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Information in Support of a Recovery Potential Assessment of Northern Brook Lamprey (*Ichthyomyzon fossor*) – Saskatchewan-Nelson River Populations

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Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Northern Brook Lamprey is a small, non-parasitic lamprey species, and is one of three species of the genus *Ichthyomyzon* found in Canada. Northern Brook Lamprey and the parasitic Silver Lamprey are a closely related species pair. Northern Brook Lamprey is at the northern edge of its range in Canada, is distributed in Ontario in the tributaries of the Laurentian Great Lakes, tributaries of the St. Lawrence River in Ontario and Quebec, and Manitoba in the Whitemouth River and upstream, including its tributary the Birch River. In November 2020, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the Great Lakes-Upper St. Lawrence populations (DU1) as Special Concern and the Saskatchewan-Nelson River populations (DU 2) were designated Endangered. The Saskatchewan-Nelson River populations have a limited distribution, a decline in the number of mature individuals 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. The most serious threats to which populations are exposed are decreases in stream flows under current and future climates, and anticipated increases in water temperature. Northern Brook Lamprey, Saskatchewan-Nelson River populations are currently not listed under Schedule 1 of the *Species at Risk Act* (SARA), while the Great Lakes-Upper St. Lawrence populations are listed as Special Concern. The Recovery Potential Assessment (RPA) provides information and scientific advice needed to inform the listing decision and various requirements of SARA for the Saskatchewan-Nelson River populations including permitting activities that would otherwise violate SARA prohibitions and the development of recovery strategies and action plans. This Research Document describes the current state of knowledge on the biology, ecology, distribution, population trends, habitat requirements, and threats of Northern Brook Lamprey. Mitigation measures and alternative activities related to the identified threats that can be used to protect the species are also presented.

INTRODUCTION

Northern Brook Lamprey (*Ichthyomyzon fossor*), a small, non-parasitic fish, is one of three lamprey species of the genus *Ichthyomyzon* found in Canada (Scott and Crossman 1998). Northern Brook Lamprey and the parasitic Silver Lamprey (*Ichthyomyzon unicuspis*) are a closely related species pair. Such "paired" species exist in seven of the 10 extant lamprey genera in the world (Docker 2009, Docker and Potter 2019). Northern Brook Lamprey is restricted to eastern North America in the Hudson Bay, Great Lakes, St. Lawrence River, and Mississippi River drainages (Potter et al. 2015). In Canada, Northern Brook Lamprey is found in Manitoba in the Whitemouth River and its tributary the Birch River, in Ontario tributaries to the Laurentian Great Lakes and St. Lawrence River, and in Québec tributaries to the St. Lawrence River.

Northern Brook Lamprey was considered a single designatable unit (DU) in Canada and was assessed as Special Concern in April 1991 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Lanteigne 1991). The species was split into two DUs in April 2007 based on the species occurring in two national freshwater biogeographic areas, the Great Lakes-Upper St. Lawrence populations (DU1) was designated Special Concern and the Saskatchewan-Nelson River populations (DU2) Data Deficient (COSEWIC 2007). In the November 2020 COSEWIC assessment, the Saskatchewan-Nelson River populations were assessed as Endangered, and the Great Lakes-Upper St. Lawrence population's status of Special Concern was reconfirmed (COSEWIC 2020). The Saskatchewan-Nelson River populations have a limited distribution, a decline in the number of mature individuals 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. Populations are exposed to threats such as decreases in stream flows under current and possible future climates and are highly susceptible to anticipated increases in water temperature.

Northern Brook Lamprey Saskatchewan-Nelson River populations are currently not listed under Schedule 1 of the *Species at Risk Act* (SARA). The Recovery Potential Assessment (RPA) provides information and scientific advice needed to fulfill various requirements of SARA including permitting activities that would otherwise violate SARA prohibitions and the development of recovery strategies and action plans. This research document follows a prescribed format that addresses elements important to understanding the species: Biology, Abundance, Distribution and Life History Parameters; Habitat and Residence Requirements; Threats and Limiting Factors to the Survival and Recovery of Northern Brook Lamprey; and Scenarios for Mitigation of Threats and Alternatives to Activities. Information contained in the RPA and this document may be used in the development of recovery strategies, action plans, inform listing decisions, and for assessing SARA Section 73 permit applications.

BIOLOGY, ABUNDANCE, DISTRIBUTION AND LIFE HISTORY PARAMETERS

Element 1: *Summarize the biology of Northern Brook Lamprey*

SPECIES DESCRIPTION

Lampreys, including Northern Brook Lamprey, are distinguished from most other fishes by the 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) (Scott and Crossman 1998, Renaud et al. 2011). Northern Brook Lamprey exhibit three distinct life history phases: 1) the larval phase (termed ammocoete), when lamprey are blind, toothless, and possess an oral hood for filter feeding from burrows built in the soft substrate of slower-flowing portions of streams and rivers; 2) the juvenile phase, which follows metamorphosis from larvae but prior to sexual maturation when fish have a sucking oral disc with knob-like teeth; and, 3) the adult phase, when fish retain the sucking oral disc and teeth, and develop mature gametes (COSEWIC 2020).

Figure 1. Adult Northern Brook Lamprey (Ichthyomyzon fossor). Photo by Doug Watkinson.

Lampreys of 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 (COSEWIC 2020). Distinguishing among the six *Ichthyomyzon* lamprey species is more difficult. Juvenile Silver Lamprey and Chestnut Lamprey (*Ichthyomyzon castaneus*) have a parasitic feeding phase following metamorphosis prior to sexual maturation in the adult phase, while Northern Brook Lamprey do not feed at all following metamorphosis. Therefore, adult non-parasitic Northern Brook Lamprey are easily distinguished from adult Silver and Chestnut lamprey by their body size, as well as smaller eye and oral disc (COSEWIC 2020). Northern Brook and Silver lampreys are distinguished from the Chestnut Lamprey by the absence or low counts of bicuspid inner lateral (or circumoral) teeth (range 0–2) compared to typically 6–8 bicuspid inner lateral teeth (range 1–8) in the Chestnut Lamprey (Renaud 2011).

The closely related Northern Brook and Silver lampreys are distinguishable from one another by mid- to late metamorphosis. The non-parasitic Northern Brook Lamprey averages 115–119 mm total length (TL) at maturity (Hubbs and Trautman 1937, Morman 1979, Docker 2009), has a relatively small eye, small oral disc (which is narrower than the width of the head or body), and poorly developed, knob-like teeth compared to the Silver Lamprey. The parasitic Silver Lamprey, which feeds following metamorphosis, is larger at maturity, averaging 224–248 mm TL (Hubbs and Trautman 1937, Vladykov 1951, Morman 1979, see Docker 2009), has a relatively large eye, large oral disc (which is wider than the width of the head or body), and sharper, more prominent teeth.

Despite the pronounced morphological differences between Northern Brook and Silver lampreys after they metamorphose, they are indistinguishable as larvae. Nor are there any diagnostic genetic differences known to date, as mitochondrial DNA (mtDNA) sequence data shows 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).

Location of capture can sometimes be an indication of species identity, as Northern Brook Lamprey is more likely to be found in smaller streams than Silver Lamprey (Scott and Crossman 1998). In Manitoba, Northern Brook Lamprey are the only lamprey species known in the Whitemouth River drainage (Stewart and Watkinson 2004, COSEWIC 2020). Silver Lamprey occur in the Winnipeg River at the confluence with the Whitemouth River, but it is uncertain if both species co-occur in Manitoba. As well, Northern Brook Lamprey are more likely to be found above barriers, while Silver Lamprey are more migratory and tend to be limited to the lower reaches of rivers (COSEWIC 2020). The presence of adults of one species or the other can sometimes correctly infer species identification of larvae collected from the same locality, but this is not always reliable, as both species occur together in some tributaries elsewhere in their range. The difference in the size at which metamorphosis occurs can help distinguish between parasitic and non-parasitic lampreys as generally metamorphosing Northern Brook Lamprey are larger than metamorphosing Silver Lamprey (Docker 2009).

LIFE CYCLE

All lamprey are oviparous and semelparous, and they invest a considerable amount of biological resources in a single spawning season (Scott and Crossman 1998, Docker et al. 2019). The Northern Brook Lamprey life cycle includes an embryonic period, a larval period ending with metamorphosis, a non-parasitic juvenile period, and an adult reproductive period.

Most of the information related to Northern Brook Lamprey life-history is from Great Lakes populations. The larval stage is thought to last for approximately 3–7 years (Purvis 1970, Scott and Crossman 1998). Male Northern Brook Lamprey metamorphose at earlier ages than females (i.e., 97% of the individuals undergoing metamorphosis at age 3 were male), a pattern that has been observed in many other lamprey species (Dawson et al. 2015, Manzon et al. 2015, Docker et al. 2019). 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) (COSEWIC 2020).

Metamorphosis is thought to begin in early to mid-summer in Manitoba and is a 3- to 4-month process; it may begin in August in other populations (Leach 1940, Manzon et al. 2015). Northern Brook Lamprey begins sexual maturation during metamorphosis, and spawns and dies within 6–8 months of metamorphosis without ever feeding again. Therefore, the overall average life span (or generation time) of Northern Brook Lamprey is approximately 6 years (COSEWIC 2020).

Northern Brook Lamprey typically remain within their natal stream following metamorphosis and undergo only short upstream migrations (typically less than a few kilometres) to their spawning grounds (Malmqvist 1980). Larval densities can be very high in optimal habitat (e.g., up to 126 Northern Brook Lamprey larvae per m^2 in the Brule River in Wisconsin (Churchill 1945). Growth is slow, with average annual growth increments of 37, 28, and 15 mm for the first three years of growth, respectively, in a Lake Superior tributary (Purvis 1970).

