Atrazine and other pesticides may also have direct toxic effects. Lampreys in both the Great Lakes and upper St. Lawrence watersheds continue to be exposed to a variety of pesticides. In Quebec, a 49% increase in area of pesticide application has been observed between 1996 and 2006. In Lake Ontario, the concentration of atrazine increased by 57% between 1998 and 2006 (Fisheries and Oceans Canada 2018). Agricultural pollution also can lead to eutrophication, and the resulting algal and bacterial production can smother both the spawning gravels (preventing spawning or killing embryos) and the larval rearing areas. However, the effects on spawning and embryonic development are likely greater than the effects on the filter-feeding larvae.

(8) Invasive & Other Problematic Species & Genes (Medium-Low)

(8.1) Invasive Non-native/Alien Species

Competition between invasive Sea Lamprey and Northern Brook Lamprey likely poses a threat to the latter (Hubbs and Trautman 1937; Schuldt and Goold 1980). Given its considerably higher fecundity, dispersal abilities, and high adaptability to new environments, the Sea Lamprey is more able to recolonize lampricide-treated streams and it reaches much higher abundance than Northern Brook Lamprey (Schuldt and Goold 1980; *see* **Biology**). However, Northern Brook Lamprey will have a competitive advantage above barriers that sever connectivity between spawning and feeding habitats used by the Sea Lamprey. The accidental introduction of American Brook Lamprey into streams along the north shore of Lake Superior could also pose a threat to the Northern Brook Lamprey in this region. American Brook Lamprey has a higher average fecundity (2,380) than Northern Brook Lamprey (1,200; *see* Docker *et al.* 2019), and it occurs at higher densities when both species are present (*see* **Abundance**).

Some non-native fish species likely prey upon Northern Brook Lamprey eggs and adults. Rainbow Trout (e.g., as migratory steelhead) and Brown Trout have been introduced into the Great Lakes and Quebec, and they are known predators of adult Northern Brook Lamprey in other parts of this species' range (*see* **Interspecific Interactions**). Many native fishes are known to prey on lamprey eggs, and egg predation by non-native fishes is also likely. For example, the Round Goby (*Neogobius melanostomus*) is thought to be a significant predator on Channel Darter (*Percina copelandi*) eggs and young in areas of the St. Clair River, Lake St. Clair, Detroit River, Lake Ontario, and the St. Lawrence River (*see* COSEWIC 2016), although predation on lamprey eggs has not been documented.

(7) Natural Systems Modifications (Medium-Low)

(7.2) Dams & Water Management/Use

There are hundreds of dams in Ontario and Quebec that are impassable to Northern Brook Lamprey. In Ontario, over 300 dams are owned and operated by the Ontario Ministry of Natural Resources and Forestry, and at least 160 hydroelectric generating stations are located across Quebec. Dams prevent Northern Brook Lamprey that drift downstream passively during the larval stage from completing their compensatory upstream movement to the spawning areas (*see* **Biology**). As a result, brook lampreys in headwater areas show reduced genetic diversity and are more vulnerable to local extirpation (Spice *et al.* 2019). In addition to acting as barriers to migration, the impact of dams on hydrologic regimes may also disrupt native lampreys, particularly during the larval stage. Larval mortality as the result of dewatering can be significant, and several larval year classes are at risk from a single dewatering event (Maitland *et al.* 2015). Conversely, flood conditions may carry larvae downstream and potentially out of the tributary. Dams can also negatively affect stream-resident fishes by causing warming and sedimentation (Heinrich *et al.* 1980). There has been little study of the potential effects of smaller barriers (e.g., culverts and spill gates) on the distribution of small-bodied brook lampreys, but they may also be significant (*see* Spice *et al.* 2019).

Conversely, however, dams that prevent establishment of Sea Lamprey in the upper reaches of tributaries occupied by Northern Brook Lamprey protect the latter species from exposure to lampricides. Furthermore, in addition to these dams that have been built for other purposes (e.g., power generation), barriers specifically for Sea Lamprey control have been built on critical Sea Lamprey-producing tributaries. In total, Sea Lamprey barriers are present on 68 Great Lakes tributaries; although they block passage of many non-target fishes, they eliminate the need for lampricide treatment in an estimated 1,400 km of stream (*see* Marsden and Siefkes 2019) and protect many populations of the non-migratory Northern Brook Lamprey from exposure to lampricides. Of the 143 Canadian Great Lakes tributaries where *Ichthyomyzon* lampreys have been reported, 29 have Sea Lamprey barriers, and post-metamorphic Northern Brook Lamprey have been confirmed in 17 of these tributaries (Table 2).

Therefore, removal of barriers as a means to restore habitat connectivity for other fishes (e.g., Lake Sturgeon, Walleye, salmonids) could represent a substantial threat to Northern Brook Lamprey in the Great Lakes portion of DU1. For example, possible removal or modification of the Camp 43 Dam on the Black Sturgeon River, which is located 17 km upstream from its outlet into Lake Superior, is currently being considered (Fisheries and Oceans 2018). However, permitting Sea Lamprey access to spawning habitat above the dam would require an increase in lampricide applications to larger sections of the river, which puts the 14.6 million Northern Brook Lamprey larvae in the river at risk (Smyth 2011; Steeves pers. comm. 2018). The Ontario government is still in the environmental assessment phase and is considering removing the Camp 43 Dam and moving it 50 km upstream; however, no immediate decision regarding its removal or alteration is expected (Steeves pers. comm. 2018).

(7.3) Other Ecosystem Modifications

Destruction of habitat can result from various construction or maintenance projects including dredging, road maintenance (e.g., road crossings and culvert insertion), and grade-control of stream banks (*see* Maitland *et al.* 2015). These activities disturb and sometimes remove the sediment in which larval lampreys burrow. These depositional areas are not typically important fish habitat, and even well-intentioned conservation efforts meant to help other fishes can negatively affect native lampreys when they replace their preferred habitat with other substrate types such as gravel (Maitland *et al.* 2015). Furthermore, larvae may often be removed along with the sediments, which can have multi-generational consequences, and dewatering during flow regulation and maintenance can cause mortality through temperature fluctuations and desiccation (Streif 2009). Conversely, Northern Brook Lamprey require gravel for spawning, and sedimentation plumes generated by instream activities can cover lamprey spawning grounds with silt.

Northern Brook Lamprey in DU1 may also be negatively affected by the loss of riparian regions, which causes soil erosion and increased sedimentation in riverbeds. These zones also provide shade, an important habitat component for larval lampreys (Potter *et al.* 1986), and they filter and stabilize riverbanks, and protect rivers against the effects of fertilizers and pesticides (Society of Wildlife and Parks of Quebec 2003).

(5) Biological Resource Use (Low)

(5.3) Logging & Wood Harvesting

The loss of riparian vegetation and other alterations that result in increased siltation levels (e.g., deforestation) may threaten native lampreys (Starrett *et al.* 1960; Fortin *et al*. 2007). Moderate amounts of sedimentation associated with logging may be beneficial for larval lampreys (particularly in high-gradient streams or other sediment-poor areas; Beamish 1998), but excessive sediment inputs likely negatively impact spawning habitat.

(5.4) Fishing & Harvesting Aquatic Resources

Northern Brook Lamprey was once used as bait for sport fishing (Vladykov 1973). Vladykov (1952) refers to a total annual harvest of about 300,000 larvae (from all species) in the 1940s and 1950s in Quebec (Renaud 2007). However, the use of lamprey larvae as bait is now illegal in Quebec (Fortin et al. 2007), and there is no indication that it has continued.

(11) Climate Change & Severe Weather (Medium/Low)

Climate change is expected to increase water and air temperatures, lower water levels, shorten the duration of ice cover, increase the frequency of extreme weather events, and produce shifts in predator-prey dynamics in aquatic communities of the Great Lakes and St. Lawrence basins (Lemmen and Warren 2004). Climate change has the potential to adversely affect Northern Brook Lamprey through periods of drought (11.2; *see* **Dams and Water Management/Use**), and periods of heavy rain in the autumn and winter could wash out and destroy larval silt beds (11.4). Rapid increases in temperature during embryonic development could lead to increased mortality (11.3; *see* Maitland *et al.* 2015). Conversely, because Northern Brook Lamprey in Canada is at the northern limit of its range, warming temperatures might allow this species to expand its distribution, shift the time of its spawning, and extend its growing season (11.1; Cochran *et al.* 2012; Maitland *et al.* 2015). However, range expansion by Sea Lamprey into streams occupied by Northern Brook Lamprey would likely increase the latter species' exposure to lampricides, and warming trends may also favour the establishment of potentially harmful invasive species that are currently limited by cooler water temperatures.

Silver Lamprey

Based on the threats calculator, the overall threat impact is Very High (Appendix 5).

(9) Pollution – Lampricides (High)

As with Northern Brook Lamprey (*see* above), lampricides constitute the primary threat to Silver Lamprey in the Great Lakes portion of DU1. However, Silver Lamprey may be even more vulnerable to lampricide treatments because they are generally restricted to a relatively short stretch of river downstream of Sea Lamprey barriers; thus, much more of their distribution appears to be exposed to the effects of the lampricide (Schuldt and Goold 1980). Of the 76 *Ichthyomyzon*-containing streams that receive lampricide treatments, Silver Lamprey presence was confirmed in 46 of them (20, 18, and eight in Category 1, 2, and 3 streams, respectively), although Silver Lamprey adults have been reported in only 18 of them in the last three generations (Table 2). Silver Lamprey in the Quebec portion of DU1 are not exposed to lampricides.

(9.1) Household Sewage & Urban Waste Water

As with Northern Brook Lamprey, household sewage and urban waste water are likely not significant threats to Silver Lamprey in DU1, although anoxic sediment or urban waste outflow during embryonic development are likely harmful.

(9.2) Industrial & Military Effluents

Industrial effluents in some parts of DU1 may have a negative impact on Silver Lamprey. In addition to accumulating mercury from the sediments (*see* above), high levels of mercury have also been detected in other species of lampreys following the parasitic feeding phase (e.g., MacEachen *et al.* 2000). Silver Lamprey are top predators, feeding on the blood of large-bodied fishes that may themselves be significantly contaminated with environmental pollutants (*see* Maitland *et al.* 2015).

(9.3) Agricultural & Forestry Effluents

As with Northern Brook Lamprey, agricultural activity in DU1 could pose a threat to Silver Lamprey embryos and larvae due to the toxic effects of herbicides and their effect on phytoplankton food source of the larvae, or as a result of eutrophication (*see* above).

(7) Natural Systems Modifications (Medium-Low)

(7.2) Dams & Water Management/Use

Dams and Sea Lamprey barriers pose a more serious threat to Silver Lamprey than to Northern Brook Lamprey, because they prevent Silver Lamprey from accessing spawning and larval habitat in some river systems. According to Sullivan *et al.* (2003), the Silver Lamprey, which was once abundant in Lake Erie's western basin, was heavily impacted by dam construction, siltation of spawning beds, turbidity, and pollution long before the advent of Sea Lamprey control measures. This has been exacerbated by the construction of Sea Lamprey barriers. Silver Lamprey were known to occur in 22 of the 29 *Ichthyomyzon*-containing streams with Sea Lamprey barriers, although adults have been reported in only 11 of them in the last three generations (Table 2). At Sea Lamprey barriers with traps, Canadian and American Sea Lamprey Control agents often hire contractors to monitor the catches. Contractors usually have some fish identification experience, which allows them to release incidental native fishes (including Silver Lamprey) from the trap back to the river or over the barrier. In the United States, not all contractors are able to distinguish Silver Lamprey from Sea Lamprey and, therefore, no lampreys are passed over barriers

(COSEWIC 2011). Given the non-homing tendencies of Silver Lamprey, these mortalities may impact the Canadian Great Lakes populations as well. Barriers to migration will also limit gene flow among localities (*see* **Population Spatial Structure and Variability**).

(7.3) Other Ecosystem Modifications

Destruction of habitat from other ecosystem modifications (e.g., dredging, road maintenance) also may negatively impact Silver Lamprey habitat (*see* above).

(8) Invasive & Other Problematic Species & Genes (Medium-Low)

(8.1) Invasive Non-native/Alien Species

Competition between invasive Sea Lamprey and Silver Lamprey likely poses a threat to the latter. Schuldt and Goold (1980) found that, even before adult numbers were affected by lampricide treatments, Sea Lamprey outnumbered Silver Lamprey 9:1 (*see* **Interspecific Interactions**). The fecundity of Sea Lamprey is approximately 3–4 times higher than that of the smaller Silver Lamprey (*see* **Biology**), and Silver Lamprey appears to be limited by more stringent spawning requirements (Schuldt and Goold 1980). Some non-native fish species likely prey on Silver Lamprey eggs (e.g., Round Goby; *see* above), although such predation has not been documented. Conversely, some non-native fish species (e.g., Common Carp) may serve as hosts during the parasitic feeding phase.

(5) Biological Resource Use (Low)

(5.3) Logging & Wood Harvesting

As with Northern Brook Lamprey, loss of riparian vegetation and other effects of forestry activities may negatively impact Silver Lamprey (*see* above).

(5.4) Fishing & Harvesting Aquatic Resources

There is likely little or no intentional harvesting of Silver Lamprey. However, Silver Lamprey are caught as bycatch, and they may be destroyed if they are not distinguished from the invasive Sea Lamprey.

(11) Climate Change & Severe Weather (Medium-Low)

As with Northern Brook Lamprey, the effects of climate change may adversely affect Silver Lamprey (11.2, 11.4). However, migratory Silver Lamprey presumably would be better able to colonize new river systems with more suitable thermal regimes (11.1), although barriers to migration would limit this.

Saskatchewan-Nelson River (DU2)

Northern Brook Lamprey

Based on the threats calculator, the overall threat impact is High-Medium (Appendix 5).

(11) Climate Change & Severe Weather (High-Low)

The general effects of climate change on Northern Brook Lamprey are likely similar to those briefly discussed for this species in DU1 (*see* above), but they are expected to have a greater impact on this species in DU2. Climate change has the potential to reduce precipitation and water levels in DU2, which will exacerbate the effects of increases in temperature. The Birch River, where low flow and low oxygen conditions already occur in summer and winter (Clarke 1998), may be particularly vulnerable to changes, and temperatures in July and August may already be approaching this species' thermal limits. In 2011, data loggers at two sites in the Birch River showed water temperatures reaching almost 30°C by the third week of July, when flow was very low (almost negligible) and water depth had decreased from 1.2–2.4 m in the spring to only 0.1 m (Watkinson unpubl. data). At 30.5°C, Potter and Beamish (1975) reported that Northern Brook Lamprey larvae emerge from their burrows and die on top of the sediment. Warming waters may allow Northern Brook Lamprey to spread northwards, as the Whitemouth River watershed represents the northernmost part of its range, although this is will be limited by the relatively low mobility of this species.