Northern Brook Lamprey spawning occurs in tributaries, generally in May or June once water temperatures reach a minimum of 13°C (Vladykov 1949, Manion and Hanson 1980). In Manitoba, spawning has been observed in mid-June (Stewart and Watkinson 2004). Northern Brook Lamprey typically spawn 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 (Johnson et al. 2015)). Northern Brook and Silver lampreys have been observed in the nests of the other lamprey species (Morman 1979), and lab-generated hybrids of the two species have survival rates equivalent to that of pure individuals for at least the first few weeks following fertilization (Piavis et al. 1970). However, long-term survival and fertility of Northern Brook Lamprey-Silver Lamprey hybrids are unknown. Piavis et al. (1970) found 0% survival in experimental hybrids between Northern Brook and Chestnut lampreys.

During migration or at spawning sites, adult sex ratios are reported to range from 54 to 75% male (i.e., ~ 3:1; Churchill 1945, Purvis 1970, Schuldt et al. 1987), but larval sex ratios are generally at parity or with an excess of females (Purvis 1970, Docker et al. 2019).

There is likely a fitness trade-off between fecundity and mortality in the non-parasitic Northern Brook Lamprey relative to the parasitic Silver Lamprey (Docker 2009). This is presumably related to the longer and more exposed feeding and migratory phase of Silver Lamprey. It is presumed that, similar to other species, Northern Brook Lamprey mortality is high immediately following hatching, but it is relatively low and uniform throughout the remainder of the larval stage with annual survival rates estimated at 47–77% (Dawson et al. 2015). Predation can occur during the larval stage (Arakawa and Lampman 2020), but is likely low with mortality rates elevating again for lamprey during metamorphosis (Docker et al. 2015). Predation by aquatic, avian, and terrestrial predators can be high on spawning adults, as spawning generally occurs in daytime hours and in shallow water (Docker et al. 2015). Lamprey eggs appear to be preyed upon by a number of fish species (Cochran 2009, Smith and Marsden 2009).

Age at metamorphosis in lampreys appears to be largely dependent on size and varies with growth rate. Growth rates are generally higher at lower larval densities (Murdoch et al. 1992). Size at metamorphosis also varies among individuals and systems. For example, Purvis (1970) reported that metamorphosing Northern Brook Lamprey were 97–127 mm in length (average 114 mm), while Morman (1979) reported a wider range and larger upper limit (84–182 mm) and higher average (126 mm). Female Northern Brook Lamprey are typically older and larger than males when they undergo metamorphosis (Purvis 1970).

In general, during metamorphosis, lampreys tend to move to coarser substrates with better oxygenated water and higher water velocities, and, because of downstream drift while moving, they may accumulate in more downstream reaches during the larval stage (Dawson et al. 2015). After metamorphosis, Northern Brook Lamprey tend to remain burrowed in the sediment until at least January or February (in Wisconsin), when they may begin to emerge from their burrows and swim periodically (Becker 1983). They overwinter in or near the coarse substrate, and full sexual maturity is only reached in May or June, just before spawning (Docker et al. 2019).

Spawning lamprey are usually concentrated in a small area with nests located in spaces between large stones (Morman 1979) or, occasionally, under different types of cover such as rocks (Cooper 1983, Cochran and Gripentrog 1992). Multiple individuals (3–13) have been observed in a single nest (Morman 1979, Cochran and Pettinelli 1987). When a female enters a nest, the male attaches to the female, and spawning occurs with vigorous vibration occurring (Scott and Crossman 1998). After fertilization, the eggs are sometimes covered with the substrate surrounding the nest by the male (Johnson et al. 2015).

Lamprey fecundity increases approximately with the cubic power of total length (Docker et al. 2019). Information on Northern Brook Lamprey fecundity is available from the Great Lakes drainages, with 1,095 (Leach 1940) to 1,979 eggs (Vladykov 1951) reported with an overall population mean of 1,200 eggs per female (Docker et al. 2019). Average egg size ranges from 1.0 to 1.2 mm (Vladykov 1951, Schuldt et al. 1987), and eggs hatch in 2–4 weeks post spawn (Leach 1940). Adult lampreys generally die within 1 to 4 weeks of spawning (Pletcher 1963, Docker et al. 2019).

FEEDING AND DIET

Larvae burrow in soft sediments in the slower-flowing regions of streams and rivers, feeding predominantly on organic detritus as well as algae (mostly diatoms), protozoans, and bacteria that they extract from the water overlying their burrows (Churchill 1945, Moore and Mallatt 1980, Sutton and Bowen 1994, Yap and Bowen 2003, Dawson et al. 2015). Larval lamprey diet is most important during warmer months when stream temperatures and food quality are more favorable for feeding, digestion, and growth (Sutton and Bowen 1994). A study on Sea Lamprey found that system productivity and individual growth may influence sex determination (Johnson et al. 2017). Once metamorphosis begins, juvenile and adult stage Northern Brook Lamprey do not feed.

Physiology and adaptability

Little is known about the physiology of Northern Brook Lamprey specifically; however, inferences can be made from other lamprey species. For this reason, any speculation about the oxygen or temperature requirements of Northern Brook Lamprey needs to be made with caution.

The egg and embryo stages are most physiologically sensitive (e.g., to high temperatures) whereas larvae are generally more tolerant (Dawson et al. 2015). For example, Sea Lamprey eggs hatch only between 15.5 and 21.1°C, and newly hatched larvae show marked increases in mortality at 22°C (Piavis 1961). The preferred thermal niche of Sea Lamprey was determined in one study to be between 17.8 and 21.8°C, and may be similar for most lamprey species, including Northern Brook Lamprey (Holmes and Lin 1994). Potter and Beamish (1975) determined that incipient lethal temperature for Northern Brook Lamprey acclimated to 15°C in a laboratory study was 30.5°C and sublethal effects likely occur below 30.5°C. This is an area of research that should be explored further, as temperature could potentially limit populations.

Larval lampreys can tolerate relatively low oxygen concentrations (7–10 mmHg) for up to four days, particularly at low temperatures (5°C; Potter et al. 1970). The rate of oxygen consumption is likely lower in lamprey larvae than that observed in teleost fishes of similar weight (Hill and Potter 1970). The low oxygen consumption of lamprey larvae allows them to burrow and respire in silty substrates in slow-flowing areas of streams. Nevertheless, oxygen concentrations could be limiting to larval lampreys during peak seasonal water temperatures coupled with low flows. The rate of oxygen consumption increases during metamorphosis, although it appears to increase less dramatically in non-parasitic compared to parasitic species (Lewis 1980).

Although Northern Brook Lamprey has a relatively wide geographic distribution, its restricted mobility could mean populations may be capable of adaptation to local conditions more so than migratory species (COSEWIC 2020). In contrast, with limited gene flow among disjunct localities, isolated populations will tend to have smaller effective population sizes. This limits their ability to respond to change via selection, and the random process of drift becomes more powerful than selection (Kimura et al. 1963, Willi et al. 2013).

SPECIAL SIGNIFICANCE

Hagfishes (Order Myxiniformes) and lampreys are the only extant jawless vertebrates (Kuraku and Kuratani 2006). They diverged from the rest of the vertebrate lineage > 500 million years ago (Kuraku and Kuratani 2006) and provide important insights into the origins and early evolution of vertebrates (Docker et al. 2015, McCauley et al. 2015, York et al. 2019). They also serve as important model organisms in biomedical research (Docker et al. 2015).

Lampreys are important ecologically for nutrient cycling by facilitating the conversion of nutrients derived from detritus and algae into biomass that serves as a food source for other animals, including aquatic, aerial, and terrestrial predators (Scott and Crossman 1998, Docker et al. 2015). Lampreys' burrowing and feeding activity also increase substrate oxygen levels, potentially benefiting other organisms (Shirakawa et al. 2013).

Study of paired Northern Brook and Silver lampreys is of scientific interest, providing insight into the evolution of alternative feeding strategies and speciation in lampreys. Understanding the genetic mechanisms by which the parasitic feeding phase was eliminated in the Northern Brook Lamprey could lead to an understanding of new controls for the invasive Sea Lamprey (McCauley et al. 2015).

Element 2: *Evaluate the recent species trajectory for abundance, distribution, and number of populations*

ABUNDANCE

No population estimates or density data are available for larval lampreys in Manitoba. There is limited targeted sampling effort for Northern Brook Lamprey, and the effort that has occurred has seldom followed a standardized approach. The highest observed collections are from targeted backpack electrofishing surveys where 22 and 45 *Ichthyomyzon* larvae were collected from the Whitemouth River in 2011 and 2013, respectively (M.F. Docker, University of Manitoba, unpublished data). A survey in the Birch River collected 23 larvae at one site in 1023 seconds of backpack electroshocking (D. Watkinson, DFO, unpublished data). Based on their known distribution, these larvae are presumed to be Northern Brook Lamprey (COSEWIC 2020).

Since 2008, 15 metamorphosing and adult Northern Brook Lamprey have been recorded in the Whitemouth drainage in Manitoba (M.F. Docker, University of Manitoba, unpublished data).

DISTRIBUTION

Global range

The distribution of Northern Brook Lampreys is restricted to eastern North America (Figure 2) in the Hudson Bay, Great Lakes, St. Lawrence River, and Mississippi River drainages (Potter et al. 2015). In Canada, they are found in Manitoba, Ontario, and Quebec (Scott and Crossman 1998). 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 (Page and Burr 2011).

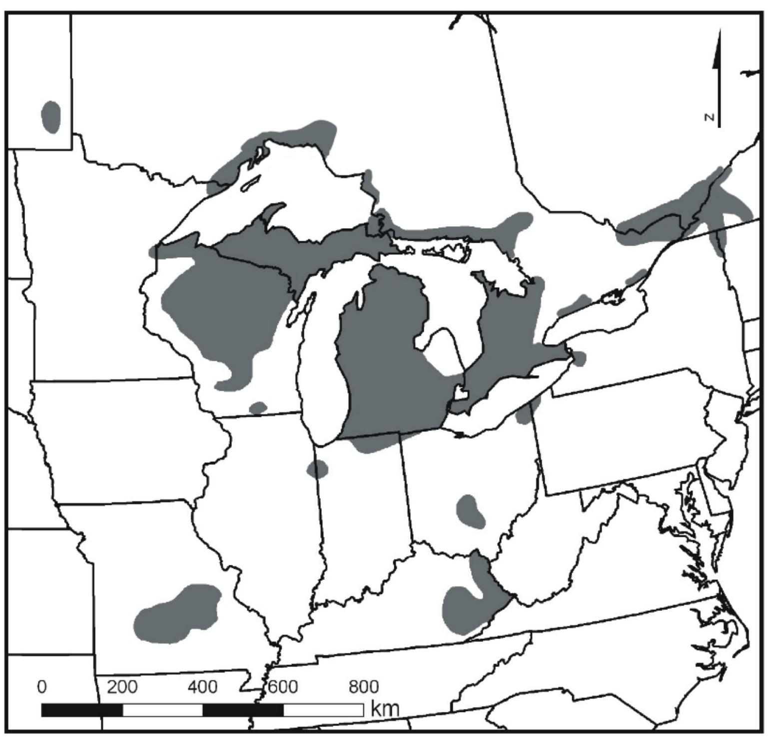

Figure 2. Global distribution of Northern Brook Lamprey, Ichthyomyzon fossor (adapted from Renaud et al. 2009). Distribution is represented by the grey shaded regions.

Canadian range

In Canada, Northern Brook Lamprey is found in Ontario in tributaries to the Laurentian Great Lakes and St. Lawrence River, in southern Quebec in tributaries to the St. Lawrence River, and Manitoba in the Whitemouth River and its tributary the Birch River (Figure 3). In addition, larval lamprey have been collected in the Winnipeg River at the confluence of Whitemouth River and Winnipeg River. It is uncertain if larvae collected below the confluence are Northern Brook or Silver lamprey. It is possible that other populations exist in Saskatchewan-Nelson River drainage, but they have not been identified.

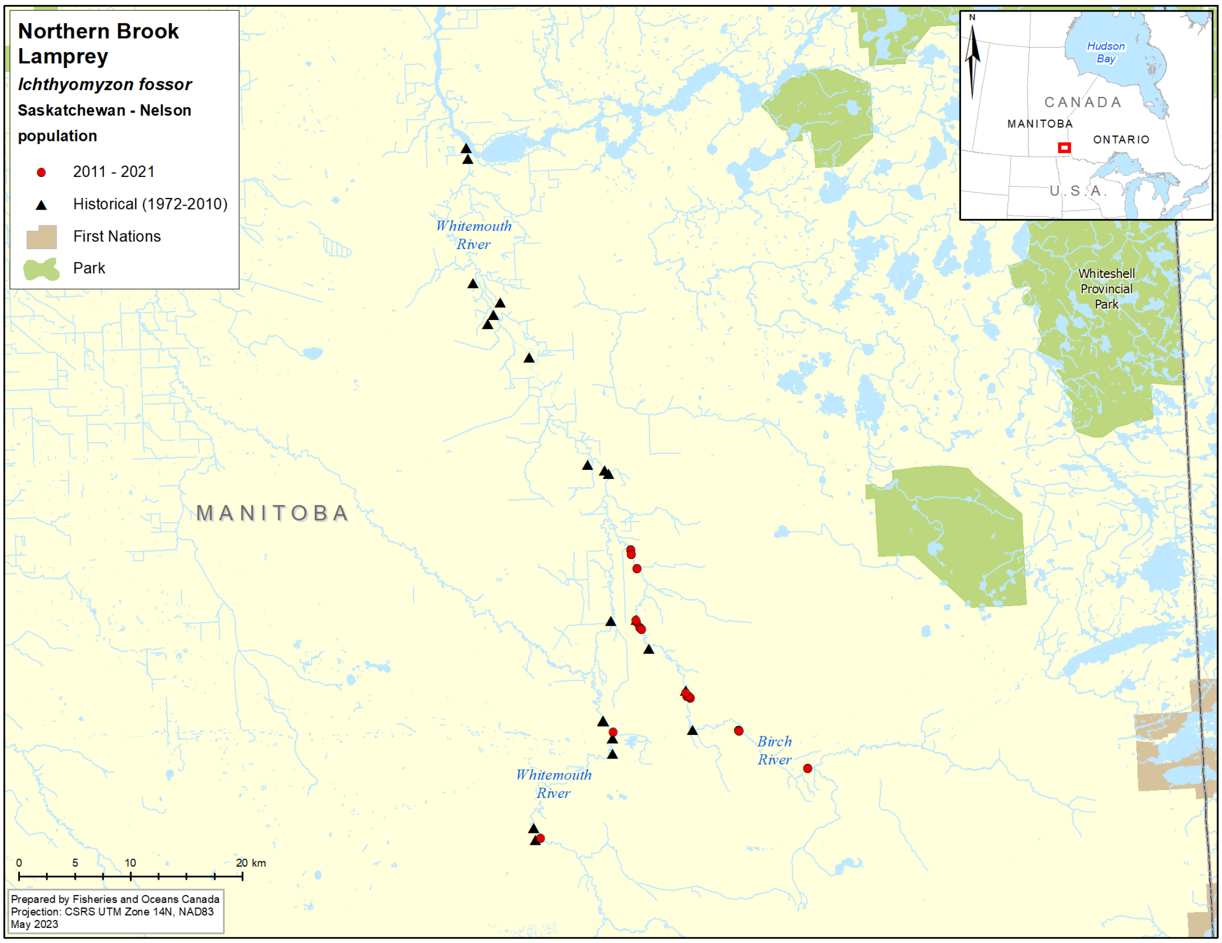

Figure 3. Distribution of Northern Brook Lamprey in the Saskatchewan-Nelson River populations. The red circles represent the last 2011–2021 collections, and the black triangles are all collection records prior to 2011.

CURRENT STATUS

Population assessment studies targeting Northern Brook Lamprey have not occurred in Manitoba, thus, fluctuations and trends related to Northern Brook Lamprey Saskatchewan-Nelson River populations are difficult to assess accurately due to inconsistent sampling equipment and monitoring through time. Fisheries and Oceans Canada has undertaken a number of directed seine net surveys between 2002–2021 to collect Carmine Shiner (*Notropis percobromus*) within the known range of Northern Brook Lamprey (Table 1). In total, considering all sampling completed by Fisheries and Oceans Canada, 64 lamprey have been collected, with backpack electrofishing having the highest catch per unit effort (CPUE). Since individuals are most often released after capture, determination of larvae or adult is not possible from these collections. The majority of the sampling effort has been boat electrofishing and seine netting, but these methods are not effective at collecting larval lamprey (Table 1).

*Table 1. Summary of Fisheries and Oceans Canada collections of presumed Northern Brook Lamprey (adults and larvae) during Carmine Shiner (*Notropis percobromus*) surveys in the Whitemouth and Birch rivers. The number of sites sampled, Northern Brook Lamprey collected, effort, and catch per unit effort (CPUE) is included.*

Equipment	Year(s)	Number of sites	Lamprey collected	Effort efishing (min)	Effort Seine (100 m^2)	CPUE efishing (fish/min)	CPUE Seine (fish/100 m^2)
Backpack efisher	2002, 2005, 2006, 2018	17	33	297.3	-	0.111	-
Boat efisher	2011	207	10	2466.1	-	0.004	-
Seine	2011	325	18	-	325	-	0.055
Seine	2021	46	3	-	46	-	0.065

POPULATION ASSESSMENT

To assess the status of Northern Brook Lamprey populations in the Saskatchewan-Nelson River populations, each population was ranked in terms of its abundance (Relative Abundance Index) and trajectory (Population Trajectory) (Table 2).

The Relative Abundance Index was assigned as Extirpated, Low, Medium, High, or Unknown. Since population assessment studies targeting Northern Brook Lamprey have not occurred in Manitoba, the field collection data available from reported records often lacks sampling effort. The number of individual Northern Brook Lamprey caught at collection sites was considered when assigning the Relative Abundance Index. The Relative Abundance Index is a relative parameter in that the values assigned to each population are relative to the most abundant population in the Saskatchewan-Nelson River population.

The Population Trajectory was assessed as Decreasing, Stable, Increasing, or Unknown for each population based on the best available information about the current trajectory. The number of individuals caught over time for each population was considered. Trends over time were classified as Increasing (an increase in abundance over time), Decreasing (a decrease in abundance over time), or Stable (no change in abundance over time). If insufficient information was available to identify the trajectory, the Population Trajectory was listed as Unknown. Certainty has been associated with the Relative Abundance Index, and Population Trajectory rankings and is listed as: 1 = quantitative analysis; 2 = CPUE or standardized sampling; 3 = expert opinion (Table 2).

Table 2. Relative Abundance Index and Population Trajectory of each Northern Brook Lamprey population in the Whitemouth and Birch river populations. Certainty has been associated with the Relative Abundance Index and Population Trajectory rankings and is listed as: 1 = quantitative analysis; 2 = CPUE or standardized sampling; 3 = expert opinion.

Population	Relative Abundance Index	Certainty	Population Trajectory	Certainty
Birch River	Unknown	3	Unknown	3
Whitemouth River	Unknown	3	Unknown	3

The Relative Abundance Index and Population Trajectory values were then combined in the Population Status matrix (Table 3) to determine the Population Status for each area. Each Population Status is subsequently ranked as Poor, Fair, Good, Unknown or Not Applicable. Certainty assigned to each Population Status is reflective of the lowest level of certainty associated with either initial parameter (Relative Abundance Index, or Population Trajectory). The resulting Population Status is reported in Table 4. Given the limited sampling for Northern Brook Lamprey and the lack of monitoring through time the Relative Abundance Index and Population Trajectory were unknown for the Whitemouth and Birch rivers. Additional standardized surveys are required at all locations to determine the population abundance, and long-term monitoring would be required to determine population trajectory through time.