(7) Natural Systems Modifications (Low)

(7.2) Dams & Water Management/Use

Dams within the Northern Brook Lamprey's range in DU2 (predominantly within the Whitemouth and Birch rivers in the Whitemouth River Watershed, WRW) do not result in the same scale of habitat alteration and physical threat that major hydroelectric projects cause. Nevertheless, dams that alter the natural flow cycle, transform the biological and physical characteristics of river channels and floodplains, and limit the exchange of sediment, nutrients, and organisms between aquatic and terrestrial areas may still negatively impact Northern Brook Lamprey (Bednarek 2001; Becker pers. comm. 2019). There are few anthropogenic dams in the WRW Natural Area, a 4,464 km^2 area in southeastern Manitoba (Becker and Hamel 2017). A fixed-head rock weir at the outlet of Whitemouth Lake influenced the hydrology at the headwaters of the Whitemouth River, but it was washed out around 2009. At least one application to reconstruct the weir was made to Environment Canada, but it was withdrawn prior to review. At the time of communication, the Nature Conservancy Canada (NCC) planning team was not aware of any new dam proposals for the WRW (Becker pers. comm. 2019).

Other activities, such as land drainage for farming, highways, and removal of nearby vegetation for forestry or agriculture, may also affect drainage and water flow patterns. Water removal for domestic use, for lawn or agricultural irrigation, and for watering livestock can also reduce flow, particularly during dry years (Fisheries and Oceans Canada 2013). In the past, water was periodically withdrawn during the winter from the Whitemouth River for hydrostatic testing of pipelines. Water withdrawn for hydrostatic testing can cause dewatering and freezing of shallows, while discharge of water could cause flooding, scour the stream bottom, and erode the banks (Fisheries and Oceans Canada 2013). Hydrostatic testing has not been allowed in the Whitemouth River since the mid-1990s, although there is continued interest in the use of water from the area for hydrostatic testing of the TransCanada Pipeline.

(7.3) Other Ecosystem Modifications

Small-scale habitat alterations (e.g., boulder removal, beach building) are present in the WRW, but they are limited for the most part. Riparian areas in the agricultural portions of the WRW are under a high degree of threat due to development and habitat conversion (Becker and Hamel 2017). Food-web disruptions caused by aquatic invasive species could represent a secondary threat to Northern Brook Lamprey in DU2. Zebra Mussel, Spiny Water Flea (*Bythotrephes longimanus*), Common Carp, and Rainbow Smelt (*Osmerus mordax*) are causing ecosystem modifications (COSEWIC 2017). The Spiny Water Flea was first recorded from Manitoba waters at the Pointe du Bois Generating Station on the Winnipeg River in 2009, and it has since been identified in the stomachs of Cisco (*Coregonus artedi*) collected from the South basin of Lake Winnipeg near the mouth of the Winnipeg River and in Playgreen Lake on the Nelson River (Jansen *et al.* 2017).

(8) Invasive & Other Problematic Species & Genes (Low)

(8.1) Invasive Non-Native/Alien Species

Nature Conservancy Canada identified invasive alien species (both established invasive species and emerging threats) as a “medium” threat overall to the WRW Natural Area (Becker and Hamel 2017). Sources of introductions may include inter-basin water transfers (e.g., as the result of dispersal by boats, bait buckets, or possibly as a result of hydrostatic pipeline testing), live bait use by anglers (although the import of live bait into Canada is illegal), or through the stocking of game fishes (Fisheries and Oceans Canada 2013).

Invasive Rusty Crayfish (*Orconectes rusticus*) was detected in the Birch River in 2011 (Fisheries and Oceans Canada 2013), and it is expected to alter the fauna of the watershed, likely eliminating all native crayfish species (Becker pers. comm. 2019). Rusty Crayfish is a voracious feeder on the benthic community, and it could conceivably consume eggs and larvae. Furthermore, Rusty Crayfish typically reduce aquatic vegetation, which may increase erosion and sedimentation that is detrimental to spawning lampreys and embryos. Habitat alteration through initial construction and ongoing physical disturbance may result in a local increase in invasive species cover, and the potential to spread new invasive species to adjacent natural areas.

Invasive species not already present in the WRW, but that present a high risk of becoming established and problematic in the region, include Zebra Mussel (*Dreissena polymorpha*), Emerald Ash Borer (*Agrilus planipennis*), and *Phragmites* or European Common Reed (*Phragmites australis* ssp. *australis*). Zebra Mussel is not expected to have a large impact on the Winnipeg River system as the low carbonate in the water chemistry is not conducive to shell building (Claudi *et al.* 2012) but, as a filter feeder, could compete with lamprey ammocoetes. Emerald Ash Borer was detected in Winnipeg in late 2017 (Manitoba Sustainable Development 2017), and it may be present in other jurisdictions within the province as well. Emerald Ash Borer has caused the complete loss of entire stands of ash trees in Ontario. The Black Ash-dominated swamps in the southern portion of the WRW, and swamps located in Deciduous Floodplain Forests along the Whitemouth River, are at particular risk of invasion from Ontario (Becker pers. comm. 2019). A reduction in canopy cover and shading on river banks could reduce Northern Brook Lamprey spawning and larval rearing sites (*see* above). *Phragmites* is common in Ontario, but it has only established in a few places within Manitoba. Further expansion from Ontario into Manitoba would likely occur through the WRW, because many transport routes from Ontario (highways, rail and ditches) run through this watershed. If Emerald Ash Borer moves into the watershed and removes ash stands, many suitable wetland areas will be more susceptible to infestation by *Phragmites*. *Phragmites* could then crowd out native vegetation and grow quickly. Their increased water transpiration reduces water levels (OFAH and OMNRF 2012), which, coupled with climate change, has the potential to reduce or wholly remove Northern Brook Lamprey spawning sites.

Walleye and Brook Trout have been stocked into Whitemouth Lake by the Province of Manitoba since the early 1960s (Fisheries and Oceans Canada 2013). The Birch River has been stocked with Rainbow Trout, Brook Trout, Brown Trout, and Walleye (Clarke 1998), although only Walleye appears to have remained in the Birch River. Rainbow Trout and Brook Trout are known to prey on adult Northern Brook Lamprey and may represent a substantial threat.

(9) Pollution (Low)

(9.3) Agricultural and Forestry Effluents

Agricultural runoff carrying pollutants, sediment, and nutrient inputs could negatively affect Northern Brook Lamprey. Examples of some pollutants include farm fertilizers, animal waste, herbicides, and pesticides. Nutrient input from barnyards or intensive livestock operations is an ongoing problem that is being addressed by the Province of Manitoba and Prairie Farm Rehabilitation Administration. Elevated levels of phosphorus and nitrogen were detected in the lower Birch River in April 1996, but levels were lower at other times of the year (Clarke 1998). Incompatible crop and animal production practices are listed as a "medium" threat to the WRW Natural Area in general (Becker and Hamel 2017), and these activities could negatively affect Northern Brook Lamprey specifically (*see* above).

(3) Energy Production & Mining (Low)

(3.3) Mining and Quarrying

Large peatland expanses and a number of large peat mines occur in the southern portion of the WRW (Becker and Hamel 2017). Peat mining can cause habitat alteration and sedimentation. The Province of Manitoba's Forestry and Peatlands Management Branch has established effective guidelines on sedimentation pond establishment. However, there is potential for these ponds to only remove a portion of mining sediment, before it is released into the Birch and Whitemouth rivers (Becker pers. comm. 2019). The mines also require extensive drainage at the mine site that would be expected to have some impact on watershed hydrology.

(1) Residential & Commercial Development (Negligible)

Incompatible residential or recreational dwelling development has been identified as a "medium" threat to the WRW Natural Area (Becker and Hamel 2017). For example, clearing of riparian vegetation to the water's edge for cottage development can destabilize banks and increase erosion (Fisheries and Oceans Canada 2013). Dredging of stream beds and other sediment disruptions can lead to the destruction of several larval generations (*see* above).

(1.3) Tourism and Recreation Areas

Extensive shoreline development related to communities and seasonal homes or cottages has occurred in the northern reaches of the WRW, including a concentration of recreational dwellings at the western end of Whitemouth Lake (Fisheries and Oceans Canada 2013). These developments are typically associated with agro-riparian forest stands. Recreational and residential dwelling development has resulted in, and likely will continue to result in, habitat clearing, degradation and fragmentation by cabins, yard sites, laneways, and associated infrastructure. This can be accompanied by dredging for waterways and the obliteration of appropriate silty habitat by debris. Bank destabilization and increased erosion caused by clearing riparian vegetation for cottage development could also adversely affect Northern Brook Lamprey spawning habitat by causing physical disturbances or changes in water quality.

Silver Lamprey

Based on the threats calculator, the overall threat impact is High-Medium (Appendix 5).

(7) Natural Systems Modifications (Medium-Low)

(7.2) Dams & Water Management/Use

Because Silver Lamprey in this DU appear to occur mostly in large river systems, large hydroelectric projects likely pose the single largest threat. Within the Silver Lamprey's range, there are four and six hydroelectric generating stations located on the Nelson and Winnipeg rivers, respectively (Manitoba Hydro 2018). Large hydroelectric dams impede upstream migration by migratory lamprey adults and downstream movement of recently metamorphosed juveniles. Even when fish ladders or other structures are available to aid passage of bony fishes, they are impassable by lampreys given their more limited swimming and jumping capabilities (*see* Moser *et al.* 2015). In DU2, Silver Lamprey may be spawning within the same large river that they feed in (*see* **Distribution**), suggesting that dams may not sever connectivity between feeding and spawning habitats to the same extent that they do in DU1. However, dams also disrupt flow and current in the outflow regions and increase sedimentation rates in surrounding waters (Smith *et al.* 2011). A transition from silt to clay sediment in the vicinity of dams poses a threat to larvae, as it is difficult for them to burrow in clay and provides them with poorly oxygenated water (Smith *et al.* 2011). Steady, unidirectional water flow is also important for spawning lampreys as changes in currents and velocities can lead to nest abandonment (Manion and Hanson 1980), and spawning habitat may also be less accessible due to deeper water levels in reservoir and impoundment areas. Moreover, beyond habitat modification and spawning disruption, downstream-migrating juvenile lampreys are at risk of physical damage from dams. Many dams have screens to prevent juvenile and migratory teleost fishes from entering into turbines, but lampreys have been observed to become entrained in the mesh of screens (Maitland *et al.* 2015).

(7.3) Other Ecosystem Modifications

Destruction of habitat from other ecosystem modifications (e.g., dredging, road maintenance) also may negatively impact Silver Lamprey habitat (*see* above).

(8) Invasive & Other Problematic Species & Genes (Low)

(8.1) Invasive Non-Native/Alien Species

Smallmouth Bass (*Micropterus dolomieu*) has also been introduced to the Winnipeg River system (Fisheries and Oceans Canada 2013) and is known to prey on lampreys (Cochran 2009). Furthermore, the Rusty Crayfish is now distributed in a large portion of the Winnipeg River, and it is expected that Rusty Crayfish will continue to expand in the remaining reaches in the future. The impacts of Rusty Crayfish on Silver Lamprey are expected to be similar to the effects on Northern Brook Lamprey in DU2 (*see* above). Introduced species might also carry diseases and parasites to which Silver Lamprey are vulnerable. Parasitic lampreys are known to acquire parasites from host fishes (Appy and Anderson 1981).

(9) Pollution (Low)

(9.2) Industrial & Military Effluents

As with Silver Lamprey in DU1, industrial effluents in some parts of DU2 may have a negative impact on Silver Lamprey in DU2. In addition to accumulating mercury from the sediments (*see* above), high levels of mercury have been detected in other parasitic lamprey species when they feed on the blood of large-bodied fishes that are themselves contaminated with environmental pollutants (*see* Maitland *et al.* 2015).

(9.3) Agricultural & Forestry Effluents

Agricultural and forestry effluents could pose a threat to Silver Lamprey embryos and larvae (e.g., due to the toxic effects of herbicides and their effect on the phytoplankton food source of the larvae, or as a result of eutrophication; *see* above). However, their effect in DU2 will be much more limited in scope given the distribution of the species.

(11) Climate Change & Severe Weather (Low)

As with Northern Brook Lamprey, the effects of climate change may adversely affect Silver Lamprey. However, migratory Silver Lamprey presumably would be better able to colonize new river systems with more suitable thermal regimes, although barriers to migration would limit this.

(5) Biological Resource Use (Negligible)

(5.3) Logging & Wood Harvesting

As above, loss of riparian vegetation and other effects of forestry activities may negatively impact Silver Lampreys (e.g., through soil erosion and loss of shade).

(5.4) Fishing & Harvesting Aquatic Resources

There is likely little or no intentional harvesting of Silver Lamprey. However, Silver Lamprey are caught as bycatch, and they may be destroyed.

Southern Hudson Bay-James Bay (DU3)

Silver Lamprey

Based on the threats calculator, the overall threat impact is Unknown (Appendix 5).

Potential general threats in this NFBZ include mining (e.g., the large chromite mining and smelting project known as the Ring of Fire that is planned for development in the James Bay Lowlands of northern Ontario), plans for diversion dams, forestry (e.g., in southern James Bay), roads and railroads. However, no potential threats have been identified in the Hayes River system where the Silver Lamprey has been confirmed to occur. The Hayes River is pristine and undeveloped, representing the longest naturally flowing river in Manitoba (Canadian Heritage Rivers System 2017).

Limiting Factors

One significant characteristic that makes Northern Brook and Silver Lamprey particularly susceptible to disturbance is the prolonged larval stage (averaging approximately 5 and 4 years, respectively) in which they remain burrowed in the substrate. During this time, they are susceptible to natural and anthropogenic influences with a limited ability to evade threats that may be present. They are able to passively move downstream with the current, but, as larvae, they have a very limited ability to recolonize their original or other suitable habitat upstream (*see* **Biology**). Furthermore, even periodic perturbations (e.g., lampricide treatments every 3–5 years or periodic droughts) can eliminate multiple generations (Maitland *et al.* 2015).

Another limiting factor is that they are semelparous. They invest a considerable amount of resources in their one and only spawning event, but if they are prevented from reaching suitable spawning habitat (e.g., as the result of barriers to migration), all their potential reproductive output is wasted. Their complex life cycle, with different habitat requirements at different stages (*see* **Habitat**), means that these species (particularly the migratory Silver Lamprey) are vulnerable to anthropogenic factors that sever connectivity between habitats or modify the habitat of one life stage.

The lower fecundity of Northern Brook and Silver lampreys likely makes them poor competitors to the highly fecund invasive Sea Lamprey (Docker *et al.* 2019; *see* **Biology**). Fecundity of the Northern Brook Lamprey is particularly low, although mortality rates following metamorphosis are likely markedly lower than those of the migratory and parasitic Sea Lamprey. In contrast, post-metamorphic mortality rates in Silver Lamprey and landlocked Sea Lamprey are likely comparable, despite the much higher fecundity of the latter species (*see* **Interspecific Interactions**). In 1959, even before initiation of lampricide treatments affected adult numbers, Schuldt and Goold (1980) found that Sea Lamprey captured at electric barriers on Canadian tributaries to Lake Superior outnumbered Silver Lamprey 9:1. The numerical dominance of Sea Lamprey appears significantly greater since initiation of Sea Lamprey control. In 2008–2018, in traps monitored in Canadian tributaries to the Great Lakes, 887 Sea Lamprey were collected for every one Silver Lamprey (*see* **Abundance**).