Table 3. The Population Status Matrix combines the Relative Abundance Index and Population Trajectory rankings to establish the Population Status for each Northern Brook Lamprey population in the Saskatchewan-Nelson River population. The resulting Population Status is categorized as Extirpated, Poor, Fair, Good, or Unknown.

		Population Trajectory			
		Increasing	**Stable**	**Decreasing**	**Unknown**
Relative Abundance Index	**Low**	Poor	Poor	Poor	Poor
	Medium	Fair	Fair	Poor	Poor
	High	Good	Good	Fair	Fair
	Unknown	Unknown	Unknown	Unknown	Unknown
	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated

Table 4. Population Status for all Northern Brook Lamprey in the Birch and Whitemouth river populations, resulting from an analysis of both the Relative Abundance Index and Population Trajectory. Certainty assigned to each Population Status is reflective of the lowest level of certainty associated with either initial parameter (Relative Abundance Index, or Population Trajectory).

Population	Population Status (Certainty)
Birch River	Unknown (3)
Whitemouth River	Unknown (3)

***Element 3:** Estimate the current or recent life-history parameters for Northern Brook Lamprey*

The larval stage, or feeding stage, is thought to last for approximately 3–7 years (Purvis 1970; Scott and Crossman 1998) (average 5 years; COSEWIC (2020) with metamorphosis occurring as young as 3 years old (Purvis 1970). Larval growth is slow, with annual growth increments of 37, 28, and 15 mm for the first three years of growth, respectively, in a Lake Superior tributary (Purvis 1970). Male Northern Brook Lamprey metamorphose at earlier ages than females (Purvis 1970). Metamorphosis begins in early to mid-summer and is a 2- to 3-month process (Leach 1940, Manzon et al. 2015) during which sexual maturation begins (COSEWIC 2020). Full sexual maturity is only reached in May or June, just before spawning (Docker et al. 2019). Northern Brook Lamprey spawn and die within 6–8 months of metamorphosis without ever feeding again. The overall average life span (or generation time) of Northern Brook Lamprey is approximately 6 years (COSEWIC 2020).

Spawning begins in May or June once water temperatures are within 13 to 22°C (Vladykov 1949, Manion and Hanson 1980, Johnson et al. 2015). Northern Brook Lamprey typically spawns in communal groups (Morman 1979, Cochran and Pettinelli 1987), and its mating system is polygynandrous (Johnson et al. 2015). At spawning sites, adult sex ratios are reported to range from 54 to 75% male (Churchill 1945, Purvis 1970, Schuldt et al. 1987), but larval sex ratios are generally at parity or with an excess of females (Purvis 1970, Docker et al. 2019).

Northern Brook Lamprey mortality is high immediately following hatching, and lower and uniform throughout the remainder of the larval stage with annual survival rates estimated at 47–77% (Dawson et al. 2015). It appears that females possibly 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).

Age at metamorphosis in lampreys appears to be largely dependent on size and varies with growth rate (97–127 mm (average 114 mm) (Purvis 1970); 84–182 mm (average 126 mm) (Morman 1979)). Female Northern Brook Lamprey are typically older and larger than males when they begin metamorphosis (Purvis 1970).

Lamprey fecundity increases approximately with the cubic power of total length (Docker et al. 2019), with fecundity ranges from 1,095 (Leach 1940) to 1,979 reported (Vladykov 1951). The overall population mean is 1,200 eggs per female (Docker et al. 2019). Eggs hatch in 2–4 weeks post spawn (Leach 1940). After spawning, lampreys generally die within 1 to 4 weeks (Pletcher 1963, Docker et al. 2019).

HABITAT AND RESIDENCE REQUIREMENTS

***Element 4:** Describe the habitat properties that Northern Brook Lamprey needs for successful completion of all life-history stages. Describe the function(s), feature(s), and attribute(s) of the* *habitat, and quantify by how much the biological function(s) that specific habitat feature(s) provides varies with the state or amount of habitat including carrying capacity limits, if any*

SPAWN TO HATCH

Nests of 7.6–10.2 cm in diameter are built by male lamprey in gravel-dominated shallows with some sand, often just above riffles (Hankinson 1932, Manion and Hanson 1980, Scott and Crossman 1998), sometimes between or under larger stones (Reighard and Cummins 1916, Morman 1979). Nest sites are free of silt and clay from either site selection or nest-building activities themselves (Gardner et al. 2012). Therefore, appropriate rivers for spawning must have both gravel substrate for spawning and silty/sandy depositional areas downstream for subsequent larval rearing (Dawson et al. 2015).

Northern Brook Lamprey spawns in shallow water, 0.1 to 0.6 m deep, with water velocity at nest sites typically between 0.1 and 0.6 $m \cdot s^{-1}$ (Morman 1979). The optimal spawning temperature for Northern Brook Lamprey varies by region (Michigan - June, 18–22°C [Reighard and Cummins 1916], 16.5–20.5°C [Morman 1979]; Quebec - May, 13-16°C [Vladykov 1949]). Incubation temperature is likely optimal at ~ 18°C given egg survival (Smith et al. 1968), but this is based on Great Lakes individuals and may differ for Northern Brook Lamprey from Manitoba.

LARVAL, JUVENILE, AND ADULT

The habitat selection by larval, juvenile, and adult Northern Brook Lamprey is generally similar across the life stages. The appropriate substrate size is essential for the development of larval lamprey, as it allows for burrow construction as well as maintaining water flow through the substrate (Dawson et al. 2015). Substrate particle size determines the distribution of larval lampreys, as substrates that allow larval burrowing typically consists of sand or silt-dominated areas, with burrowing made difficult in areas of cobble, clay, or bedrock (Becker 1983, Beamish and Lowartz 1996), or burrowing is prevented entirely (e.g., bedrock). Adult lamprey tend to occur in somewhat coarse substrate (Dawson et al. 2015). Ideal substrate typically occurs in slower-flowing depositional areas and is mainly sand with some silt or organic material (Reighard and Cummins 1916, Leach 1940, Yap and Bowen 2003, Dawson et al. 2015). Collerone (2014) found that Northern Brook Lamprey larvae in Manitoba were more likely to be found in fine/very fine sand as defined on the Wentworth scale (Wentworth 1922).

The size of the tributaries where Northern Brook Lamprey are found are smaller, shallower, and slower-moving water than their parasitic counterparts Silver Lamprey (Becker 1983, Scott and Crossman 1998). Becker (1983) reported that Northern Brook Lamprey in Wisconsin were located in streams that were 19 m wide and 0.7 m deep on average. In Manitoba, Northern Brook Lamprey adults were collected at water depths averaging 0.6 m (D. Watkinson, DFO, unpublished data; M.F. Docker, University of Manitoba, unpublished data) during summer months. However, the depths lamprey are collected in is likely influenced by sampling gear and timing. Northern Brook Lamprey larvae have been reported in streams with a range of summer hydrology: 0.3–8.3 $m^3 \cdot s^{-1}$ by Schuldt and Goold (1980) and 0.2–71 $m^3 \cdot s^{-1}$ (average 12.2 $m^3 \cdot s^{-1}$ according to unpublished Sea Lamprey Control Centre data; COSEWIC 2007). The Whitemouth River flows average between 8–14 $m^3 \cdot s^{-1}$ during August and September (ECCC 2022). Larval densities of Northern Brook Lamprey in optimal habitat can be very high (e.g., up to 126 larvae per m^2 in the Brule River in Wisconsin (Churchill 1945)). Densities of other lamprey species averaged over all stream habitats are < 1 to about 20 larvae per m^2 (Hansen and Hayne 1962, Kainua and Valtonen 1980, Malmqvist 1980). Understanding densities in the Whitemouth and Birch rivers will be important for estimating population size.

Northern Brook Lampreys tend to inhabit upstream reaches (upstream of barrier dams if they are present; Morman 1979); however, Schuldt and Goold (1980) have also reported finding Northern Brook Lamprey at smaller creek mouths in Michigan. The upper lethal water temperature limit for Northern Brook Lamprey is 30.5°C (Potter and Beamish 1975).

HABITAT FUNCTIONS, FEATURES, ATTRIBUTES

A description of the functions, features, and attributes associated with the habitat of Northern Brook Lamprey in the Saskatchewan-Nelson River populations can be found in Table 5. The habitat required for each life stage has been assigned a life history function that corresponds to a biological requirement of Northern Brook Lamprey. In addition to the life history function, a habitat feature has been assigned to each life stage. A feature is considered to be the structural component of the habitat necessary for the species. Habitat attributes have also been provided; these are measurable components describing how the habitat features support the life history function for each life stage.

Table 5. Summary of the essential habitat functions, features, and attributes for each life stage of Northern Brook Lamprey in the Saskatchewan-Nelson River populations.