Number of Locations

<u>Great Lakes-Upper St. Lawrence (DU1)</u>

Northern Brook Lamprey

The most serious plausible threat to Northern Brook Lamprey in DU1 is lampricide treatment in the Great Lakes portion of the DU, which is considered to act independently within each tributary stream or within different sections of larger tributaries. Northern Brook Lamprey adults were recorded in 32 waterbodies in 2008–2018, and unidentified *Ichthyomyzon* larvae that were either Northern Brook or Silver lamprey were found in another 10 tributaries (Appendix 1, 3). Therefore, the number of locations is at least 32.

Silver Lamprey

The most serious plausible threats to Silver Lamprey in DU1 is lampricide treatment and dams and Sea Lamprey barriers in the Great Lakes portion of the DU. These threats are considered to act independently within each tributary stream where this species spawns and rears as larvae or within different sections of larger tributaries to which this species has access. Silver Lamprey adults were recorded in 22 tributary streams (plus seven lakes) in 2008–2018, and unidentified *Ichthyomyzon* larvae that were either Northern Brook or Silver lamprey were found in another 11 tributaries (Appendix 2, 3). Therefore, the number of locations is at least 22.

<u>Saskatchewan-Nelson River (DU2)</u>

Northern Brook Lamprey

The most serious plausible threat to Northern Brook Lamprey in DU2 is climate change and severe weather, which is considered to act at the scale of the watershed. Therefore, the number of locations is 1.

Silver Lamprey

There were several plausible threats, each with Low to Medium-Low impacts, that would have a cumulative impact on Silver Lamprey in DU2. No one threat was ranked as High, but the most serious plausible threat is dams and water management and use, which is considered to act independently within each waterbody where this species occurs. Silver Lamprey juveniles were recorded in two rivers and eight lakes in 2008–2018. Because the relationship between the different sites occupied by the species is unknown (i.e., where they spawn and rear as larvae, and the nature of movement between sites), the number of locations is 2–10. That is, if spawning and larval rearing occur only in rivers, as is the case for most lampreys (Johnson *et al.* 2015), the lakes used during the dispersive parasitic feeding phase are not independent and the number of locations is 2.

<u>Southern Hudson Bay-James Bay (DU3)</u>

Silver Lamprey

No plausible threats to Silver Lamprey were identified in DU3, and they were collected from a single river. Therefore, number of locations is not applicable.

PROTECTION, STATUS AND RANKS

Legal Protection and Status

<u>Federal Protection</u>

The federal *Fisheries Act* may provide protection to both species and their habitat. Other federal legislation that may indirectly protect Northern Brook and Silver lampreys include the *Navigable Waters Protection Act*, *Canadian Environmental Assessment Act*, and *Canadian National Marine Conservation Areas Act*.

Northern Brook Lamprey

Currently, the Great Lakes-Upper St. Lawrence populations are listed under Schedule 1 of the *Species at Risk Act* (SARA) as Special Concern. The general prohibitions, which apply to all federal lands, listed under this act do not apply to Special Concern species. A Management Plan was drafted for the species with the goal of ensuring the long-term persistence of the species in the Great Lakes-Upper St. Lawrence DU (Fisheries and Oceans Canada 2018). The Management Plan stated that priority should be placed on protecting known extant populations and their habitat, and on mitigating any threats that pose a risk to the Northern Brook Lamprey.

Silver Lamprey

The Great Lakes-Upper St. Lawrence populations are listed under Schedule 1 of the *Species at Risk Act* (SARA) as Special Concern.

Provincial Protection

In Ontario, both the Northern Brook and Silver lamprey are listed as “Special Concern” under the *Endangered Species Act*; as such, they do not receive any species or habitat protection. However, other provincial legislation may provide some level of protection to the species including *Environmental Assessment Act*, *Environmental Protection Act*, *Water Resources Act,* and *Conservation Authorities Act*.

In Quebec, the Northern Brook Lamprey is listed as “Threatened” under the *Loi sur les espèces menacées ou vulnérables* (Act respecting threatened or vulnerable species), and both species are protected on public lands by the *Loi sur la conservation et la mise en valeur de la faune* (Act respecting the conservation and development of wildlife). In addition, other provincial legislation may provide some level of protection including *Quebec Fisheries Regulation, 1990* (which bans use of lampreys as baitfish), the *Environment Quality Act*, and the *Respecting Land Use Planning and Development Act*.

In Manitoba, under the *Endangered Species and Ecosystem Act*, Northern Brook and Silver lampreys are not listed. However, other provincial legislation may provide some level of protection to the species including *The Environment Act*, *The Wildlife Act, The Contaminated Sites Remediation Act,* and *The Water Protection Act.*

Non-Legal Status and Ranks

Northern Brook Lamprey

NatureServe ranked the global population of Northern Brook Lamprey as G4 (Apparently Secure), the Great Lakes-Upper St. Lawrence population as T3T4 (Vulnerable-Apparently Secure), and the Saskatchewan-Nelson River population as TNR (Not Yet Ranked). Northern Brook Lamprey was assessed as “Vulnerable” (N3) in Canada, “Vulnerable” (S3) in Ontario, “Imperiled-Vulnerable” (S2S3) in Quebec, and “Imperiled” (S2) in Manitoba (NatureServe 2018). Northern Brook Lamprey is ranked as “Apparently Secure” (N4) in the United States, “Secure” (S5) in Wisconsin, “Apparently Secure” (S4) in Michigan and Missouri, “Vulnerable” (S3) in Minnesota, “Imperiled” (S2) in Kentucky and New York, and “Critically Imperiled” (S1) in Illinois, Indiana, Ohio, Pennsylvania, Vermont, and West Virginia (NatureServe 2018). The General Status ranks for Northern Brook Lamprey were assessed as N3 (Vulnerable) at the National Level, S3 (Vulnerable) for the Ontario population, S2 (Imperilled) for the Quebec population, and SU (Unrankable) for the Manitoba population (Canadian Endangered Species Conservation Council 2016). The International Union for Conservation of Nature (IUCN) Red List categorized the species as “Least Concern” in 2012. The Convention for International Trade in Endangered Species of Wild Fauna and Flora (CITES) does not have the species listed.

Silver Lamprey

NatureServe ranked the global population as G5 (Secure), the Great Lakes-Upper St. Lawrence population as TNR (Not Yet Ranked), and the Saskatchewan-Nelson River population as TNR (Not Yet Ranked). Silver Lamprey was assessed as “Vulnerable” (N3) in Canada, “Vulnerable” (S3) in Ontario and Manitoba, and “Vulnerable-Apparently Secure” (S3S4) in Quebec (NatureServe 2018). Silver Lamprey is ranked as “Secure” (N5) in the United States, “Apparently Secure” (S4) in Indiana, Michigan, Ohio, and Wisconsin, “Vulnerable” (S3) in Illinois, Iowa, and New York, “Imperiled-Vulnerable” (S2S3) in West Virginia, “Imperiled” (S2) in Tennessee, “Imperiled Uncertain” (S2?) in Vermont, “Critically Imperiled” (S1) in Mississippi, Nebraska, and Pennsylvania, and “Unranked” (SNR) in Minnesota and Missouri (NatureServe 2018). General Status ranks for Silver Lamprey were assessed as N3 (Vulnerable) at the National Level, S3 (Vulnerable) for the Ontario population, S3S4 (Vulnerable-Apparently Secure) for the Quebec population, and SU (Unrankable) for the Manitoba population (Canadian Endangered Species Conservation Council 2016). The IUCN Red List categorized the species as “Least Concern” in 2012. CITES does not have the species listed.

Habitat Protection and Ownership

Given its severely limited distribution, the protection of Northern Brook Lamprey habitat in DU2 is particularly relevant. The Whitemouth River Watershed Natural Area (which encompasses the entire WRW) is a 4,464 km^2 area that affords some protection to Northern Brook Lamprey that resides only in this system (*see* Becker and Hamel 2017). Conservation efforts of another fish found in this system, Carmine Shiner (*Notropis percobromus*) (assessed as “Threatened” under Schedule 1 of SARA), are ongoing, and they may also have the unintended benefit of protecting the Northern Brook Lamprey and its habitat. Additionally, a 0.13 km^2 headwater section of the Whitemouth River, designated as an Ecological Reserve in 1986 to protect river-bottom forest, may also provide some incidental protection for Northern Brook Lamprey habitat (Hamel 2003). While most of the land within the WRW is Provincial Forest or Crown lands, a substantial proportion of the land directly bordering the river and tributaries is privately owned.

The habitat of Northern Brook and Silver lampreys is protected in principle under the federal *Fisheries Act* and SARA). In Quebec, it is protected by the *Loi sur la conservation et la mise en valeur de la faune*.

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Name of jurisdiction	Name of contact(s) and date(s)*
Canadian Museum of Nature	Robert Anderson – May 31, 2018 Jennifer Doubt – May 31, 2018
Canadian Wildlife Service	Ron Bennett – May 28, 2018 Karolyne Pickett[1] – May 28, 2018 Sydney Cannings[1] – May 28, 2018 Karine Picard – May 28, 2018 Judith Girard – Feb 12, 2019
Department of Fisheries and Oceans	Simon Nadeau – May 31, 2018 Jennifer Shaw – May 31, 2018
Parks Canada	Shelley Pruss – June 1, 2018 Pippa Shepherd – June 1, 2018 Cass Stabler – Feb 17, 2020
Provincial / territorial representative(s) corresponding to the range of the species	Manitoba: Ken De Smet – June 1, 2018 Bill Watkins – June 1, 2018 Ontario: Christina Davy – June 25, 2018 Colin Jones – June 25, 2018 Quebec: Julien April – May 22, 2018 Myriam Bourgeois – July 23, 2019 Marc-Antoine Couillard – July 23, 2019 Isabelle Gauthier – Sept 12, 2018 Non-governmental: Dana J. Leaman – Sept 12, 2018 John Reynolds – Sept 12, 2018 Arne Mooers[1] – Sept 12, 2018
Conservation Data Centre(s) or Natural Heritage Information Centre(s) corresponding to the range of the species	Ontario NHIC – May 29, 2018 Centre de données sur le patrimoine naturel du Québec[1] – Sept 13, 2018 Manitoba CDC: Chris Friesen – May 30, 2018 Colin Murray – May 30, 2018
Wildlife Management Board(s)	Nunavik Marine Region Wildlife Board – Sept 13, 2018 Eeyou Marine Wildlife Board – Sept. 13, 2018

Name of jurisdiction	Name of contact(s) and date(s)*
COSEWIC Secretariat for information and instruction on: a) sources of Aboriginal Traditional Knowledge b) the preparation of distribution maps and the calculation of extent of occurrence, area of occupancy, and index of area of occupancy	a) Sept 17, 2018 b) Jan 21, 2019
Recovery team (if one exists)	Not applicable
Other relevant contacts (e.g., experts, third-party agencies, suggestions by jurisdictions) as directed by Co-chair.	*See* below

[1] In cases where jurisdiction and/or individual(s) have been contacted but a response was not received, indicate as such.

* Where multiple emails or phone calls ensued, date given is date of first contact.

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Margaret Docker is a Professor in the Department of Biological Sciences at the University of Manitoba. She has worked on lampreys for over 30 years, and much of her current research deals with the evolution and conservation genetics of lampreys. She is particularly interested in "paired" lamprey species and in the environmental, ecological, and genetic factors that contribute to lamprey feeding type. She has written or co-written three other COSEWIC species status reports, and she is the editor of a two-volume book about the biology of lampreys.

Justin Budyk is an undergraduate student completing an Environmental Science degree at the University of Manitoba. His research interests lie in the field of freshwater ecology and fish biology. He has worked for the International Institute for Sustainable Development-Experimental Lakes Area (IISD-ELA) and Fisheries and Oceans Canada conducting multi-trophic level lake surveys including sampling for a variety of freshwater fish species.

Doug Watkinson is a Research Biologist with Fisheries and Oceans Canada in Winnipeg. He has sampled fish in many of the major river systems of the Hudson Bay drainage from northwestern Ontario west to the Rockies, including sampling for lampreys. His current research focuses on species at risk, habitat impacts, and aquatic invasive species. He has co-written seven COSEWIC species status reports and the field guide, The Freshwater Fishes of Manitoba.

Anthony Wightman has an Honours degree in Political Studies and a Bachelor's degree in Science from the University of Manitoba. He primarily studied biology and microbiology. He received an NSERC Undergraduate Student Research Award to use environmental DNA sampling to survey native lamprey distribution in Manitoba.

COLLECTIONS EXAMINED

University of Manitoba Stewart-Hay Fish Collection (MZF)

Appendix 1. Waterbodies in Canada where post-metamorphic Northern Brook Lamprey have been reported, by DU and watershed. Data were compiled from: Sea Lamprey Control Centre (SLCC) and other Fisheries and Oceans Canada (DFO) records, National Heritage Information Centre (NHIC), Royal Ontario Museum, Global Biodiversity Information Facility, Ontario Ministry of Natural Resources and Forestry (OMNRF), Canadian Museum of Nature, Royal Military College, Ministère des Forêts, de la Faune et des Parcs du Québec (MFFP), Manitoba Sustainable Development, University of Western Ontario, Hamilton Conservation Authority, Docker (unpubl. data), Momot and Stephenson (1996), and Fisheries and Oceans Canada (2018) and Fortin *et al.* (2007) and sources therein.

Stream	Year(s) of Observation
GREAT LAKES–UPPER ST. LAWRENCE (DU1)	
Lake Erie	
Big Cr	1955, 1973
Grand R	1984, 2001
Little Otter Cr	1980
NL Cr	1931
Point Pelee Marsh	---
South Otter Cr	2009
Speed R	2006
Stoney Cr	1973
Waubuno Cr	2004
Whitemans Cr	2006
Young's Cr	2018
Lake Huron	
Bannockburn R	1967, 1970, 1974
Bar R	1999, 2002, 2007
Bayfield R	1974
Bayne R	1957
Beatty Saugeen R	1976
Beaver R	2004, 2007, 2008
Browns Cr	2002
Camp Cr	1976
Chikanishing R	1999, 2000, 2002, 2007, 2014
Coldwater R	1978, 1989, 2001, 2007, 2009, 2011, 2015, 2017
Echo R	2002

Stream	Year(s) of Observation
French R	1978, 1997
Hog Cr	2001, 2004, 2006, 2007, 2015
Key R	2012
Manitou R	2001, 2004
Mindemoya R	2007
Nine Mile R	2001, 2007
Nottawasaga R	1958, 1968, 1973–1974, 1989, 1996, 1997, 2000–2002, 2004, 2007, 2008, 2013, 2015, 2016
Oxbow Cr	2011
Pine Cr	1958
Rankin R	1985
Root R	2010
Sauble R	1957, 1970, 1978, 1985, 2001, 2008, 2009
Saugeen R	1951, 1952, 1997, 2001
Shebeshekong R	1997
Spanish R	1978, 2007
St. Marys R	1978
Still R	1956
Sydenham R	1947
Thessalon R	1978, 1987, 2002, 2007, 2008
Tosorontio Cr	1974
Willow Cr	1958, 1974, 1996, 2000, 2001, 2004
Wye R	2002, 2007, 2013
Lake Ontario	
Cobourg Cr	1984, 2013
Credit R	1982
Lynde Cr	2011
Niagara R	1928
L Ontario	1995, 1997, 2005, 2007
Salmon R	2009, 2011, 2014, 2015

Stream	Year(s) of Observation
Shelter Valley Cr	2011
Stokely Cr	2002
Sulphur Cr	2008
Lake Superior	
Batchawana R	1967
Black Sturgeon R	1978, 1997, 2006
Cash Cr	1998, 2000
Chain Cr	1983
Gravel R	1997
L. Helen	1978
Jackfish R	1996
Kagiano R	1963
Kaministiquia R	1959
McIntyre R	1954, 1960
Michipicoten R	1957, 1959
Neebing R	1960, 1971, 1997
Nipigon R	1997–1999, 2007
Pays Plat R	1954, 1965, 1997
Pearl R	1955, 1996, 2001, 2007
Pic R	1978, 1984, 1997
Prairie R	1995, 1997
Sibley Cr	1992
Squawk L	1977
Wolf R	1980’s and 1990’s[1]
Lake St. Clair	
St. Clair R	1986, 1999
Thames R	1884, 1931

Stream	Year(s) of Observation
Lake Nipissing	
Bear Cr	2003, 2007
Chippewa Cr	1954, 2000, 2001, 2003, 2007, 2008
L Nipissing	1960
South Cr	2003, 2007
Wolseley R	2003, 2007
Ottawa River	
Ottawa R	1979, 1980, 1982, 1991, 2002
Petite-Nation R	2011
Saumon R	2011
St. Lawrence River	
Châteauguay R	1990, 1992, 2012
Coaticook R	2015, 2018
Dorman Cr	2014
Gatineau R	1999
Hinchinbrooke R	1976
Massawippi R	1995, 2014, 2015, 2018
Nicolet R	1951
Prairies R	1998
Richelieu R	1990
Saint-François R	1947, 1949–1951, 1990, 2003, 2009, 2011, 2013–2015, 2018
St. Lawrence R	1950, 2009–2013
L Saint-Louis	1941
Stacey R	2010, 2014, 2018
Steele Cr	2018
Tomifobia R	2008, 2014, 2015, 2018
Trout R	1976, 2001, 2011
Washington Cr	2006
Williams Cr	1985

Stream	Year(s) of Observation
Willow Cr	2009
Yamaska R	1946–1949, 1959

SASKATCHEWAN–NELSON RIVER (DU2)	
Winnipeg River	
Birch R	1972, 1977, 2002, 2011, 2013, 2015
Whitemouth R	1977, 1984, 1986–1988, 1991, 2002, 2005, 2006, 2013, 2015
Winnipeg R	2003

[1] Observed in at least one year during interval reported, not necessarily in each year

Appendix 2. Waterbodies in Canada where post-metamorphic Silver Lamprey have been reported, by DU and watershed. Data were compiled from: SLCC and other DFO records, NHIC, Royal Ontario Museum, Global Biodiversity Information Facility, OMNRF, Canadian Museum of Nature, MFFP, Manitoba Sustainable Development, Manitoba Hydro, University of Manitoba Stewart-Hay Museum, Lakehead University, Parks Canada, Stewart and Watkinson (2007), Tyson and Watkinson (2013), Momot and Stephenson (1996), and Docker (unpubl. data).

Stream	Year(s) of Observation
GREAT LAKES-UPPER ST. LAWRENCE (DU1)	
Lake Erie	
Big Cr	1973, 1995, 1997, 1998, 2000–2002, 2006, 2007, 2013–2017
Black Cr	1950
Canard R	2016, 2017
Cedar Cr	2017
Detroit R	2004, 2012, 2014, 2015
L Erie	1919–1921, 1928, 1930, 1935–1937, 1952, 1996, 1997, 2001, 2004, 2005, 2010, 2015
Hillman Marsh	2002
Horner Cr	1964
South Otter Cr	2009
Young’s Cr	1989, 1992, 1995, 1998, 2003–2018
Lake Huron	
Ausable R	2015–2017
Beaver R	1998, 2002–2006
Bighead R	1998, 2000
Boyne R	1971
Coldwater R	1998, 1999, 2001, 2006, 2007, 2009, 2011, 2015
Echo R	1988, 1990, 1995, 1997, 1999, 2014
French R	2006
Garden R	2001
Georgian Bay	1975
Harris R	1965, 1966, 1978
Hog Cr	1998, 2001, 2007
Lake 22	1971
L Huron	1940, 1989
Kaskawong R	1978
Koshkawong R	1998
Manitou R	1968

Stream	Year(s) of Observation
Musquash R	1996
Naiscoot R	1965, 1966, 1978
Nottawasaga R	1937, 1958, 1961, 1968, 1985, 1993, 1996, 1998, 2002, 2005, 2013
Rankin R	1974
Saugeen R	1960, 1987, 1998, 2002–2004, 2007
Silver Cr	1974
Spanish R	1989, 1997, 1998, 2001
Squawk L	1977
St. Marys R	1986, 1988–2007, 2009–2013, 2015, 2016, 2018
Still R	1966, 1978
Sturgeon R	2003
Sydenham R	2015
Thessalon R	2000
Willow Cr	1958
Lake Ontario	
Bowmanville Cr	2001
Cobourg Cr	1998–2001
Humber R	2006
Otonabee R	---
Port Britain Cr	1990
Royal Botanical Gardens Fishway	2006, 2008, 2010
Salmon R	2004–2006
Shelter Valley Cr	1990, 1998, 2003
Lake Superior	
Batchawana R	1953–1972[1]
Big Carp R	1953–1972[1], 1998, 1999–2001, 2012
Carp R	1954, 1998
Chippewa Cr	1953–1972[1]
Cloud R	1953–1972[1], 1975
Cranberry Cr	1953–1972[1]
Goulais R	1953–1972[1]
Harmony R	1953–1972[1] (1954)[2]
Havilland Cr	1955
Kaministiquia R	1950
Little Carp R	1953–1972[1]
McIntyre R	1950, 1953–1972[1] (1957)[2], 1987, 1998

Stream	Year(s) of Observation
Michipicoten R	1953–1972[1] (1963)[2]
Neebing R	1953–1972[1] (1955)[2], 1987, 1998
Pancake R	1953–1972[1] , 1998
Pays Plat R	1953–1972[1]
Pearl R	1980’s and 1990’s[1]
Prairie R	1953–1972[1]
Sable R	1953–1972[1]
Sibley Cr	1953–1972[1], 1980’s and 1990’s[1]
Stokely Cr	1953–1972[1] (1954)[2], 1998
L Superior	1945, 1953, 1957
White R	1953–1972[1]
Wolf R	1980’s and 1990’s[1]
Lake St. Clair	
Jeanette's Cr	2015, 2016
L St. Clair	1882, 1978–1980, 1985, 1986, 1989, 1991, 1992, 1996–2000, 2005–2009, 2011, 2014, 2016
Ruscom R	2016
St. Clair R	2003, 2004, 2007, 2012, 2014, 2017
Thames R	2013–2016
Lake Nipissing	
Chippewa Cr	2007
L Nipissing	1932, 1960, 2009
South Cr	2003, 2007
Ottawa River	
Brewery Cr	1971, 1976
Dow’s L	---
Hare R	2000, 2002
Hawkesbury Cr	2000
Kingham R	2004
L Leamy	2000
Ottawa R (Outaouais)	1927, 1936, 1963–1965, 1969, 1971, 1973, 1977–1980, 1983, 1986–1988, 1990, 1999, 2000, 2007, 2012
Red R	1901, 2000
L Simard	1976
South Nation R	2000, 2006
Thurso R	2000

Stream	Year(s) of Observation
L of Two Mountains (Deux Montagnes)	1964–1966, 1968, 1969, 1978, 1979, 2009, 2010, 2018
St. Lawrence River	
L'Assomption R	1969, 1986, 1989, 1990
Batiscan R	1967
Beauport R	1947–1949, 2010
L Bois Franc	1939
L Boitel	1979
L Ceizur	2000
Châteauguay R	1963, 1987
Gatineau R	1998, 1999
Gentilly R	1948–1950
Hinchinbrooke R	2005
Loup, Petite R du	1972
Mascouche R	2015
Mitchel, Ruisseau	2006
Nicolet R	1944
Oak, Ruisseau	2006
Ouareau R	2004
des Prairies, R	1971
Richelieu R	1965, 1969, 1970, 1977,1993,1995, 2004, 2006, 2007–2011
L Saint-Louis	1941, 1942, 1967–1969, 1971, 1974, 1992, 2005, 2009, 2011, 2013
L Saint-Pierre	1944, 1946, 1972, 2002, 2007, 2009–2011, 2013, 2015
Stacey R	1977, 1980
L Saint-François	1938, 1968, 2004
Saint-François R	1946–1950, 1990, 1998
St. Lawrence R	1913, 1928, 1938, 1939, 19411944–1950, 1954, 1959, 1961, 1964, 1965, 1971–1973, 1975, 1977, 1982, 1983, 1984, 1991, 1992, 1994, 1995, 2000–2002, 2004–2013, 2015, 2017
Yamaska R	1967
Lake Champlain	
Pike R	1989–2007[1]

Stream	Year(s) of Observation
SASKATCHEWAN-NELSON RIVER (DU2)	
Assiniboine River	
Assiniboine R	2002
Shell R	1991
Nelson River	
Angling Cr	2006
Burntwood R	2005
Gull L	2003
Limestone R	2005–2007
MacMillan Cr	2006
Nelson R	1946, 1986, 1989, 2002, 2004–2008
Seagull	2006
Seal Cr	1948, 1987
Split L	2004
Stephens L	2003
Swift Cr	2006
Red River	
Joubert Cr	1963
Rat R	1986
Red R	1957, 1960, 1961, 1974
Seine R	1974
Winnipeg River	
Berry Cr	2004
Bird R	2004
Crooked L	1972
Eaglenest L	2010
Kawnipi L	2017
La Croix L	1974
L of the Woods	1970
Lonely L	2017
Namakan L	2014, 2017
Nutimik L	1995, 2018
Olifaunt L	2014–2017[1]
Rainy R	1970, 1989, 2003, 2004
Saganaga L	1960’s and 1970’s[1]
Sand Point L	1978, 2012

Stream	Year(s) of Observation
Swan L	1981
Walter L	2017
Winnipeg R	1969, 1984, 2003, 2006–2010, 2012–2016
SOUTHERN HUDSON BAY-JAMES BAY (DU3)	
Hayes River	
Hayes R	1976
Seeber R	2011

[1] Observed in at least one year during interval reported, not necessarily in each year
[2] Specific year of observation reported from other sources

Appendix 3. Waterbodies in Canada where *Ichthyomyzon* sp. (usually unidentified larvae) have been reported, by DU and watershed. Data were compiled from: SLCC, Royal Ontario Museum, COSEWIC (2011), Schuldt and Goold (1980), MFFP (unpubl. data), and Docker (unpubl. data).

Stream	Year(s) of Observation
GREAT LAKES-UPPER ST. LAWRENCE (DU1)	
Lake Erie	
Big Cr NB/S	2011, 2012, 2015, 2016
Big Otter Cr	2007, 2010–2012, 2016
Conewango Cr	1997
Detroit R	1989–2007[1]
Grand R NB	2008, 2011, 2014, 2017
Normandale Cr	2008
Silver Cr	2007, 2016
South Otter Cr NB/S	2009
Young's Cr NB/S	2012
Lake Huron	
Ausable R S	2012, 2018
Bar R NB	1989–2007[1]
Bayfield R NB	2010, 2013, 2017
Beaver R NB/S	1984, 1985, 2007, 2008 2014, 2018
Bighead R S	2015, 2017
Blackstone Cr	2013
Blind R	2016
Blue Jay Cr	2017
Chikanishing R NB	2007, 2011, 2012, 2014, 2015, 2017
Coldwater R NB/S	2007, 2011, 2014, 2015, 2017
Echo R NB/S	2007, 2011, 2012, 2017
French R system NB/S	1989–2007[1]
Garden R S	1989–2007[1]
Hog Cr NB/S	2007, 2011, 2014, 2015, 2017
L Huron S	1982
Indian Br	2018
Kagawong R	1989–2007[1]
Keenansville Cr	2005
Key R NB	2007, 2009, 2012, 2015
Magnetawan R	2009
Manitou R NB/S	2010, 2011, 2014, 2017

Stream	Year(s) of Observation
McKinnon Cr	2002
Mississagi R	2007, 2016
Musquash R[S]	2011
Naiscoot R[S]	2007, 2015
Nine Mile R[NB]	2007, 2013, 2018
Nottawasaga R[NB/S]	2002, 2007–2009, 2011, 2013–2017
Rankin R[NB/S]	1985
Root R[NB]	2017
Sauble R[NB]	2004, 2007–2009, 2011, 2013, 2015, 2016, 2018
Saugeen R[NB/S]	2007, 2013, 2014
Serpent R	2007, 2015, 2018
Shawanaga Landing Cr	2014
Shebeshekong R[NB]	2008, 2013, 2016, 2017
Silver Cr[S]	2012, 2015, 2018
Simcoe/Severn System	1989–2007[1]
Spanish R[NB/S]	1950, 2007–2010, 2013, 2014, 2017
Still R[NB/S]	2009
Sturgeon R[S]	2009, 2016, 2017
Styx R	1981, 2004
Sydenham R[NB/S]	1989–2007[1]
Thessalon R[NB/S]	2007–2011, 2013, 2015–2017
Wye R[NB]	2007, 2013
Lake Ontario	
Niagara R[NB]	2010
L Ontario[NB]	1995
Lake Superior	
Batchawana R[NB/S]	1953–1972[1], 1973–1977[1], 2014
Big Carp R[S]	1953–1972[1]
Big Pic R	1953–1972[1], 1973–1977[1]
Big Trout Cr	2010
Black Cr	1953–1972[1]
Black Sturgeon R[NB]	1953–1972[1], 1973–1977[1], 2007, 2008, 2010, 2012–2015
Cash Cr[NB]	1953–1972[1]
Cedar Cr	2000
Chippewa Cr[S]	1953–1972[1] (1953)[2], 1973–1977[1], 2002
Cloud R[S]	1953–1972[1]