Life Stage	Function	Feature	Attributes		
			Literature	Current Knowledge	For Identification of Critical Habitat
Spawning (egg to hatch)	Spawning	Spawns in a nest that is built in shallow riffles over clean gravel substrate	• The optimal spawning temperature for Northern Brook Lamprey varies by region (Michigan - June, 18–22°C (Reighard and Cummins 1916), 16.5–20.5°C (Morman 1979); Quebec - May, 13–16°C (Vladykov 1949). Incubation temperature is likely optimal at ~ 18°C (Smith et al. 1968). • Spawning occurs in shallow water (0.1–0.6 m deep) (Morman 1979), high-gradient pool-riffle reaches of the stream (Scott and Crossman 1998) with water velocity at nest sites typically between 0.1–0.6 $m \cdot s^{-1}$ (Morman 1979). • Spawning lamprey are usually concentrated in a small area with nests located in spaces between large stones (Morman 1979) or, occasionally, under rocks (Cooper 1983, Cochran and Gripentrog 1992). • Male lamprey build nests measuring approximately 7.6–10.2 cm in diameter by moving gravel with their oral disc and sand with vigorous swimming (Scott and Crossman 1998)	-	• Shallow riffles with gravel substrate, mean depth 0.1–0.6 m. • Water velocities of 0.1–0.6 $m \cdot s^{-1}$ • Water temperature 13–22°C
Larvae	Feeding Cover	• Slower water velocity shallow runs, and depositional edges of riffles • Substrate dominated by sand with some silt and organic detritus	• The appropriate substrate size is essential for the development of larval lamprey, as it allows for burrow construction as well as maintaining water flux (Dawson et al. 2015). Larval lamprey are found in mainly sand with some silt or organic material (Reighard and Cummins 1916, Leach 1940, Yan and Bowen 2003, Dawson et al. 2015). • Water depth is usually 0.7 m deep on average in Wisconsin (Becker 1983). • Water temperature of 30.5°C is the lethal upper limit (Potter and Beamish 1975).	• In Manitoba, larval lamprey have been collected 0.11–1.5 m water (median 0.35 m), though this is gear dependent (boat electroshocker in deeper water, backpack electroshocker in shallow water). Typically collected in low gradient reaches with slow to moderate velocities (0.01–0.25 $cm \cdot s^{-1}$); silt/sand/gravel/cobble substrate are present at collection sites, with sand the dominant substrate (D. Watkinson, DFO unpublished data).	•Slow to moderate flow with substrate dominated by sand with some silt, organic detritus, and small gravel in shallow pools and runs. • Depths > 0.10 m • Water velocities > 0–< 0.6 $m \cdot s^{-1}$ • Water temperature 0–< 30.5°C

Life Stage	Function	Feature	Attributes		
			Literature	Current Knowledge	For Identification of Critical Habitat
Juvenile (from the beginning of metamorphosis to maturation)	Cover	See larvae	See larvae • During metamorphosis lampreys tend to move to coarser substrates with better oxygenated water and higher water velocities (see Dawson et al. 2015)	See larvae	See larvae
Adult	Cover	See larvae	See larvae	• In Manitoba, Northern Brook Lamprey adults were collected at water depths averaging 0.6 m (M.F. Docker, University of Manitoba, unpublished data).	See larvae

Element 5: *Provide information on the spatial extent of these areas in Northern Brook Lamprey distribution that are likely to have these habitat properties*

The stream and river reaches within the current distribution of Northern Brook Lamprey in Manitoba, including the Whitemouth River and its tributary, the Birch River, have suitable habitat available for Northern Brook Lamprey. The headwater habitat in the Whitemouth and Birch rivers becomes unsuitable as it transitions to very low gradient and velocity, with bog riparian habitat.

Element 6: *Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.*

Northern Brook Lamprey can move freely within and between the Whitemouth and Birch rivers. The Whitemouth River has a weir to control the water level of Whitemouth Lake that may act as a barrier to movement, but it is upstream of the known distribution of the species and not a concern. Lamprey can move downstream into the Winnipeg River over the Whitemouth Falls at the confluence of the Whitemouth River with the Winnipeg River, but likely cannot move upstream into the Whitemouth River from the Winnipeg River.

Element 7: *Evaluate to what extent the concept of residence applies to the species, and if so, describe the species' residence*

Residence is defined in SARA as a "dwelling-place, such as a den, nest or other similar area or place, which is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating". Residence is interpreted by DFO as having been constructed, created, or at least modified, by the organism. In the context of the above narrative description of habitat requirements, Northern Brook Lamprey occupy residences during spawning (nest building) and during the larval, juvenile, and adult stages of its life cycle (burrows).

THREATS AND LIMITING FACTORS TO SURVIVAL AND RECOVERY

Element 8: *Assess and prioritize the threats to the survival and recovery of the Northern Brook Lamprey*

THREAT CATEGORIES

The following threats were identified in the last COSEWIC species status assessment (COSEWIC 2020). The threat level is indicated in brackets as a single value or a potential range.

Climate Change and Severe Weather (High-Low)

Climate change has the potential to reduce precipitation and water levels in the Whitemouth River drainage (ECCC 2023), which will exacerbate the effects of high temperatures. The Birch River has had documented low flow and oxygen conditions in summer and winter (Clarke 1998). This river may be particularly vulnerable, with temperatures in July and August already approaching this species' upper thermal limits. In 2011, data loggers at two sites in the Birch River showed water temperatures above the substrate reaching near 30°C by the third week of July, when flow was negligible and water depth had decreased from 1.2 m (49.60770, -95.62305) and 2.4 m (49.81981, -95.87385) in the spring to only 0.2 and 0.4 m respectively (Figure 4). The preferred thermal niche of lamprey is likely ~ 20°C (Holmes and Lin 1994), and at 30.5°C, Northern Brook Lamprey larvae have been observed in a laboratory study emerging from their burrows and dying (Potter and Beamish 1975). Higher temperatures less than observed maximum would still have a negative consequence to individuals, as it would limit their aerobic metabolic scope, which determines the amount of energy available for critical processes including growth, digestion, locomotion and reproduction (Schulte 2015, Wilkie et al. 2022).

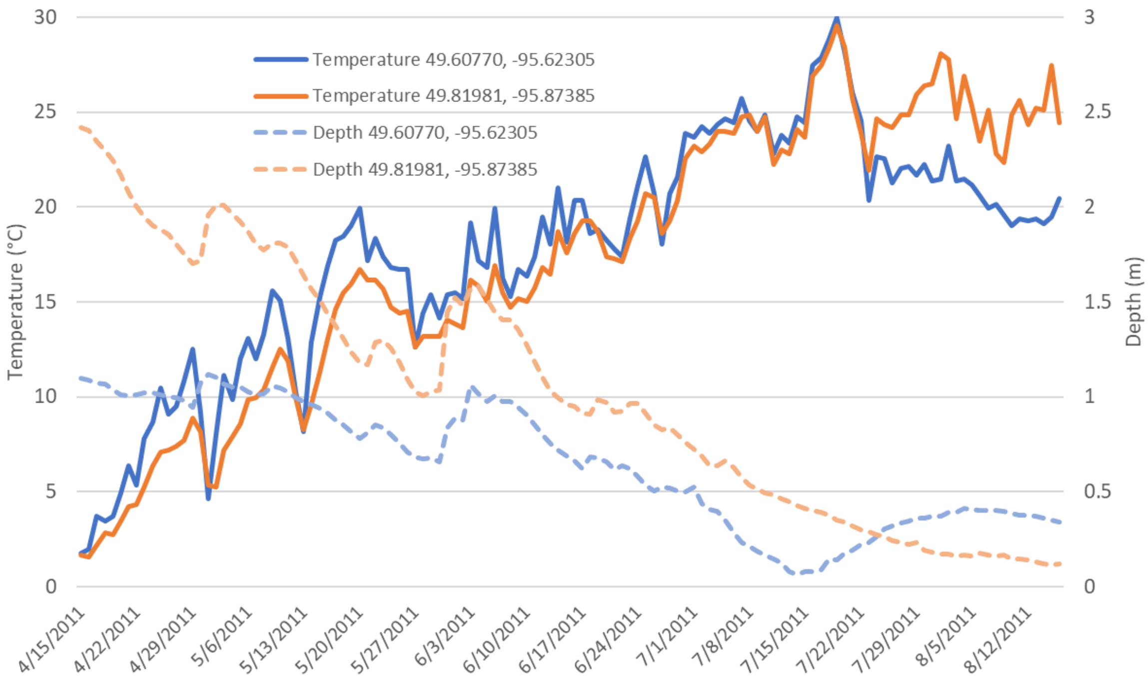

Figure 4. Water temperature (solid line) and depth (dashed lines) at two sites on the Birch River in 2011. Note, a beaver dam constructed in mid-July altered the temperature and depth of the upstream site (blue solid and dashed lines).

Natural systems modifications (low)

Dams and water management/use

Dams can alter the natural flow, 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 (Bednarek 2001). There is only one permanent dam in the Whitemouth River, a fixed-head rock weir at the outlet of Whitemouth Lake that influences the hydrology of the Whitemouth River at its headwaters. Any dam construction would likely have negative impacts, as the forebay would create mostly unsuitable habitat and the dam could restrict spawning migrations. Several large hydroelectric dams regulate flows on the Winnipeg River.

A number of activities such as farming, highways, peat mines, and removal of nearby vegetation for forestry or agriculture affect drainage and water flow patterns in the Whitemouth River system. Water removal for domestic use, lawn or agricultural irrigation, and watering livestock could reduce flow, particularly during dry years (DFO 2013) as low or no flows have occurred (Figure 5). In the past, water was periodically withdrawn during the winter from the Whitemouth River for hydrostatic testing of pipelines; however, this practice ended in the mid-1990s as it was deemed a risk to aquatic life through potential for dewatering and freezing shallows or through water discharge causing flooding, scouring of the stream bed, and bank erosion (DFO 2013). There is continued interest in the use of water from the area for hydrostatic testing of the TransCanada Pipeline.