Stream	Year(s) of Observation
Cranberry Cr [S]	1953–1972[1], 1989–2007[1]
D'Arcy Cr	2018
Digby Cr	1953–1972[1]
Downey Cr	1953–1972[1]
Goulais R [S]	1953–1972[1], 1989–2007[1]
Gravel R [NB]	1953–1972[1], 1973–1977[1], 2007
Harmony R [S]	1953–1972[1]
Havilland Cr	2014
Hewitson Cr	1953–1972[1]
Horseshoe Cr	1953–1972[1]
Jackfish R [NB]	1953–1972[1], 1973–1977[1], 2011, 2018
Jones Landing Cr	1989–2007[1]
Kaministiquia R [NB/S]	1953–1972[1], 1973–1977[1], 1987
L Munroe Cr	1989–2007[1]
Little Carp R [NB]	1953–1972[1], 2007
Little Gravel R	1953–1972[1], 2007
Little Pic R	1953–1972[1], 1989–2007[1]
Mackenzie R	1953–1972[1], 1973–1977[1], 1989–2007[1]
Michipicoten R [NB/S]	1953–1972[1], 1973–1977[1]
Middle R	1997
Mignet Cr	2000
Neebing/McIntyre R [NB/S]	1989–2007[1]
Nipigon R [NB]	1953–1972[1], 1973–1977[1], 2007, 2014, 2018
Nixon Cr	1953–1972[1]
Pancake R[S]	1953–1972[1]
Pays Plat R [NB/S]	1953–1972[1], 1973–1977[1], 1989–2007[1]
Pearl R [NB/S]	1953–1972[1], 1973–1977[1], 2008, 2014, 2018
Pic R [NB]	2018
Pigeon R	1953–1972[1]
Prairie R [NB/S]	1953–1972[1], 1973–1977[1], 2018
Sable R [S]	1953–1972[1], 1973–1977[1]
Sawmill Cr	1953–1972[1]
Sibley Cr [NB/S]	1953–1972[1], 1973–1977[1], 2010, 2014, 2018
Stillwater Cr	1953–1972[1]
Stokely Cr [S]	1953–1972[1], 1989–2007[1]
Tiny Cr	1953–1972[1]
Unger Cr	1953–1972[1]
West Davignon Cr	1989–2007[1]

Stream	Year(s) of Observation
White R [S]	1953–1972[1]
Wolf R [NB/S]	1953–1972[1]
Lake St. Clair	
St. Clair R [NB/S]	1986, 2008, 2011–2018
Thames R [NB/S]	2010, 2012–2016, 2018
Lake Nipissing	
Bear R [NB]	1989–2007[1]
South Cr [NB/S]	1989–2007[1]
Wolseley R [NB]	1989–2007[1]
Ottawa-St. Lawrence River	
Adrien, Lac	1961
Allet, Lac	1958
Anne, Lac	1932
Araigneés, Lac aux	1953
Argenté, Lac	1931
Barbotte, Lac à la	1948
Barnes, Lac	1957
Baumel, Lac	1948
Bayette, Lac	1948
Beaulieu, Lac	1948
Beauvais, Lac	1948
Beauvais, 2^{e} Lac	1948
Beauvais,3^{e} Lac	1948
Bécancour, Lac	1951, 1952
Bertrand, Lac	1960
Bessette, Lac	1957
Bevin, Lac	1931
Bidou, Lac	1939
Blanc, Lac	1939
Blondin, Lac	1956
Bois Franc, Lac [S]	1948
Bouchette, Lac	1948
Bourdeau, Lac	1948
Bourque, Lac	1939, 1948
Bouthillier, Étang	1948
Bowker, Lac	1956

Stream	Year(s) of Observation
Brochet, Lac du	1934
Brochet, Petit Lac du	1954
Brompton, Petit Lac	1952
Brûlé, Lac	1931, 1953
Brunet, Lac	1951, 1959
Bull, Étang	1954
Caché, Lac	1934
Capri, Lac	1948
Caribou, Lac	1931, 1934
Carman, Lac	1954
Caron, Lac	1950
Carré, Lac	1931, 1938, 1948
Casgrain, Lac	1931
Castor, Lac	1948, 1953
Castor, 1er Lac	1959
Chabot, Lac	1939, 1957
Champagne, Lac	1939, 1951
Charbonneau, Lac	1948
Chasseurs, Lac aux	1948
Chats, Lac des	1931, 1948
Chevreuil, Lac	1948
Chevreuil	1948
Clair, Lac	1958
Clément, Lac	1958
Coaticook, R [NB]	2015
Cochand, Petit Lac à	1931
Comeau, Lac	1957
Croix, Lac à la	1948
Dame, Lac	1957
Désert, Lac	1932
Desroches, Lac	1950
Deux Montagnes, Lac des	1941
Dumouchel, Lac	1934
Écorces, Lac des	1932
Edmond, Lac	1948
Édouard, Lac	1948
Est, Lac de l’	1952
Etchemin, R	1953

Stream	Year(s) of Observation
Fairburn, Lac	1954
Farley, Petit Lac	1956
Fer à Cheval, Lac	1938
Fiddler, Lac	1950
Foin, Lac à	1948
Fortier, Lac	1958
Fortin, Lac	1960
Français, Lac des	1931, 1950
Fraser, Lac	1959
Gauthier, Lac	1939
Groulx, Lac	1948
Hamel, Lac	1951
Île, Lac à la	1952
Jean, Lac	1951
Labelle, Lac	1932
Lajeunesse, Lac	1931
Lamoureux, Lac	1954
Lanthier, Petit Lac	1952
Larose, Ruisseau	1938
Larouche, Lac	1952
Laurel, Lac	1931, 1950
Deslauriers, Lac	1943
Lavallée, Lac	1932
Lefebvre, Lac	1948, 1950
Lemay, Lac	1953
Léonard, Lac	1958
Libby, Étang	1931
Lièvre, R	1958
Lindsay, Lac	1951
Lippé, Lac	1950
Lippé, Lac	1951
Litchfield	1935
Loaf Pond	1931
Long, Lac	1939, 1948, 1958
Long Pond	1957
Loup, Étang du	1952
Loutre, Lac	1931, 1935, 1958
Loutre, Trib Lac à la	1948

Stream	Year(s) of Observation
Madisson, R	1952
Magog, R	1953
Marois, Lac	1931
Marquis, Lac	1953
Massawippi, R [NB]	2015
Masson, Lac	1931
Matley, Lac	1948
Maxime, Lac	1931
McConge, Lac	1951
McConnell, Lac	1958
McDonald, Lac	1931
McLeod, Lac	1955
McRae, Lac	1931
Ménard, Lac	1931
Michaudville, Lac	1958
Nantel, Lac	1931
Newman, Lac	1948
Nick, Lac	1931
Nicolet, Lac	1956
Noir, Lac	1948
Nymark, Lac à	1948
Orford, Lac	1931
Orignal, Lac à l’	1938, 1957, 1961
Patterson, Lac	1954
Peasley, Étang	1931
Pékan, Lac	1948
Pelletier, Lac	1948
Perkins, Lac	1950
Pierre, Lac de la	1948
Pierre-Paul, Lac	1934
Raquette, Lac	1952
Renne, R le	1956
Sables, Lac des	1931
Saint-Denis, Lac	1948
Sainte-Adèle, Lac	1931, 1948
Sainte-Marie, Lac	1948, 1951
Sainte-Rose, Lac	1939
Saint-François, R [NB/S]	2014, 2015

Stream	Year(s) of Observation
Saint-François, Petit Lac	1958
Saint-François-Xavier, Lac	1931, 1948
Saint-Joseph, Lac	1948, 1951
Saint-Louis, Lac [NB/S]	1939, 1941, 1957
Saint-Pierre, Lac [S]	1939, 1944, 1957, 1976
Sally, Étang	1931
Sarrazin, Lac	1931
Saumons, R aux	1951, 2015
Sauvage, Lac	1950
Schmidt, Lac	1948
Seize Îles, Lac des	1931
Serpentine, R	1935
Sim, Lac	1948
Simon, R	1948
Sinclair, Lac	1952
Sir John, Lac	1948
Souris, Lac des	1950
Sparling, Lac	1935
Spring, Lac	1952
Stevens, Lac	1961
Stoke, R	1955
Taillefer, Lac	1948
Tapani, Lac	1961
Taylor, Petit Lac	1950
Théodore, Lac	1948
Thérien, Lac	1948
Thompson, Lac	1948
Ti-Lane, Lac à	1956
Tomifobia, R [NB]	2015
Travers, Lac	1943
Trois Frères, Lac des	1948
Trousers, Lac	1948
Trout, R	1952
Truite, Lac à la	1931, 1932, 1948, 1951
Valiquette, Lac	1950
Vert, Lac	1932, 1952
Vezeau, Lac	1954
Wener, Lac	1934

Stream	Year(s) of Observation
William, Lac	1953
Williams, Lac [NB]	1948
Windigo, Lac	1955
Woods, Lac	1950
Lake Champlain	
Pike R [S]	1989–2007[1]
SASKATCHEWAN-NELSON RIVER (DU2)	
Winnipeg River	
Birch R [NB]	2011
English R	2015
Whitemouth R [NB]	2011
Winnipeg R [NB/S]	2015, 2017

[1] Observed in at least one year during interval reported, not necessarily in each year

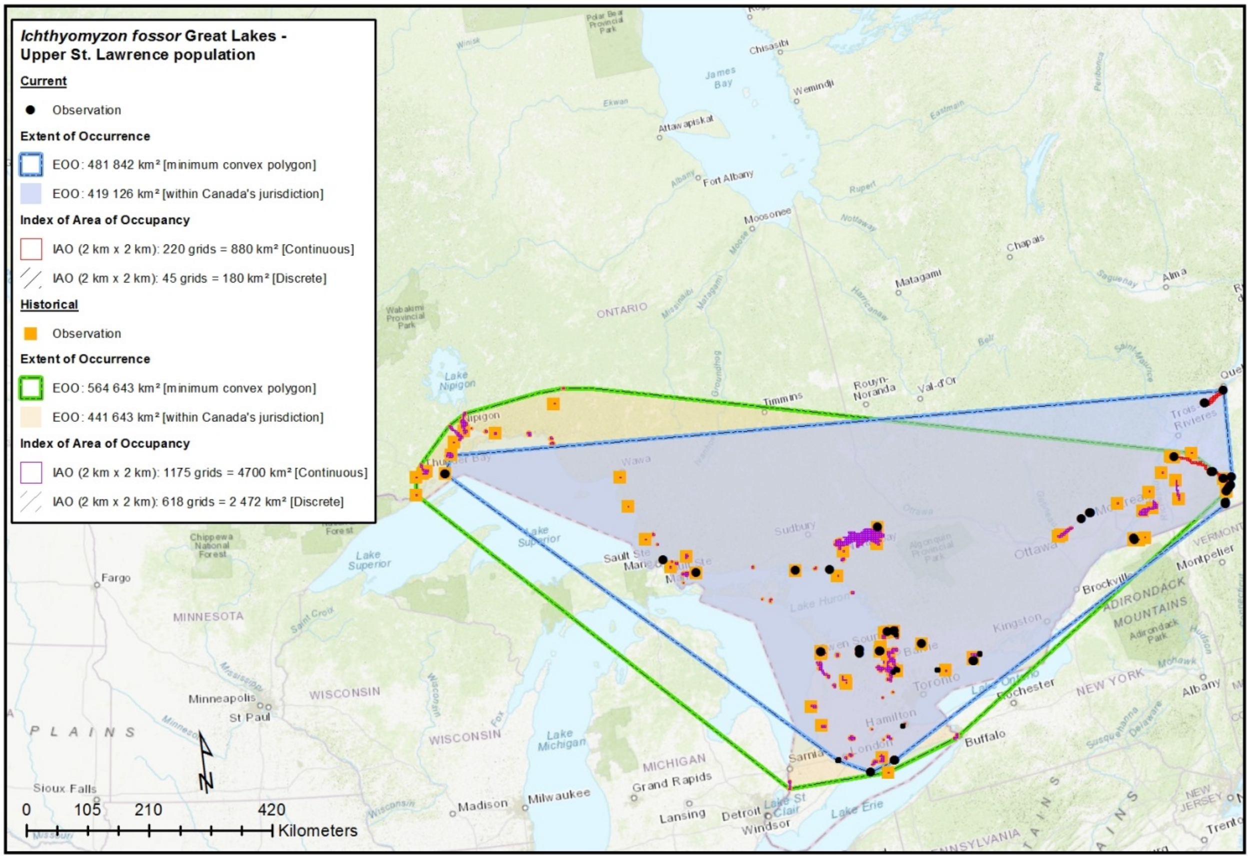
[2] Specific year of observation reported from other sources

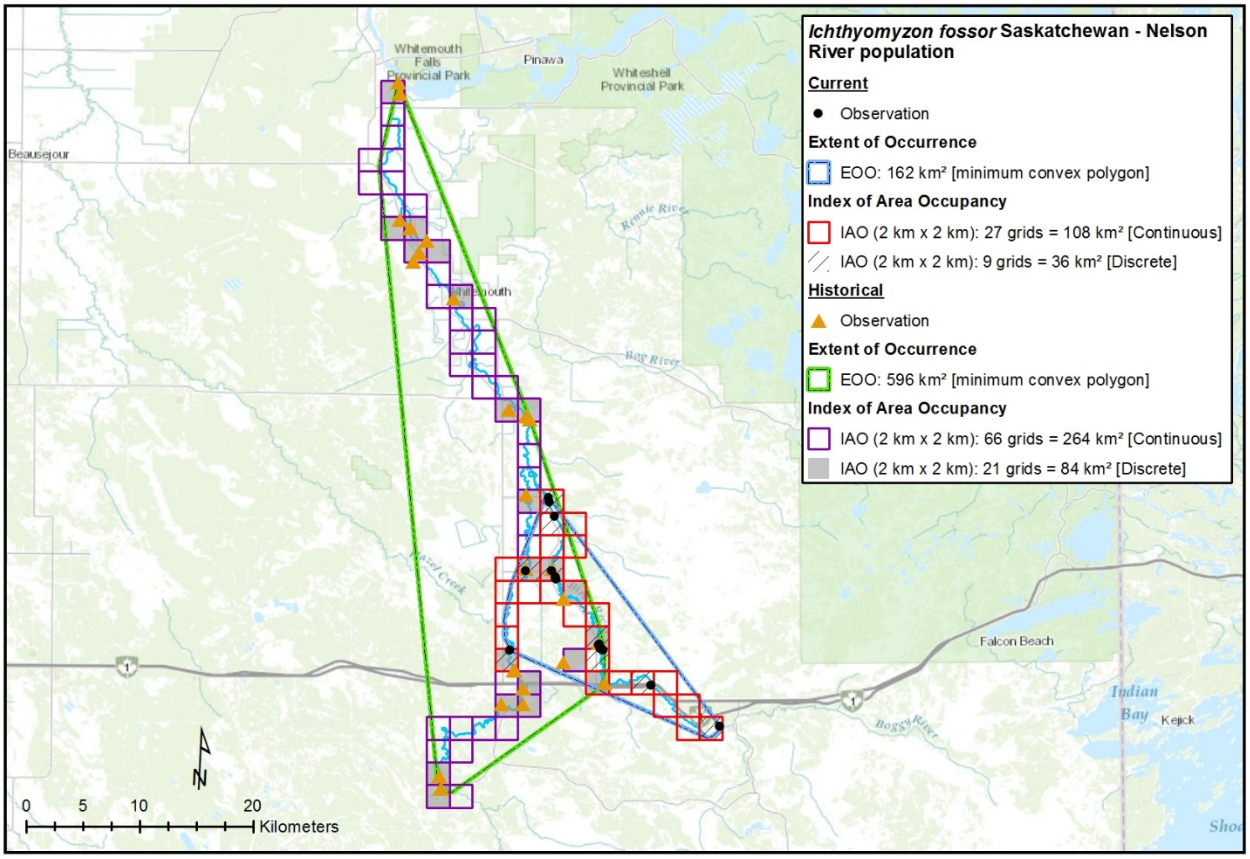
[NB] Northern Brook Lamprey have been found in this tributary, not necessarily in the same observed years

[S] Silver Lamprey have been found in this tributary, not necessarily in the same observed years

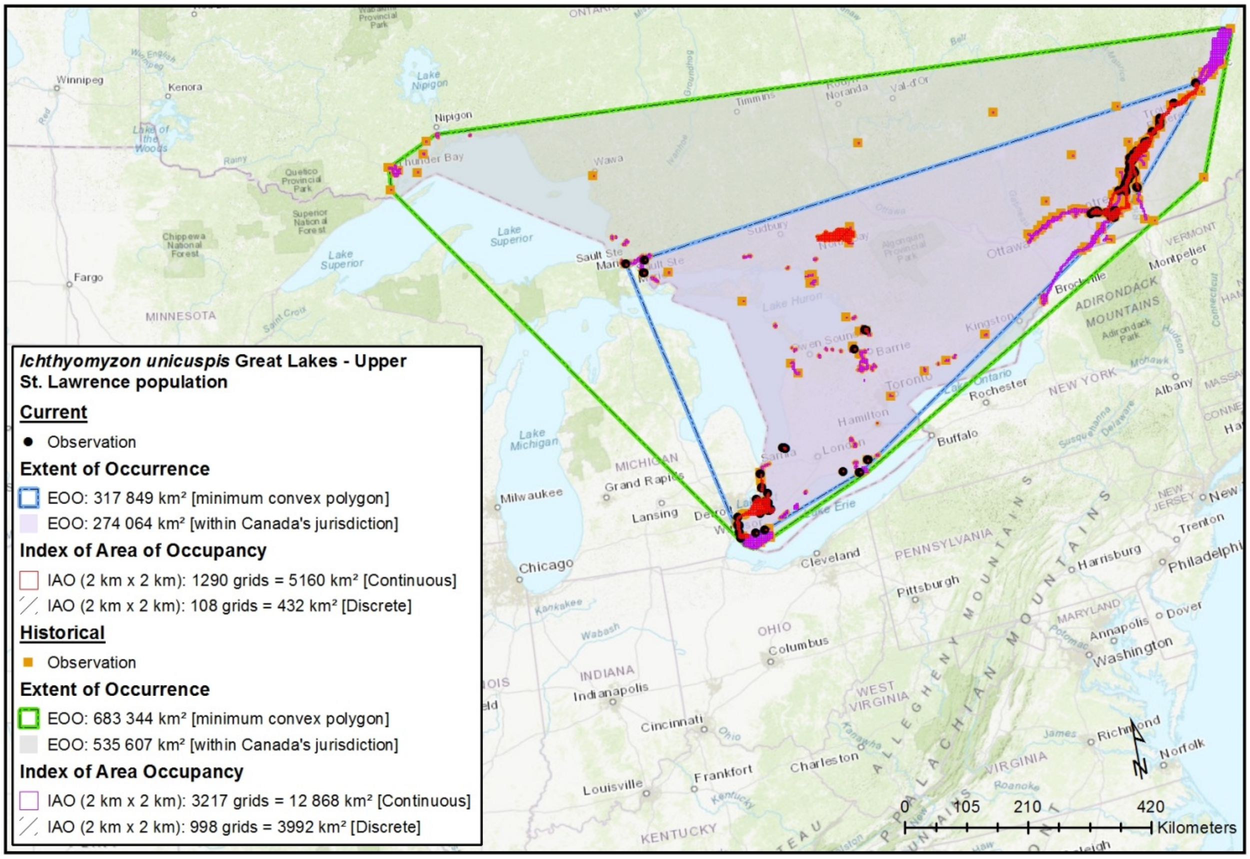
[NB/S] Northern Brook and Silver lamprey have both been found in this tributary, not necessarily in the same observed years

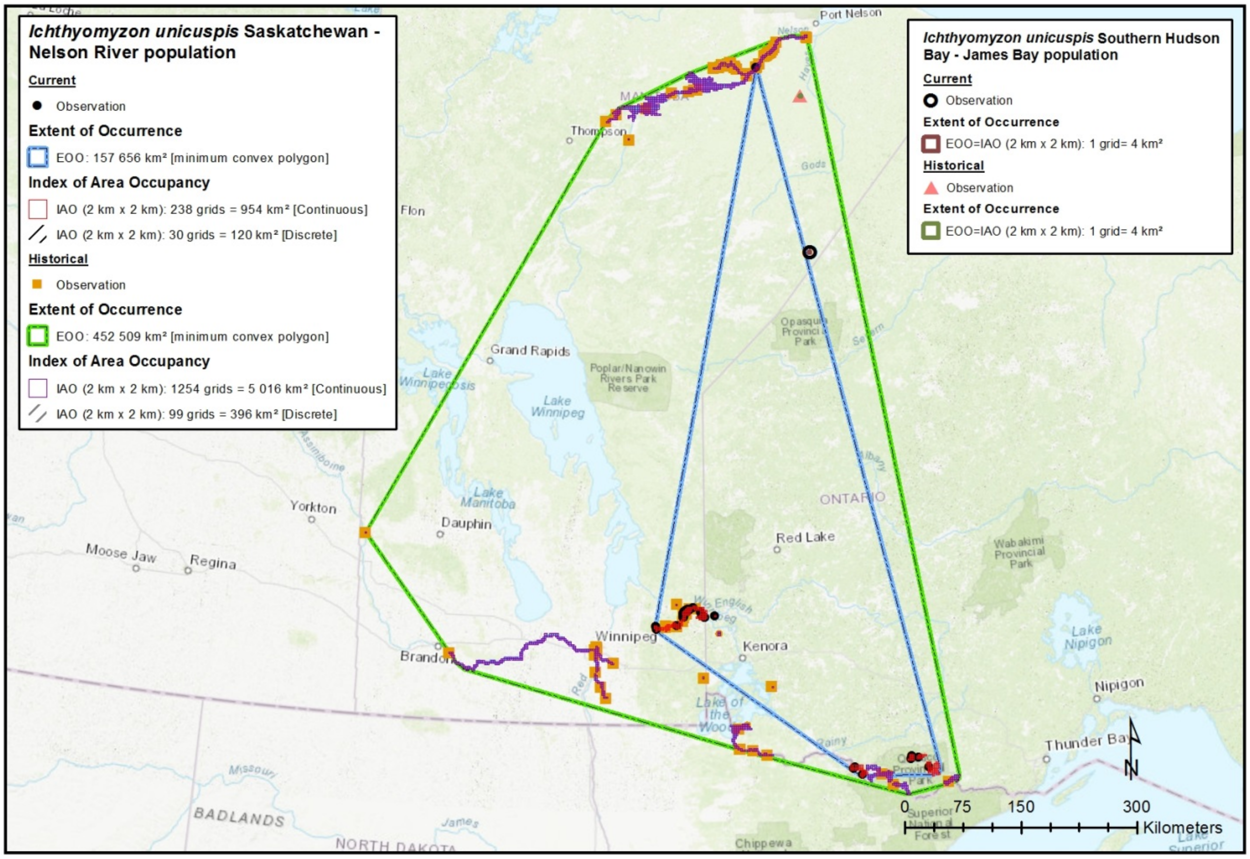
Appendix 4. Estimated Extent of Occurrence (EOO) and Index of Area of Occupancy (IAO) for Northern Brook and Silver lampreys in each DU (maps created by the COSEWIC Secretariat).





Ichthyomyzon fossor Saskatchewan - Nelson River population
Current
Observation
Extent of Occurrence
EOO: 162 km² [minimum convex polygon]
Index of Area Occupancy
IAO (2 km x 2 km): 27 grids = 108 km² [Continuous]
IAO (2 km x 2 km): 9 grids = 36 km² [Discrete]
Historical
Observation
Extent of Occurrence
EOO: 596 km² [minimum convex polygon]
Index of Area Occupancy
IAO (2 km x 2 km): 66 grids = 264 km² [Continuous]
IAO (2 km x 2 km): 21 grids = 84 km² [Discrete]
Whitemouth Falls Provincial Park
Pinawa
Whiteshell Provincial Park
Beausejour
Rennie River
Whitemouth
Bog River
Hazel Creek
Falcon Beach
Indian Bay
Kejick
Boggy River
N
0 5 10 20
Kilometers


Ichthyomyzon unicuspis Great Lakes - Upper St. Lawrence population
Current
Observation
Extent of Occurrence
EOO: 317 849 km² [minimum convex polygon]
EOO: 274 064 km² [within Canada's jurisdiction]
Index of Area of Occupancy
IAO (2 km x 2 km): 1290 grids = 5160 km² [Continuous]
IAO (2 km x 2 km): 108 grids = 432 km² [Discrete]
Historical
Observation
Extent of Occurrence
EOO: 683 344 km² [minimum convex polygon]
EOO: 535 607 km² [within Canada's jurisdiction]
Index of Area Occupancy
IAO (2 km x 2 km): 3217 grids = 12 868 km² [Continuous]
IAO (2 km x 2 km): 998 grids = 3992 km² [Discrete]
0 105 210 420 Kilometers
N


Ichthyomyzon unicuspis Saskatchewan - Nelson River population
Current
Observation
Extent of Occurrence
EOO: 157 656 km² [minimum convex polygon]
Index of Area Occupancy
IAO (2 km x 2 km): 238 grids = 954 km² [Continuous]
IAO (2 km x 2 km): 30 grids = 120 km² [Discrete]
Historical
Observation
Extent of Occurrence
EOO: 452 509 km² [minimum convex polygon]
Index of Area Occupancy
IAO (2 km x 2 km): 1254 grids = 5 016 km² [Continuous]
IAO (2 km x 2 km): 99 grids = 396 km² [Discrete]
Ichthyomyzon unicuspis Southern Hudson Bay - James Bay population
Current
Observation
Extent of Occurrence
EOO=IAO (2 km x 2 km): 1 grid= 4 km²
Historical
Observation
Extent of Occurrence
EOO=IAO (2 km x 2 km): 1 grid= 4 km²
Port Nelson
Thompson
Flon
Grand Rapids
Lake Winnipegosis
Lake Winnipeg
Poplar/Nanowin Rivers Park Reserve
Opasquia Provincial Park
Lake Manitoba
Yorkton
Dauphin
Moose Jaw
Regina
ONTARIO
Red Lake
Wabakimi Provincial Park
Winnipeg
Kenora
Brandon
Lake of the Woods
Lake Nipigon
Nipigon
Thunder Bay
BADLANDS
NORTH DAKOTA
Chippewa
0 75 150 300 Kilometers

Appendix 5. Threats Assessment Worksheets.

Species or Ecosystem Scientific Name	Northern Brook Lamprey (NBL) *Ichthyomyzon fossor* (Great Lakes-Upper St. Lawrence)			
Element ID			**Elcode**	
Date:	2019-05-28			
Assessor(s):	Jennifer Heron (facilitator), Nicholas Mandrak (co-chair), Margaret Docker (report author), Jordan Becker, Gale Bravener, Fraser Neave, Mike Steeves, Tim Haxton, Julien April, Doug Watkinson, Constance O'Connor, Christina Davy, Doug Tate, Dan Wellers, Marie-Eve Paquet (secretariat) and Marie-France Noel (secretariat)			
References:				
Overall Threat Impact Calculation Help:			**Level 1 Threat Impact Counts**	
	Threat Impact		**high range**	**low range**
	A	Very High	0	0
	B	High	1	1
	C	Medium	3	0
	D	Low	1	4
Calculated Overall Threat Impact:			Very High	High
Assigned Overall Threat Impact:			**A = Very High**	
Impact Adjustment Reasons:				
Overall Threat Comments			**Generation time 6 years (3 generations = 18 years) Northern Brook Lamprey (NBL) is non-parasitic and non-migratory, completing its life cycle in its natal stream**	

Threat		**Impact (calculated)**		**Scope (next 10 Yrs)**	**Severity (10 Yrs or 3 Gen.)**	**Timing**	**Comments**
1	Residential & commercial development						
1.1	Housing & urban areas						
1.2	Commercial & industrial areas						
1.3	Tourism & recreation areas						
2	Agriculture & aquaculture						
2.1	Annual & perennial non-timber crops						
2.2	Wood & pulp plantations						
2.3	Livestock farming & ranching						Siltation, eutrophication covered under 7.3, 9.1
2.4	Marine & freshwater						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
	aquaculture						
3	Energy production & mining						
3.1	Oil & gas drilling						
3.2	Mining & quarrying						
3.3	Renewable energy						
4	Transportation & service corridors						
4.1	Roads & railroads						Covered under 7.3
4.2	Utility & service lines						
4.3	Shipping lanes						
4.4	Flight paths						
5	Biological resource use	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	
5.1	Hunting & collecting terrestrial animals						
5.2	Gathering terrestrial plants						
5.3	Logging & wood harvesting	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	Logging is selective, no log dump areas in the water, and riparian strips are left (sediment loading accounted for in 7.3); temporary crossings across waterways are meant to minimize impact (covered in 7.3)
5.4	Fishing & harvesting aquatic resources						Not applicable; NBL was once used as bait for sport fishing but it is now illegal
6	Human intrusions & disturbance		Negligible	Pervasive (71-100%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs)	
6.1	Recreational activities						
6.2	War, civil unrest & military exercises						
6.3	Work & other activities		Negligible	Pervasive (71-100%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs)	Electrofishing surveys during Sea Lamprey Control assessment result in some taking/killing of NBL to confirm species ID, but proportion of population lethally sampled very small (e.g., approx. 1,000 *Ichthyomyzon* larvae per year in 2013-2018); likewise, negligible scientific sampling/research.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
7	Natural system modifications	CD	Medium - Low	Large - Restricted (11-70%)	Moderate (11-30%)	High (Continuing)	
7.1	Fire & fire suppression						
7.2	Dams & water management/use	CD	Medium - Low	Large - Restricted (11-70%)	Moderate (11-30%)	High (Continuing)	Disruption of hydrologic regimes downstream of dams affects NBL; most severe effect is dewatering that puts several larval year classes at risk of mortality. Hundreds of dams in this DU, but proportion of NBL range in affected portion of regulated rivers uncertain. However, because risk of dewatering is higher in tributaries with peak load hydro plants (20% generating stations in Ontario) versus run-of-river plants (55–60%), scope is likely not at the high end of the Large range. Dams and barriers that exclude Sea Lamprey from accessing upstream reaches protect NBL from exposure to lampricides (see 9.2). As such, removal of barriers could represent a substantial threat to NBL in the Great Lakes.
7.3	Other ecosystem modifications	D	Low	Large - Restricted (11-70%)	Slight (1-10%)	High (Continuing)	Construction and maintenance projects (e.g., dredging, road maintenance, culvert insertion) ongoing throughout most of range, but generally only point-source threats. Activities likely to reduce number of NBL (e.g., dredging of sediment in which multiple generations of larval lampreys burrow), but unlikely to lose population unless entire spawning bed affected (e.g., dredged or covered with sedimentation plumes).
8	Invasive & other problematic species & genes	CD	Medium - Low	Pervasive - Large (31-100%)	Moderate - Slight (1-30%)	High (Continuing)	
8.1	Invasive non-native/alien species	CD	Medium - Low	Pervasive - Large (31-100%)	Moderate - Slight (1-30%)	High (Continuing)	May be competition with invasive Sea Lamprey for larval/spawning habitat, but extent of impact is unknown. Sea Lamprey is better able to recolonize lampricide-treated streams and, because it is more fecund, reaches higher abundance than NBL where they co-occur, but the two species appear to co-exist and NBL has a competitive advantage above barriers (see 9.2). Accidentally introduced American Brook Lamprey on the north of Lake Superior probably displaced some NBL, but NBL persist. Non-