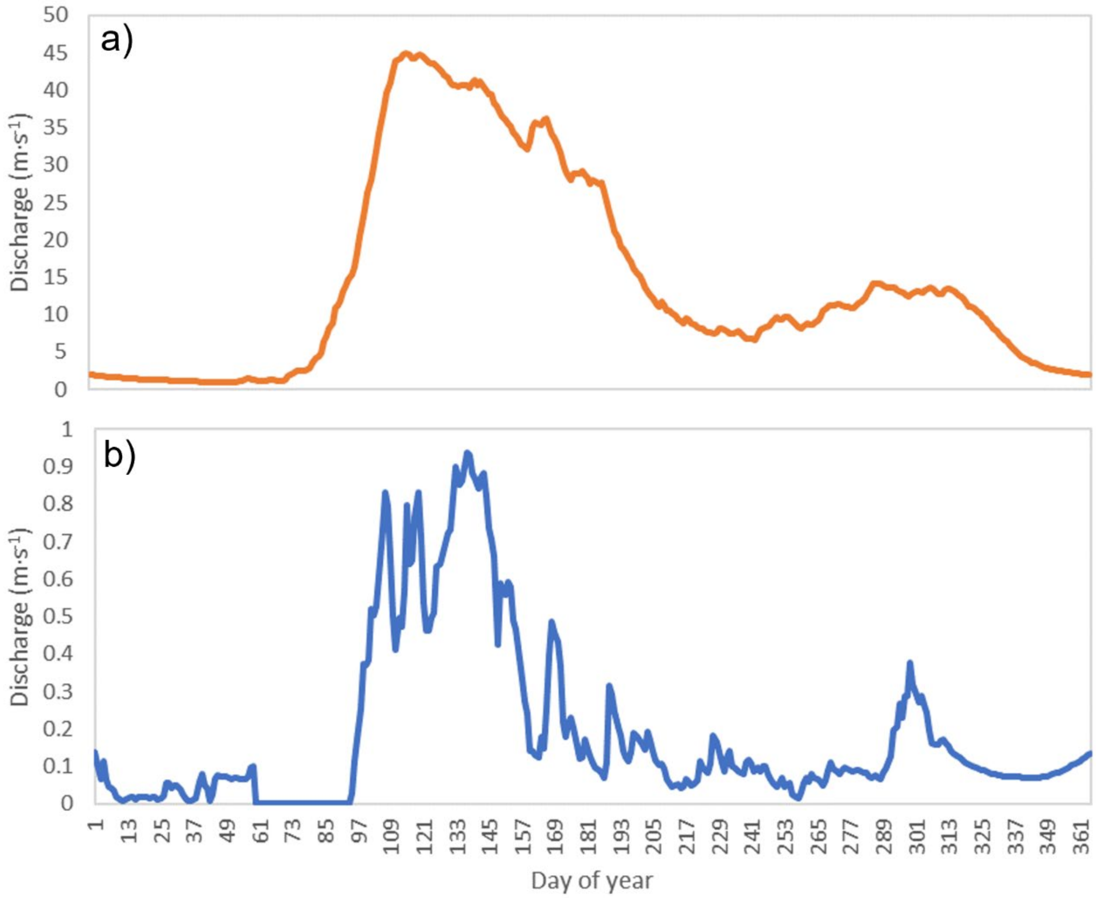

Figure 5. Mean (a – orange line) and minimum (b – blue line) daily discharge ($m \cdot s^{-1}$) in the Whitemouth River (05PH003; ECCC 2023) for 1942–2021.

Other ecosystem modifications

Small-scale habitat alterations (e.g., boulder removal, beach building) are present in the Whitemouth River drainage, but are limited for the most part. Riparian areas in the agricultural portions of the drainage are under a high degree of threat due to development and habitat conversion (Becker and Hamel 2017).

Invasive and other problematic species and genes (low)

Invasive non-native/alien species

Rusty Crayfish (*Faxonius rusticus*) was detected in the Birch River in 2011 (DFO 2013) and is expected to alter the fauna if a population establishes. Rusty Crayfish typically reduces aquatic vegetation, which may increase erosion and sedimentation that is detrimental to spawning lampreys and embryos (COSEWIC 2020). Directed sampling in 2023 collected Rusty Crayfish in the Birch River near the site it was found in 2011 (D. Watkinson, DFO, unpublished data).

A number of invasive species currently absent in the Whitemouth River drainage have a high risk of becoming established and problematic in the region within the next 10 years, including Zebra Mussel (*Dreissena polymorpha*), Emerald Ash Borer (*Agrilus planipennis*), and Phragmites or European Common Reed (*Phragmites australis* ssp. *australis*; COSEWIC 2020). Zebra Mussel is not expected to significantly impact the Winnipeg River as low carbonate in the water chemistry is not conducive to shell building (Claudi et al. 2012); however, the Whitemouth River drainage water chemistry may be more favourable to colonization where Zebra Mussel could compete with lamprey ammocoetes for food and alter the substrate that negatively affects burrowing. Emerald Ash Borer was detected in the city of Winnipeg in late 2017 (Manitoba Sustainable Development 2017). This terrestrial invertebrate has caused the complete loss of entire stands of ash trees in Ontario. Black Ash dominates the swamps in the southern portion of the drainage as well as the riparian floodplain along the Whitemouth River (J. Becker, Nature Conservancy of Canada, 2019 in COSEWIC 2020, pers. comm.). A reduction in canopy cover and shading on riverbanks could influence water temperatures and increase erosion, thereby altering Northern Brook Lamprey spawning and larval rearing sites. Phragmites has only established in a few places within Manitoba. Further expansion is expected because of transport routes through this watershed. Emerald Ash Borer has the potential to remove ash stands, increasing the suitability of wetland areas to infestation by Phragmites (COSEWIC 2020). Phragmites has high levels of water transpiration (OFAH and OMNRF 2012), which coupled with climate change has the potential to reduce flows, but only if its abundance was to increase substantially.

Walleye (*Sander vitreus*), a known predator of lamprey (Cochran 2009), have been stocked outside their native range in Manitoba into Whitemouth Lake by the Province of Manitoba since 1960 (DFO 2013). Walleye, Brook Trout (*Salvelinus fontinalis*), Rainbow Trout (*Oncorhynchus mykiss*), and Brown Trout (*Salmo trutta*) have been stocked in the Birch or Whitemouth rivers, with the last salmonid stocking in the 1980s and the last Walleye stocking in 1997. Of these introductions, only Walleye remains in the Whitemouth and Birch rivers where the impacts of this introduced species on Northern Brook Lamprey in Manitoba remain unknown.

Pollution (low)

Agricultural and forestry effluents

Agricultural runoff carrying pollutants (farm fertilizers, herbicides, and pesticides), sediment, and nutrient inputs could negatively affect Northern Brook Lamprey. Nutrient input from barnyards or intensive livestock operations is an ongoing problem in Manitoba and to an extent the Whitemouth drainage, this is being addressed by the Province of Manitoba (COSEWIC 2020). Elevated levels of phosphorus and nitrogen could negatively affect Northern Brook Lamprey specifically by altering water quality to unfavourable conditions. These pollutants are not expected to have population-level effects at current levels, but could impact individuals located near point-source inputs more severely.

Energy production and mining (low)

Mining and quarrying

Extensive peatland and several peat mines occur in the Whitemouth River drainage. The Province of Manitoba’s Forestry and Peatlands Management Branch has established guidelines on sedimentation pond establishment. However, there is potential for these ponds to release some mining sediment (peat) when waters are released into the Whitemouth and Birch rivers (J. Becker, Nature Conservancy of Canada, 2019 in COSEWIC 2020, pers. comm.). The mines also require extensive drainage near the mine site and may have some impact on watershed hydrology.

Residential and commercial development (negligible)

Limited residential and commercial development occurs within the drainage. Clearing of riparian vegetation to the water's edge at properties can destabilize banks and increase erosion (DFO 2013).

Housing and urban areas/Tourism and recreation areas

Shoreline development related to residences, vacation communities, and seasonal homes or cottages has occurred in the northern reaches of the Whitemouth River drainage, and to a more limited extent at the western end of Whitemouth Lake (DFO 2013). Development has resulted in, and likely will continue to result in, riparian forest clearing, yard sites, laneways, and associated infrastructure. Bank destabilization and increased erosion caused by clearing riparian vegetation could adversely affect Northern Brook Lamprey spawning habitat by causing physical disturbances or changes in water quality.

Limiting factors

Northern Brook Lamprey is particularly susceptible to disturbance given its prolonged larval stage (averaging ~ 5 years) in which it remains burrowed in the substrate. During this time, lamprey are unable to evade acute threats and are susceptible to natural and anthropogenic disturbances. They can passively move downstream with the current, but as larvae, they have a very limited ability to recolonize their original or other suitable habitat upstream (COSEWIC 2020).

Lampreys' semelparous reproductive strategy requires the investment of a considerable amount of resources into a single spawning season. If prevented from reaching suitable spawning habitat (e.g., as the result of barriers to migration), all potential reproductive output is wasted (COSEWIC 2020).

THREAT ASSESSMENT

Threats were assessed following guidelines in DFO (2014). Each threat was ranked in terms of the threat Likelihood of Occurrence (LO), threat Level of Impact (LI) and Causal Certainty (CC). Threats were considered over a 10-year timeframe. The Likelihood of Occurrence was assigned as Known, Likely, Unlikely, Remote, or Unknown, and refers to the probability of a specific threat occurring for a given population over 10 years. The Level of Impact was assigned as Extreme, High, Medium, Low, or Unknown and refers to the magnitude of the impact caused by a given threat, and the level to which it affects the survival or recovery of the population (Table 6). The level of certainty associated with each threat was assessed and classified as: 1 = very high, 2 = high, 3 = medium, 4 = low, 5 = very low. The Population-Level Threat Occurrence (PTO), Threat Frequency (PTF) and Threat Extent (PTE) were also evaluated and assigned a status based on the definitions outlined in Table 6 with rankings in Table 7. The LO and LI for each population were subsequently combined in the population-level Threat Risk Matrix (Table 8; rankings in Table 9). The species-level Threat Assessment in Table 10 is a roll-up of the population-level threats identified in Table 7.

Table 6. Definition and terms used to describe Likelihood of Occurrence (LO), Level of Impact (LI), Causal Certainty (CC), Population-level Threat Occurrence (PTO), Population-level Threat Frequency (PTF) and Population-level Threat Extent (PTE) reproduced from DFO (2014).

Term	Definition
Likelihood of Occurrence (LO)	
Known or very likely to occur (K)	This threat has been recorded to occur 91–100%
Likely to occur (L)	There is a 51–90% chance that this threat is or will be occurring
Unlikely (UL)	There is 11–50% chance that this threat is or will be occurring
Remote (R)	There is 1–10% or less chance that this threat is or will be occurring
Unknown (U)	There are no data or prior knowledge of this threat occurring or known to occur in the future
Level of Impact (LI)	
Extreme (E)	Severe population decline (e.g., 71–100%) with the potential for extirpation
High (H)	Substantial loss of population (31–70%) or threat would jeopardize the survival or recovery of the population
Medium (M)	Moderate loss of population (11–30%) or threat is likely to jeopardize the survival or recovery of the population
Low (L)	Little change in population (1–10%) or threat is unlikely to jeopardize the survival or recovery of the population
Unknown (U)	No prior knowledge, literature or data to guide the assessment of threat severity on population
Causal Certainty (CC)	
Very high (1)	Very strong evidence that threat is occurring and the magnitude of the impact to the population can be quantified
High (2)	Substantial evidence of a causal link between threat and population decline or jeopardy to survival or recovery
Medium (3)	There is some evidence linking the threat to population decline or jeopardy to survival or recovery
Low (4)	There is a theoretical link with limited evidence that threat is leading to a population decline or jeopardy to survival or recovery
Very low (5)	There is a plausible link with no evidence that the threat is leading to a population decline or jeopardy to survival or recovery
Population-Level Threat Occurrence (PTO)	
Historical (H)	A threat that is known to have occurred in the past and negatively impacted the population.
Current (C)	A threat that is ongoing, and is currently negatively impacting the population.
Anticipatory (A)	A threat that is anticipated to occur in the future, and will negatively impact the population.
Population-Level Threat Frequency (PTF)	
Historical (H)	A threat that is known to have occurred in the past and negatively impacted the population.
Current (C)	A threat that is ongoing, and is currently negatively impacting the population.
Anticipatory (A)	A threat that is anticipated to occur in the future, and will negatively impact the population.
Population- Level Threat Extent (PTE)	
Extensive (E)	71-100% of the population is affected by the threat.
Broad (B)	31–70% of the population is affected by the threat.
Narrow (N)	11–30% of the population is affected by the threat.
Restricted (R)	1–10% of the population is affected by the threat.

Table 7. Threat Likelihood of Occurrence (LO), Level of Impact (LI), Causal Certainty (CC), Population-level Threat Occurrence (PTO), Population-level Threat Frequency (PTF), and Population-level Threat Extent of each Northern Brook Lamprey population in Saskatchewan-Nelson River populations. Threats are ordered from high to low impact. Definitions and terms used to describe the threat ratings are found in Table 6.

IUCN Threat Category	Sub-category	Details	Whitemouth River						Birch River					
			LO	LI	CC	PTO	PTF	PTE	LO	LI	CC	PTO	PTF	PTE
(11) Climate change and severe weather (high-low)	(11.2) Droughts	• Reduce precipitation and water levels, which will exacerbate the effects of increases in temperature.	K	H	3	A	C-A	E	K	H	3	A	C-A	E
	(11.3) Temperature extremes	• Temperatures in July and August may already be approaching this species' thermal limits in some years (incipient lethal temperature 30.5°C). • Sublethal effects are expected at temperatures < 30.5°C	K	H	3	A	C-A	E	K	H	3	A	C-A	E
(7) Natural systems modifications (low)	(7.2) Dams and water management/use	• There is only one permanent dam in the Whitemouth River, and it influences the hydrology of the Whitemouth River at its headwaters. Several hydroelectric dams regulate the Winnipeg River. • Land drainage for farming, highways, and removal of nearby vegetation for forestry or agriculture occurs, may affect drainage and water flow patterns in the Whitemouth drainage. • Water removal for domestic use, for lawn or agricultural irrigation, and for watering livestock occurs and could reduce flow, particularly during dry years. • Whitemouth River water was used for hydrostatic testing of pipelines until the 1990s. There is continued interest in the use of water from the area for hydrostatic testing of the TransCanada Pipeline.	K	L	4	C	C	E	K	L	4	C	C	E
	(7.3) Other ecosystem modifications	• Small-scale habitat alterations (e.g., boulder removal, beach building) are present in the Whitemouth River drainage, but they are relatively limited in area. • Riparian areas in the agricultural portions of the drainage are under a high degree of threat due to development and habitat conversion.	K	L	4	C	C	R	K	L	4	C	C	R

IUCN Threat Category	Sub-category	Details	Whitemouth River						Birch River					
			LO	LI	CC	PTO	PTF	PTE	LO	LI	CC	PTO	PTF	PTE
(8) Invasive and other problematic species and genes (low)	(8.1) Invasive non-native/alien species	• Invasive Rusty Crayfish was detected in the Birch River in 2011; presence in the system is currently unknown due to a lack of directed sampling. • Risk of Zebra Mussel, Emerald Ash Borer, and Phragmites or European Common Reed. • Walleye have been stocked into Whitemouth Lake by the Province of Manitoba since 1960. Walleye, Brook Trout, Rainbow Trout, and Brown Trout have been stocked in the Birch or Whitemouth rivers, with the last salmonid stocking in the 1980s and the last Walleye stocking in 1997. Only Walleye remains in the Whitemouth and Birch rivers.	K	L	4	C-A	C	E	K	L	4	C-A	C	E
(9) Pollution (low)	(9.3) Agricultural and forestry effluents	• Agricultural runoff carrying pollutants (farm fertilizers, herbicides, and pesticides), sediment, and nutrient inputs occurs in the drainage. The impacts are likely to be minimal at a watershed scale, but the potential exists for locally extreme impacts (e.g., point source inputs). • Nutrient input from barnyards or intensive livestock operations is an ongoing problem that is being addressed by the Province of Manitoba.	K	L	5	C	C	E	K	L	5	C	C	E
(3) Energy production and mining (low)	(3.3) Mining and quarrying	• Several peat mines occur in the Whitemouth River drainage. The Province of Manitoba's Forestry and Peatlands Management Branch has established guidelines on sedimentation pond establishment. • The mines also require extensive drainage near the mine site and are expected to have some impact on watershed hydrology.	K	L	5	C	C	R	K	L	5	C	C	R
(1) Residential and commercial development (negligible)	(1.1) Housing and urban areas	• Limited residential and commercial development occurs with the drainage. It is often associated with clearing of riparian vegetation to the water's edge.	K	L	5	C	C	R	K	L	5	C	C	R
	(1.3) Tourism and recreation areas	• Extensive shoreline development related to residential, vacation communities and seasonal homes or cottages has occurred in the northern reaches of the Whitemouth River drainage, and to a more limited extent at the western end of Whitemouth Lake. • Recreational development has resulted in, and likely will continue to result in, riparian forest clearing, yard sites, laneways, and associated infrastructure.	K	L	5	C	C	R	K	L	5	C	C	R

Table 8. The Threat Level Matrix combines the Likelihood of Occurrence and Level of Impact rankings to establish the Threat Level for each Northern Brook Lamprey population in Saskatchewan-Nelson River populations. The resulting Threat Level has been categorized as low, medium, high, or unknown. Reproduced from DFO (2014).

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known or very likely	Low	Medium	High	High	Unknown
	Likely	Low	Medium	High	High	Unknown
	Unlikely	Low	Medium	Medium	Medium	Unknown
	Remote	Low	Low	Low	Low	Unknown
	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown

Table 9. Threat Level assessment of all Northern Brook Lamprey in the Whitemouth and Birch rivers, resulting from an analysis of both the Threat Likelihood of Occurrence and Threat Level of Impact. The number in brackets refers to the Causal Certainty associated with the threat impact (1 = Very High; 2 = High; 3 = Medium; 4 = Low; 5 = Very Low).

Threat Category	**Sub-category**	**Whitemouth River**	**Birch River**
(11) Climate change and severe weather (high-low)	(11.2) Droughts	High (4)	High (4)
	(11.3) Temperature extremes	High (4)	High (4)
(7) Natural systems modifications (low)	(7.2) Dams and water management/use	Low (4)	Low (4)
	7.3) Other ecosystem modifications	Low (4)	Low (4)
(8) Invasive and other problematic species and genes (low)	(8.1) Invasive non-native/alien species	Low (4)	Low (4)
(9) Pollution (low)	(9.3) Agricultural and forestry effluents	Low (5)	Low (5)
(3) Energy production and mining (low)	(3.3) Mining and quarrying	Low (5)	Low (5)
(1) Residential and commercial development (negligible)	(1.1) Housing and urban areas	Low (5)	Low (5)
	(1.3) Tourism and recreation areas	Low (5)	Low (5)

Table 10. Species-level Threat Assessment for Northern Brook Lamprey in Saskatchewan-Nelson River populations, resulting from a roll-up of the population-level Threat Assessment. The species-level Threat Assessment retains the highest level of risk for any population, all categories of Threat Occurrence and Threat Frequency are retained, and the species-level Threat Extent is the mode of the population-level Threat Extent.

Threat Category	Sub-category	Species-level Threat Risk	Species-level Threat Occurrence	Species-Level Threat Frequency	Species-level Threat Extent
(11) Climate change and severe weather (high-low)	(11.2) Droughts	High	Current, Anticipatory	Recurrent	Extensive
	(11.3) Temperature extremes	High	Current, Anticipatory	Recurrent	Extensive
(7) Natural systems modifications (low)	(7.2) Dams and water management/use	Low	Current	Continuous	Extensive
	7.3) Other ecosystem modifications	Low	Current	Continuous	Restricted
(8) Invasive and other problematic species and genes (low)	(8.1) Invasive non-native/alien species	Low	Current, Anticipatory	Continuous	Extensive
(9) Pollution (low)	(9.3) Agricultural and forestry effluents	Low	Current	Continuous	Extensive
(3) Energy production and mining (low)	(3.3) Mining and quarrying	Low	Current	Continuous	Restricted
(1) Residential and commercial development (negligible)	(1.1) Housing and urban areas	Low	Current	Continuous	Restricted
	(1.3) Tourism and recreation areas	Low	Current	Continuous	Restricted

Element 9: *Identify the activities most likely to threaten (i.e., damage or destroy) the habitat properties identified in elements 4–5 and provide information on the extent and consequences of these activities*

The threat most relevant to Northern Brook Lamprey habitat is climate change, specifically the sub-categories drought and temperature extremes. Drought can reduce the available wetted stream habitat as well as flowing water required for oxygenation of the substrata and movement of food particles. Reduced flows also have the potential to strand Northern Brook Lamprey. Temperature extremes can exclude organisms from a system when environmental variables like temperature exceed their physiological tolerances (30.5°C). Sublethal effects are expected at temperatures < 30.5°C.