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
							native Rainbow Trout and Brown Trout are known predators of NBL, but no known substantial reductions in NBL. Round Goby may prey on NBL eggs (e.g., in areas of the St. Clair R), but extent of overlap likely not large (e.g., not in upstream areas).
8.2	Problematic native species						Not applicable; Lake Sturgeon and American Eel likely prey on burrowed lamprey larvae, but numbers of both still well below historical levels and no supplemental releases have local impact on NBL.
8.3	Introduced genetic material						
9	Pollution	B	High	Large (31-70%)	Extreme (71-100%)	High (Continuing)	
9.1	Household sewage & urban waste water		Negligible	Negligible (<1%)	Serious - Moderate (11-70%)	Moderate (Possibly in the short term, < 10 yrs)	NBL not in many urban areas; larval lampreys appear tolerant of sewage outflow/eutrophication, although anoxic sediment or urban waste outflow during embryonic development are likely harmful.
9.2	Industrial & military effluents	B	High	Large (31-70%)	Extreme (71-100%)	High (Continuing)	Approx. 50% of Great Lakes streams with current or historical records of Ichthyomyzon lampreys have been exposed to lampricide (TFM) treatment, about half of these every 2-5 years (i.e., killing multiple larval age classes). Reservoirs of NBL not exposed to lampricide include Great Lakes populations upstream of dams or Sea Lamprey barriers and NBL populations in Quebec. Industrial effluents in some parts of DU1 (e.g., SW Ontario and the St. Lawrence River) may have a negative impact.
9.3	Agricultural & forestry effluents	D	Low	Small (1-10%)	Serious - Slight (1-70%)	High (Continuing)	The herbicide atrazine was implicated in extirpation of NBL from the upper Yamaska River in Quebec in the 1960s; atrazine still used (e.g., in corn fields in SW Ontario and Quebec); significant dilution in larger rivers, but agricultural run-off during flooding a concern.
9.4	Garbage & solid waste						
9.5	Air-borne pollutants						
9.6	Excess energy						
10	Geological events						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
10.1	Volcanoes						
10.2	Earthquakes/tsunamis						
10.3	Avalanches/landslides						
11	Climate change & severe weather	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	
11.1	Habitat shifting & alteration	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High - Moderate	Warming temperatures might allow NBL to expand its distribution (northwards and further upstream) and extend its growing season; NBL may be somewhat more tolerant of warmer temperatures than Sea Lamprey or American Brook Lamprey, reducing potential overlap (see 8.1), especially upstream of barriers that prevent Sea Lamprey upstream expansion. May also lessen overlap with non-native trouts, but could increase overlap with Round Goby.
11.2	Droughts	CD	Medium - Low	Restricted - Small (1-30%)	Extreme (71-100%)	Moderate (Possibly in the short term, < 10 yrs)	Dewatering due to drought would impact multiple generations of larval NBL.
11.3	Temperature extremes	CD	Medium - Low	Restricted - Small (1-30%)	Extreme - Moderate (11-100%)	Moderate (Possibly in the short term, < 10 yrs)	Climatic anomalies (e.g., temperatures > about 22°C) during embryonic development in the late spring, early summer could lead to increased mortality.
11.4	Storms & flooding	CD	Medium - Low	Restricted - Small (1-30%)	Serious - Slight (1-70%)	Moderate (Possibly in the short term, < 10 yrs)	Extreme flooding could wash out and destroy larval silt beds, although effect likely less severe than drought.

Classification of Threats adopted from IUCN-CMP, Salafsky *et al*. (2008).

Species or Ecosystem Scientific Name	Northern Brook Lamprey (NBL) *Ichthyomyzon fossor* (Saskatchewan-Nelson River)			
Element ID			**Elcode**	
Date (Ctrl + ";" for today's date):	2019-06-25			
Assessor(s):	Kristiina Ovaska, Margaret Docker, Nicholas Mandrak, Doug Watkinson, Christina Davy, Marie-France Noel			
References:	COSEWIC status report (draft, spring 2019)			
Overall Threat Impact Calculation Help:			**Level 1 Threat Impact Counts**	
	Threat Impact		**high range**	**low range**
	A	Very High	0	0
	B	High	1	0
	C	Medium	0	0
	D	Low	4	5
Calculated Overall Threat Impact:			High	Medium
Assigned Overall Threat Impact:			**BC = High - Medium**	
Impact Adjustment Reasons:				
Overall Threat Comments			**Generation time 6 years (3 generations = 18 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%)	High (Continuing)	
1.1	Housing & urban areas		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	<1% of watershed is developed and limited population growth in recent years.
1.2	Commercial & industrial areas						
1.3	Tourism & recreation areas		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Only some fishing, swimming, or quadding.
2	Agriculture & aquaculture						
2.1	Annual & perennial non-timber crops						Not an issue. <10% of the Whitemouth River watershed is cropland; effects of agriculture to aquatic systems accounted for under 7.2, 9.3.
2.2	Wood & pulp plantations						
2.3	Livestock farming & ranching						Not an issue. Rangeland <5% of watershed, and most people fence cattle so that few cattle go into stream, although some trampling of larval lamprey or spawning habitat plausible. Effects to aquatic systems from feed lot runoff accounted for under 9.3.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
2.4	Marine & freshwater aquaculture						
3	Energy production & mining	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	
3.1	Oil & gas drilling						
3.2	Mining & quarrying		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	3-4 large peat mines in watershed (30-60% NBL range), but not right close to water. There may be some sedimentation in the Birch and Whitemouth rivers, and might be some impact on watershed hydrology, but likely not significant.
3.3	Renewable energy						
4	Transportation & service corridors						
4.1	Roads & railroads						As a whole, the watershed has limited roads. Bridge replacement taking place at both Birch R (completed) and Whitemouth River (under construction as of August 2017), but threat is negligible; crossings are small.
4.2	Utility & service lines						Utility and service lines (TransCanada pipeline, City of Winnipeg Aqueduct) cross the watershed; risk of spill into Whitemouth or Birch R accounted for under pollution.
4.3	Shipping lanes						
4.4	Flight paths						
5	Biological resource use						
5.1	Hunting & collecting terrestrial animals						
5.2	Gathering terrestrial plants						
5.3	Logging & wood harvesting						<5% harvesting in watershed. Deforestation may result in sediment loading, accounted for in 9.3, and potential reduction in detritus on which larval NBL feed (see 7.3).
5.4	Fishing & harvesting aquatic resources						Not an issue; NBL not likely harvested for bait and not likely harvested incidentally.
6	Human intrusions & disturbance		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	
6.1	Recreational activities						Not an issue; recreational activities are mostly low impact (e.g., hiking, birdwatching, camping). Very limited power boating. Some fishing, swimming, and ATVing.
6.2	War, civil unrest & military exercises						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
6.3	Work & other activities		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Negligible scientific sampling/research.
7	Natural system modifications	D	Low	Pervasive - Large (31-100%)	Slight (1-10%)	High (Continuing)	
7.1	Fire & fire suppression						Not much burnt in past 50-100 years; not relevant.
7.2	Dams & water management/use	D	Low	Large (31-70%)	Slight (1-10%)	High (Continuing)	Only one dam on Whitemouth River System, but at upstream extent of watershed so that downstream modifications affect large portion (>50%) of the watershed and NBL's range. Severity unknown; not an actively managed dam, so negative effect probably slight, but uncertain and effects may be higher in some years. Periodic withdrawal of water for hydrostatic testing of pipelines, which can cause dewatering during low-flow fall periods and freezing of shallows in winter, has not been allowed in the Whitemouth River since the mid-1990s, but there is continued interest for hydrostatic testing of the TransCanada Pipeline. Water removal for domestic use, for lawn or agricultural irrigation, and for watering livestock can also reduce flow, particularly during dry years.
7.3	Other ecosystem modifications	D	Low	Pervasive - Large (31-100%)	Slight (1-10%)	High (Continuing)	Much of the system has Ash trees and is likely to be affected by Emerald Ash Borer within the next 10 years, which could reduce canopy cover and shading on river banks, thus reducing NBL spawning and larval rearing sites. Might also affect diet of NBL larvae, given reliance on detritus, including from terrestrial plants, although other trees will eventually replace Ash. Small-scale habitat alterations (e.g., boulder removal) are present in the WRW, but they are mostly limited in scope. NBL like faster-flowing areas, so removing boulders might disrupt flow, thus reducing NBL spawning and larval rearing sites.
8	Invasive & other problematic species & genes	D	Low	Restricted (11-30%)	Slight (1-10%)	High (Continuing)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
8.1	Invasive non-native/alien species	D	Low	Restricted (11-30%)	Slight (1-10%)	High (Continuing)	Invasive Rusty Crayfish detected in the Birch R in 2011; has probably expanded but although not yet surveyed well; in lake, Rusty Crayfish move 1-2 km per year, probably low end of 11-30% in next 10 years. Rusty Crayfish may consume NBL eggs but, more likely as grazers, negatively alter NBL habitat.
8.2	Problematic native species						
8.3	Introduced genetic material						
9	Pollution	D	Low	Large (31-70%)	Slight (1-10%)	High (Continuing)	
9.1	Household sewage & urban waste water		Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	Human waste lagoon present at town of Whitemouth, and some town effluent pumped out into river or septic leakage, but limited given low population density in watershed; towns further downstream on watershed.
9.2	Industrial & military effluents						
9.3	Agricultural & forestry effluents	D	Low	Large (31-70%)	Slight (1-10%)	High (Continuing)	NBL mostly downstream of Hwy 1; corn and soybean farming contribute some pesticides to downstream reaches; some cattle farming upstream. Animal waste lagoons are present along the Whitemouth River in several localities.
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	BD	High - Low	Pervasive (71-100%)	Serious - Slight (1-70%)	High (Continuing)	
11.1	Habitat shifting & alteration						Warming waters may allow NBL to spread northwards, although some uncertainty related to connectivity, and doesn't appear that NBL is limited currently by temperature.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
11.2	Droughts	BD	High - Low	Pervasive (71-100%)	Serious - Slight (1-70%)	High (Continuing)	Very low flows in last decade in both Whitemouth and Birch rivers; almost stopped sometimes; because river system so small, affects almost entire NBL population. Dewatering due to drought every few years could wipe out multiple year classes of larval NBL at once.
11.3	Temperature extremes	BD	High - Low	Pervasive (71-100%)	Serious - Slight (1-70%)	High (Continuing)	Temperature loggers in drought years currently show summer temperatures close to 27C; lethal temperatures for larvae 28-30.5C, but embryos more sensitive to high temperature; rapid increases in temperature during embryonic development in the late spring/early summer could lead to increased mortality. Severity will depend on the year and how much drought is occurring at the same time. Not much groundwater in this region; thus, increased propensity for greater temperature extremes, including freezing to the bottom in years with low water and particularly cold temperatures.
11.4	Storms & flooding						
Classification of Threats adopted from IUCN-CMP, Salafsky *et al*. (2008).							

Species or Ecosystem Scientific Name	Silver Lamprey *Ichthyomyzon unicuspis* (Great Lakes-Upper St. Lawrence)			
Element ID		**Elcode**		
Date:	2019-05-28			
Assessor(s):	Jennifer Heron (facilitator), Nicholas Mandrak (co-chair), Margaret Docker (report author), Jordan Becker, Gale Bravener, Fraser Neave, Mike Steeves, Tim Haxton, Julien April, Doug Watkinson, Constance O'Connor, Christina Davy, Doug Tate, Dan Wellers, Marie-Eve Paquet (secretariat) and Marie-France Noel (secretariat)			
References:				
Overall Threat Impact Calculation Help:			**Level 1 Threat Impact Counts**	
	Threat Impact		**high range**	**low range**
	A	Very High	0	0
	B	High	1	1
	C	Medium	3	0
	D	Low	1	4
Calculated Overall Threat Impact:			Very High	High
Assigned Overall Threat Impact:			**A = Very High**	
Impact Adjustment Reasons:				
Overall Threat Comments			**Generation time 6 years (3 generations = 18 years) Silver Lamprey is parasitic and migratory, migrating between stream habitat for larval rearing and spawning and lake or river habitat for feeding on ray-finned fishes**	

Threat		**Impact (calculated)**		**Scope (next 10 Yrs)**	**Severity (10 Yrs or 3 Gen.)**	**Timing**	**Comments**
1	Residential & commercial development						
1.1	Housing & urban areas						
1.2	Commercial & industrial areas						
1.3	Tourism & recreation areas						
2	Agriculture & aquaculture						
2.1	Annual & perennial non-timber crops						
2.2	Wood & pulp plantations						
2.3	Livestock farming & ranching						Siltation, eutrophication covered under 7.3, 9.1
2.4	Marine & freshwater aquaculture						
3	Energy production & mining						
3.1	Oil & gas drilling						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
3.2	Mining & quarrying						
3.3	Renewable energy						
4	Transportation & service corridors						
4.1	Roads & railroads						Covered under 7.3
4.2	Utility & service lines						
4.3	Shipping lanes						
4.4	Flight paths						
5	Biological resource use	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	
5.1	Hunting & collecting terrestrial animals						
5.2	Gathering terrestrial plants						
5.3	Logging & wood harvesting	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	Logging is selective, no log dump areas in the water, and riparian strips are left (sediment loading accounted for in 7.3); temporary crossings across waterways are meant to minimize impact (covered in 7.3)
5.4	Fishing & harvesting aquatic resources		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	There is little or no intentional harvesting of Silver Lamprey, although small numbers of Silver Lamprey are caught as bycatch (e.g., attached to host fish), and they may be destroyed if they are not distinguished from the invasive Sea Lamprey.
6	Human intrusions & disturbance		Negligible	Pervasive (71-100%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs)	
6.1	Recreational activities						
6.2	War, civil unrest & military exercises						
6.3	Work & other activities		Negligible	Pervasive (71-100%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs)	Electrofishing surveys during Sea Lamprey Control assessment result in some taking/killing of *Ichthyomyzon* larvae to confirm species ID (i.e., not Sea Lamprey), but proportion of population lethally sampled is small (e.g., approx. 1,000 *Ichthyomyzon* larvae per year in 2013-2018); likewise, negligible scientific sampling/research. At Sea Lamprey barriers with traps, adult Silver Lamprey released by contractors on Canadian side of the Great Lakes (but generally not on the American side).