Dams and water management/use, other ecosystem modifications, pollution, agricultural and forestry effluents, and mining and quarrying can all impact extensive areas of habitat through changes in quantity and quality, but these threats have a low level of impact with low causal certainty (Table 7). Any dam built within the current distribution of Northern Brook Lamprey would result in habitat loss in the forebay and impair spawning migrations and population connectivity.

Housing and urban areas, and tourism and recreation would typically alter habitat and impact the species locally, near the disturbance. These threats have a very low level of impact with very low causal certainty (Table 7).

Element 10: *Assess any natural factors that will limit the survival and recovery of the Northern Brook Lamprey*

Predation by aquatic, avian, and terrestrial predators can occur over the extended larval phase, but is considered highest during spawning, as spawning generally occurs in daytime hours and in shallow water (Docker et al. 2015). The distribution of Northern Brook Lamprey in North America is generally restricted to smaller streams or rivers, although these systems have lower populations of large bodied fish. Northern Brook Lamprey may be susceptible to predation by large bodied fish. Many diseases, pathogens, and parasites are known to impact lampreys (Shavalier et al. 2021), but the prevalence and level of impact to the Northern Brook Lamprey Saskatchewan-Nelson River populations is not known.

Element 11: *Discuss the potential ecological impacts of the threats identified in element 8 to the target species and other co-occurring species. List the possible benefits and disadvantages to the target species and other co-occurring species that may occur if the threats are abated. Identify existing monitoring efforts for the target species and other co-occurring species associated with each of the threats, and identify any knowledge gaps*

The threats most relevant to Northern Brook Lamprey and all other freshwater fish species in the Saskatchewan-Nelson River populations are climate change, specifically the sub-categories drought and temperature extremes. These threats have the potential to negatively impact all or large portions of the Saskatchewan-Nelson River populations of Northern Brook Lamprey. The level of impact of these threats is high given the likelihood of occurrence (known) and the level of impact (high). Carmine Shiner has a status of Endangered under the SARA and its distribution overlaps with the Northern Book Lamprey. The most important threats identified for Carmine Shiner were dams and water management/use; agricultural effluents; habitat alterations; and invasive or introduced species (COSEWIC 2018). Standardized sampling occurs for Carmine Shiner within the Whitemouth River drainage and the Winnipeg River (Macnaughton et al. 2020). Both species require flowing water, but Carmine Shiner can tolerate warmer water temperatures (Stol et al. 2013) than Northern Brook Lamprey (Potter and Beamish 1975).

Environment and Climate Change Canada monitors flow in the Whitemouth River (station 05PH003, 1942–2023) and Birch River (station 05PH007, 2012–2023). Long-term monitoring of water temperature and oxygen in upstream and downstream reaches of the Whitemouth River drainage would provide useful information for assessing the relative risk of climate change, natural systems modifications, and pollution. Surveys to monitor invasive species should be conducted to proactively identify changes in invasive species distribution and abundance.

All other threats identified for Northern Brook Lamprey have a low threat risk to the populations. These threats are likely to have indirect effects including shifting food webs as a result of changes to water quality variables. Food webs can also be disrupted through pollution and the introduction of invasive species such as dreissenid mussels and Rusty Crayfish, which can indirectly negatively impact all species of fish.

SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES

Element 16*: Develop an inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat (as identified in element 8 and 10)*

Threats to species survival and recovery can be reduced by implementing mitigation measures to reduce or eliminate potential harmful effects that could result from works or undertakings associated with projects or activities in Northern Brook Lamprey habitat (Saskatchewan-Nelson River populations). The DFO Program Activity Tracking for Habitat (PATH) database was queried for a variety of works, undertakings, and activities that occurred within the known distribution of Northern Brook Lamprey during the previous five years (2018–2022) that could harm or destroy its habitat. Only five projects were identified, four of which were in the Winnipeg River at the Seven Sister Generating Station (Table 11). The primary works were blasting/explosives, shoreline protection, and dams with the primary impacts from the works being infilling/footprint, deposition of non-deleterious substances, and changes in flows/water levels. The remaining project was in the Birch River where the primary work and impact was dredging/excavating. Many of the works, undertakings, and activities that occur within the distribution of Northern Brook Lamprey are likely unreported in PATH.

Habitat-related threats can be linked to the Pathways of Effects developed by DFO’s Fish and Fish Habitat Protection Program (FFHPP) (Coker et al. 2010, DFO 2021). The document provides guidance on mitigation measures for 19 Pathways of Effects for the protection of aquatic species at risk in the Central and Arctic Region (Coker et al. 2010). Coker et al. (2010) should be referred to when considering mitigation and alternative strategies for habitat-related threats. Additional mitigation and alternative measures related to non-habitat related threats such as invasive species are listed below.

Table 11. Threats to Northern Brook Lamprey populations in Saskatchewan-Nelson River populations and the Pathways of Effect associated with each threat (Coker et al. 2010) – this table is intended to accompany Coker et al. (2010) for details on mitigations to each habitat-related threat 1 – Vegetation clearing; 2 – Grading; 3 – Excavation; 4 – Use of explosives; 5 – Use of industrial equipment; 6 – Cleaning or maintenance of bridges or other structures; 7 – Riparian planting; 8 – Streamside livestock grazing; 9 – Marine seismic surveys; 10 – Placement of material or structures in water; 11 – Dredging; 12 – Water extraction; 13 – Organic debris management; 14 – Wastewater management; 15 – Addition or removal of aquatic vegetation; 16 – Change in timing, duration and frequency of flow; 17 – Fish passage issues; 18 – Structure removal.

Work/Project/Activity	**Threats (associated with work/project/activity)**						**Watercourse / Waterbody (Number of works/projects/activities between 2018–2022)**		
-	**Habitat removal and alteration**	**Nutrient loading**	**Turbidity and sediment loading**	**Contaminants and toxic substances**	**Exotic species and disease**	**Incidental harvest**	**Winnipeg R.**	**Whitemouth R.**	**Birch R.**
Applicable pathways of effects for threat mitigation and project alternatives	5,7,9,10, 11,12,13, 15,16,18	1,4,7,8, 11,12, 13,14, 15,16	1,2,3,4, 5,6,7,8,10, 11,12,13, 15,16,18	1,4,5,6, 7,11,12, 13,14, 15,16,18	-	-	-	-	-
Water crossings (bridges, culverts, open cut crossings)	X	-	X	X	-	-	-	-	1
Shoreline, streambank work (stabilization, infilling, riparian vegetation management)	X	X	X	X	-	-	2	-	-
Instream works (channel maintenance, restoration, modifications, realignments, dredging, aquatic vegetation removal)	X	X	X	X	-	-	-	-	1
Water management (timing, duration and frequency of flow, water withdrawal)	X	X	X	X	-	-	1	-	-
Structures in water (effluent outfalls, water intakes, dams)	X	X	X	X	-	-	-	-	-
Baitfishing	-	-	-	-	-	X	-	-	-
Use of Explosives	-	X	X	X	-	-	1	-	-
Invasive species introductions (accidental and intentional)	-	-	-	-	X	-	-	-	-

NON-HABITAT THREAT MITIGATION

Invasive and other problematic species and genes

As discussed in the Threats and Limiting Factors section, Rusty Crayfish, Zebra Mussel, Emerald Ash Borer, and Phragmites or European Common Reed may negatively impact Northern Brook Lamprey populations in the future. Rusty Crayfish were collected in the Birch River in 2011 and may still be present in the system.

Mitigations

- Removal/control of introduced species from areas inhabited by Northern Brook Lamprey.
- Monitor for introduced species that may negatively affect Northern Brook Lamprey populations or preferred habitat.
- Develop a plan to address potential risks, impacts, and proposed actions if monitoring detects the arrival or establishment of introduced species.
- Initiate a public awareness campaign and encourage the use of existing invasive species reporting systems.
- Do not stock non-native species in areas inhabited by Northern Brook Lamprey.
- Do not enhance habitat for non-native species in areas inhabited by Northern Brook Lamprey.

Alternatives

- Unauthorized introductions - There are no alternatives for unauthorized introduction because unauthorized introductions should not occur.
- Authorized introductions - Use only native species. Follow the National Code on Introductions and Transfers of Aquatic Organisms for all aquatic organism introductions (DFO 2017).

SOURCES OF UNCERTAINTY

There are several knowledge gaps related to the abundance and distribution of Northern Brook Lamprey in the Saskatchewan-Nelson River populations. The inability to differentiate larval Northern Brook from Silver lamprey further complicates this uncertainly. There are currently no population size estimates available for any of the three populations; thus, trends/trajectories cannot be evaluated. The species' current distribution within the known watersheds is likely well described, but most records are spatially and temporally sporadic. Additional surveys may find the species' range is larger in Manitoba than currently known. Standardized, long-term monitoring is required to resolve the distribution, abundance, and trends through time. Studies of Northern Brook Lamprey in the Saskatchewan-Nelson River populations are limited. Studies evaluating individuals from the Saskatchewan-Nelson River populations' physical habitat associations by life stage, flow and temperature preferences, and life history traits would aid in refining critical habitat.

The impacts of most threats to Northern Brook Lamprey are poorly understood. There is a need for causative studies to evaluate the impact of threats, individually and cumulatively, on Northern Brook Lamprey physiology, mortality, and productivity.

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