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
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	CD	Medium - Low	Large (31-70%)	Moderate - Slight (1-30%)	High (Continuing)	Dams and Sea Lamprey barriers that prevent Silver Lamprey from accessing upstream spawning and larval rearing habitat have historically limited distribution throughout this DU. Continuing effects of dams include disruption of hydrologic regimes; scope likely larger than in NBL because Silver Lamprey located downstream of dams. Most severe effect is dewatering that puts several larval year classes at risk of mortality, although risk may be less than in NBL if Silver Lamprey spawn and rear in deeper waters. Dams with hypolimnetic drawdown might have thermal effects. Vulnerability to lampricide exposure and competition with Sea Lamprey downstream of dams covered in 9.2 and 8.1, respectively.
7.3	Other ecosystem modifications	D	Low	Large - Restricted (11-70%)	Slight (1-10%)	High (Continuing)	Construction and maintenance projects (e.g., dredging, road maintenance, culvert insertion) ongoing throughout most of range, but generally only point-source threats. Activities likely to reduce number of Silver Lamprey larvae (e.g., dredging of sediment in which multiple generations burrow), but unlikely to lose population unless entire spawning bed affected (e.g., dredged or covered with sedimentation plumes).
8	Invasive & other problematic species & genes	CD	Medium - Low	Pervasive - Large (31-100%)	Moderate - Slight (1-30%)	High (Continuing)	
8.1	Invasive non-native/alien species	CD	Medium - Low	Pervasive - Large (31-100%)	Moderate - Slight (1-30%)	High (Continuing)	Competition with invasive Sea Lamprey for larval/spawning habitat; Sea Lamprey more fecund and appears to have less stringent spawning requirements. Some non-native fish species (e.g., Round Goby) may prey on Silver Lamprey eggs; however, non-native fish species (e.g., Common Carp) may benefit Silver Lamprey by serving as hosts during the parasitic feeding phase.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
8.2	Problematic native species						Not applicable; Lake Sturgeon and American Eel likely prey on burrowed lamprey larvae, but numbers of both still well below historical levels, supplemental releases do not have local impact on Silver Lamprey, and Lake Sturgeon benefits Silver Lamprey as a preferred fish host.
8.3	Introduced genetic material						
9	Pollution	B	High	Large (31-70%)	Extreme (71-100%)	High (Continuing)	
9.1	Household sewage & urban waste water		Negligible	Negligible (<1%)	Serious - Moderate (11-70%)	Moderate (Possibly in the short term, < 10 yrs)	Silver Lamprey not in many urban areas; larval lampreys appear tolerant of sewage outflow/eutrophication, although anoxic sediment or urban waste outflow during embryonic development are likely harmful.
9.2	Industrial & military effluents	B	High	Large (31-70%)	Extreme (71-100%)	High (Continuing)	Approx. 50% of Great Lakes streams with current or historical records of *Ichthyomyzon* lampreys have been exposed to lampricide (TFM) treatment, about half of these every 2-5 years (i.e., killing multiple larval age classes). Because Silver Lamprey larvae are generally restricted downstream of barriers along with Sea Lamprey, much of their distribution in these Great Lakes streams is exposed to lampricide; thus, scope might be at higher end of Large range compared to NBL. Silver Lamprey in Quebec are not exposed to lampricide. Industrial effluents in some parts of DU1 (e.g., SW Ontario and the St. Lawrence River) may have a negative impact. In addition, Silver Lamprey are vulnerable to the negative effects of mercury and other contaminants when they feed on the blood of large-bodied fishes contaminated with industrial pollutants.
9.3	Agricultural & forestry effluents	D	Low	Small (1-10%)	Serious - Slight (1-70%)	High (Continuing)	The herbicide atrazine was implicated in extirpation of NBL from the upper Yamaska River in Quebec in the 1960s; larval Silver Lamprey likely equally affected. Atrazine still used (e.g., in corn fields in SW Ontario and Quebec); significant dilution in larger rivers, but agricultural run-off during flooding a concern.
9.4	Garbage & solid waste						
9.5	Air-borne pollutants						
9.6	Excess energy						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
10	Geological events						
10.1	Volcanoes						
10.2	Earthquakes/tsunamis						
10.3	Avalanches/landslides						
11	Climate change & severe weather	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	
11.1	Habitat shifting & alteration	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High - Moderate	Less likely that warming temperatures will allow Silver Lamprey to expand its distribution; Silver Lamprey appear to prefer colder waters than NBL, and barriers will limit upstream expansion, possibly resulting in range contraction. Unlikely that warming temperatures will change overlap with Sea Lamprey.
11.2	Droughts	CD	Medium - Low	Restricted - Small (1-30%)	Extreme (71-100%)	Moderate (Possibly in the short term, < 10 yrs)	Dewatering due to drought would impact multiple generations of larval Silver Lamprey, although risk may be less than in NBL if Silver Lamprey spawn and rear in deeper waters.
11.3	Temperature extremes	CD	Medium - Low	Restricted - Small (1-30%)	Extreme - Moderate (11-100%)	Moderate (Possibly in the short term, < 10 yrs)	Climatic anomalies (e.g., temperatures > about 22°C) during embryonic development in the late spring, early summer could lead to increased mortality.
11.4	Storms & flooding	CD	Medium - Low	Restricted - Small (1-30%)	Serious - Slight (1-70%)	Moderate (Possibly in the short term, < 10 yrs)	Extreme flooding could wash out and destroy larval silt beds, although effect likely less severe than drought.
Classification of Threats adopted from IUCN-CMP, Salafsky *et al*. (2008)							

Species or Ecosystem Scientific Name	Silver Lamprey *Ichthyomyzon unicuspis* (Saskatchewan-Nelson River)			
Element ID			**Elcode**	
Date:	2019-06-25			
Assessor(s):	Kristiina Ovaska, Margaret Docker, Nicholas Mandrak, Doug Watkinson, Christina Davy, Marie-France Noel			
References:	COSEWIC status report (draft, spring 2019)			
Overall Threat Impact Calculation Help:			**Level 1 Threat Impact Counts**	
	Threat Impact		**high range**	**low range**
	A	Very High	0	0
	B	High	0	0
	C	Medium	1	0
	D	Low	3	4
Calculated Overall Threat Impact:			High	Medium
Assigned Overall Threat Impact:			**BC = High - Medium**	
Impact Adjustment Reasons:				
Overall Threat Comments			**Generation time 6 years (3 generations = 18 years)**	

Threat		**Impact (calculated)**		**Scope (next 10 Yrs)**	**Severity (10 Yrs or 3 Gen.)**	**Timing**	**Comments**
1	Residential & commercial development						
1.1	Housing & urban areas						Likely not an issue; Silver Lamprey in larger rivers, where effluent would be dilute.
1.2	Commercial & industrial areas						
1.3	Tourism & recreation areas						
2	Agriculture & aquaculture						
2.1	Annual & perennial non-timber crops						
2.2	Wood & pulp plantations						
2.3	Livestock farming & ranching						
2.4	Marine & freshwater aquaculture						
3	Energy production & mining						
3.1	Oil & gas drilling						
3.2	Mining & quarrying						Not an issue; few peat mines over range of Silver Lamprey in this DU.
3.3	Renewable energy						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
4	Transportation & service corridors						
4.1	Roads & railroads						
4.2	Utility & service lines						
4.3	Shipping lanes						
4.4	Flight paths						
5	Biological resource use		Negligible	Negligible (<1%)	Serious (31-70%)	High (Continuing)	
5.1	Hunting & collecting terrestrial animals						
5.2	Gathering terrestrial plants						
5.3	Logging & wood harvesting						Deforestation may result in sediment loading, accounted for in 9.3; otherwise, not an issue.
5.4	Fishing & harvesting aquatic resources		Negligible	Negligible (<1%)	Serious (31-70%)	High (Continuing)	There is little or no intentional harvesting of Silver Lamprey; when Silver Lamprey are caught as bycatch, they are likely killed, but relatively few are caught.
6	Human intrusions & disturbance		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	
6.1	Recreational activities						
6.2	War, civil unrest & military exercises						
6.3	Work & other activities		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Negligible scientific sampling/research.
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	CD	Medium - Low	Large (31-70%)	Moderate - Slight (1-30%)	High (Continuing)	There are 4 and 6 hydroelectric generating stations located within the Silver Lamprey's range on the Nelson and Winnipeg rivers, respectively, resulting in fundamental change in habitat in forebay areas; transition from silt to clay sediment in the vicinity of dams poses a threat to larvae, and spawning habitat may also be less accessible due to deeper water levels in reservoir and impoundment areas. Dams also impede upstream migration by adults and downstream movement of recently metamorphosed juveniles, which are also at risk of physical damage and death from turbines.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
7.3	Other ecosystem modifications	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	Effect of habitat destruction from construction or maintenance projects likely not an issue, because Silver Lamprey in this DU appear to rear in deeper waters in large rivers. Ecosystem modification by invasive Emerald Ash Borer likely of lesser scope than for NBL, because of significant proportion of Silver Lamprey range where Ash doesn't occur (e.g., Nelson R and tributaries not affected).
8	Invasive & other problematic species & genes	D	Low	Restricted - Small (1-30%)	Slight (1-10%)	High (Continuing)	
8.1	Invasive non-native/alien species	D	Low	Restricted - Small (1-30%)	Slight (1-10%)	High (Continuing)	Invasive Rusty Crayfish probably biggest threat; overlap with Silver Lamprey in Lake of the Woods; some uncertainly in scope, but probably not as high as 30%. Rusty Crayfish may consume Silver Lamprey eggs but, more likely as grazers, negatively alter larval habitat.
8.2	Problematic native species						Not an issue.
8.3	Introduced genetic material						
9	Pollution	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	
9.1	Household sewage & urban waste water		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Silver Lamprey in this DU in larger rivers, where effluent would be dilute, and northern watersheds especially with very low population densities.
9.2	Industrial & military effluents		Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	Still active pulp and paper mill in Kenora (and maybe Dryden), but most mills shut down and much stricter environmental controls than previously.
9.3	Agricultural & forestry effluents	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	Most forestry within Silver Lamprey range retired in the past decades (e.g., about 10-15% in the English R watershed, but Nelson R virtually untouched), so smaller scope than NBL in this DU; severity slight due to dilution in large rivers.
9.4	Garbage & solid waste						
9.5	Air-borne pollutants						
9.6	Excess energy						
10	Geological events						
10.1	Volcanoes						
10.2	Earthquakes/tsunamis						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
10.3	Avalanches/landslides						
11	Climate change & severe weather	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	
11.1	Habitat shifting & alteration						
11.2	Droughts	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Virtually all of the Saskatchewan-Nelson watershed is highly managed for water, although severity will be less than for NBL due to size of the system. Silver Lamprey in this DU will be less susceptible to dewatering than lampreys that spawn and rear in wadable streams.
11.3	Temperature extremes	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Silver Lamprey in large northern rivers may be somewhat buffered relative to warming of smaller river systems.
11.4	Storms & flooding						
Classification of Threats adopted from IUCN-CMP, Salafsky *et al*. (2008).							

Species or Ecosystem Scientific Name	Silver Lamprey *Ichthyomyzon unicuspis* (Southern Hudson Bay-James Bay)		
Element ID		**Elcode**	
Date:	2019-06-25		
Assessor(s):	Kristiina Ovaska, Margaret Docker, Nicholas Mandrak, Doug Watkinson, Christina Davy, Marie-France Noel		
References:	COSEWIC status report (draft, spring 2019)		
	Overall Threat Impact Calculation Help:	**Level 1 Threat Impact Counts**	
	Threat Impact	**high range**	**low range**
	A Very High	0	0
	B High	0	0
	C Medium	0	0
	D Low	0	0
	Calculated Overall Threat Impact:		
	Assigned Overall Threat Impact:	**U = Unknown**	
	Impact Adjustment Reasons:		
	Overall Threat Comments	**Generation time 6 years (3 generations = 18 years)**	

Threat		**Impact (calculated)**		**Scope (next 10 Yrs)**	**Severity (10 Yrs or 3 Gen.)**	**Timing**	**Comments**
1	Residential & commercial development						
1.1	Housing & urban areas						Not an issue.
1.2	Commercial & industrial areas						
1.3	Tourism & recreation areas						
2	Agriculture & aquaculture						
2.1	Annual & perennial non-timber crops						
2.2	Wood & pulp plantations						
2.3	Livestock farming & ranching						
2.4	Marine & freshwater aquaculture						
3	Energy production & mining						
3.1	Oil & gas drilling						

Threat		Impact (calculated)	Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
3.2	Mining & quarrying					Likely not an issue. Where we know Silver Lamprey to occur is largely pristine and undeveloped. Probably some hard rock mining in areas, and a large chromite mining and smelting project (known as the Ring of Fire) is planned for development in the James Bay Lowlands of northern Ontario, but not in known Silver Lamprey range.
3.3	Renewable energy					
4	Transportation & service corridors					
4.1	Roads & railroads					
4.2	Utility & service lines					
4.3	Shipping lanes					
4.4	Flight paths					
5	Biological resource use	Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	
5.1	Hunting & collecting terrestrial animals					
5.2	Gathering terrestrial plants					
5.3	Logging & wood harvesting					Not an issue; no logging.
5.4	Fishing & harvesting aquatic resources	Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	No intentional harvesting of Silver Lamprey; occasionally caught as bycatch, but presumably rare; only two communities in this area so relatively limited fishing.
6	Human intrusions & disturbance					
6.1	Recreational activities					
6.2	War, civil unrest & military exercises					
6.3	Work & other activities					No targeted scientific sampling/research; only few individuals as bycatch (covered in 5.4).
7	Natural system modifications					
7.1	Fire & fire suppression					
7.2	Dams & water management/use					Not currently an issue. Plans for diversion dams in some parts of this region (e.g., in southern James Bay), but not in areas where Silver Lamprey known to occur.
7.3	Other ecosystem modifications					
8	Invasive & other problematic species & genes					

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
8.1	Invasive non-native/alien species						
8.2	Problematic native species						
8.3	Introduced genetic material						
9	Pollution						
9.1	Household sewage & urban waste water						
9.2	Industrial & military effluents						
9.3	Agricultural & forestry effluents						
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	High (Continuing)	
11.1	Habitat shifting & alteration						
11.2	Droughts		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	So little is known about Silver Lamprey in this system. Impact may be somewhat buffered in larger systems, but, in general, northern areas are changing more rapidly and severity of change is unknown.
11.3	Temperature extremes		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	As above.
11.4	Storms & flooding						
Classification of Threats adopted from IUCN-CMP, Salafsky *et al*. (2008).							